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EDITORIAL STAFF

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EDITOR'S NOTE

At the meeting of the Committee on Publications of the Ninth Pacific Science Congress, it was agreed that the increasing number of communications and papers presented at each Congress has become a very difficult problem for the Publication Committee and the editorial staff to cope with and that too much time is required to complete the publication of the Proceedings; therefore, it was recommended that the following principles governing publication be followed:

a. That invited contributions to the scheduled symposium be published in full;

b. That reports of the Standing Committees be published in full;

c. That other papers submitted to the Congress during its sessions be published in abstract only, the abstract not to exceed 500 words;

d. That papers which, though listed on the program or included in the pre-Congress abstracts published in advance but not actually submitted to the Congress at its sessions, should be disregarded:

e. That authors be asked to indicate by a definite and early date[1] whether they prefer to publish their papers in sources other than the Congress Proceedings; that if this is done, the Congress should be acknowledged;

f. That all proof reading be the responsibility of the editorial committee, and that this committee shall consider the manuscripts in their hands by a definite date as final;[2]

g. That authors be held responsible for submitting their material in good English;

h. That on matters arising during the course of publication and not specifically covered in the statement of policy the editorial committee is empowered to act.

In accordance with the resolutions of the Committee, the editorial board has edited the reports and manuscripts where necessary to bring uniformity and consistency to the format. Typographical and grammatical errors as well as errors in phraseology, spelling, or technical terms have been corrected, wherever possible, but in cases where the exact meaning of the original copy was not clear, the text has been left as submitted by the author.

In order to reduce the cost and bulk of the publication, appendices, illustrations, and exhibits whenever considered not vital to the text have been eliminated.

If an author requested to publish elsewhere, his paper has been mentioned in the footnote under the respective titles, but if an author who presented a paper at the Congress failed to submit his manuscript either in full or in abstract, his paper and the discussions thereon have been eliminated entirely.

It was also decided that, in order to complete the publication of the Proceedings as soon as possible, each division be published in a separate volume. Short volumes or the ones that do not require too much editorial work will be released first. Therefore, among the twenty volumes planned, any volume may appear first. They will not appear in consecutive order.

The editorial board wishes to thank all authors who were prompt in submitting their revised manuscripts in good form and, in particular, members of the Standing and Organizing Committees, too numerous to be named, who have helped in collecting the manuscripts pertaining to their respective divisions.

The Board wishes in particular to thank Dr. F. Raymond Fosberg for going over and correcting the Special Symposium on *Climate, Vegetation, and Rational Land Utilization in the Humid Tropics* under Unesco;

Mr. Saman Buravas of the Royal Mines Department for helping by redrawing charts and maps in order that they might reproduce clearly when printed;

Mr. J. Alan Tubb of the FAO Regional Office, for his assistance in going over and clarifying some of the papers in the Fisheries and Oceanography volumes and in translating some of the French papers;

Dr. Pradisth Cheosakul of the Department of Science for editing the Chemistry in the Development of Natural Resources volume;

Last but not least, the Board wishes to thank the *Thai Watana Panich Press* for their cooperative efforts, far beyond the requirement of the contract, in devoting all their resources to printing these volumes.

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[1] January 1, 1958, in the case of the Ninth Congress.

[2] March 1, 1958, in the case of the Ninth Congress.

ABBREVIATIONS

APFC — Asia-Pacific Forestry Commission
CAA — Civil Air Administration
CSIRO — Commonwealth Scientific and Industrial Research Organization (Australia)
ECAFE — Economic Commission for Asia and the Far East
EQUAPAC — Equatorial Pacific (oceanographic survey)
FAO — Food and Agriculture Organization
IACOMS — International Advisory Committee on Marine Sciences
ICA — International Cooperation Administration
ICAO — International Civil Aviation Organization
ICSU — International Council of Scientific Unions
IGY — International Geophysical Year
IPFC — Indo-Pacific Fishery Commission
IRC — International Rice Commission (FAO)
JCRR — Joint Commission on Rural Reconstruction (Taiwan, China)
NORPAC — North Pacific (oceanographic survey)
PHILCUSA — Philippine Council for United States Aid
PIOSA — Pan-Indian Ocean Scientific Association
SEATO — South-East Asia Treaty Organization
SPC — South Pacific Commission
UN — United Nations
UNESCO — United Nations Educational, Scientific and Cultural Organization
UNICEF — United Nations International Children's Emergency Fund
USDA — United States Department of Agriculture
USIS — United States Information Service
USOM — United States of America Operations Mission
WHO — World Health Organization
WMO — World Meteorology Organization

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GEOLOGY AND GEOPHYSICS

Standing Committee Chairman: JAMES HEALY
Organizing Committee Chairman: LIEUTENANT-GENERAL PHYA SALWIDHAN-NIDES

Standing Committee Reports

REPORT OF THE CHAIRMAN OF THE STANDING COMMITTEE ON PACIFIC GEOLOGY AND GEOPHYSICS†

JAMES HEALY

Geological Survey, Rotorua, New Zealand.

INTRODUCTION

At the Eighth Pacific Science Congress held in Manila in 1953 a change in organization of the division of Geology and Geophysics was recommended by the members present. It was proposed that eight standing committees be set up, which would between them cover the fields of geology and geophysics. Each was to circulate up-to-date information amongst its members and maintain a bibliography.

The Council in its final session approved the appointment of a single Chairman for one Standing Committee for Geology and Geophysics. This was intended to simplify the management of the division, by leaving it open to the chairman to organize sub-committees along the lines proposed above. However, there was some difficulty in filling the position and the present chairman was not appointed for some time. Approaches were made to a number of geologists to take over sub-committees, but the response was poor, mainly because it would be necessary to spend time on organization that could be better spent on research.

The proposed organization has not therefore been pushed, and latterly a Committee has been formed as representative as possible in the time available to the Chairman, and brief accounts of geological and geophysical developments since the last Congress were requested, together with any suggestions for projects of Pacific interest on which the next Standing Committee might work.

From the reports received the report that follows has been compiled, but no suggestions for research projects have been received. The writer is of the opinion that it would be desirable either to organize the Standing Committee along lines somewhat different from those suggested at the last Congress, or to return to a limited number of Standing Committees as formerly instead of just the one. Two suggestions are put forward here for projects either as Standing Committees or as sub-committees of a single Standing Committee.

(1) *Pleistocene Research*, to embrace the correlation of research in stratigraphy, geochronology, glaciology, oceanography. The chance to elucidate and correlate earth history in all its aspects can be more appropriately applied to the Pleistocene, and more particularly during the latter part of the Pleistocene, than to any other period.

(2) *Geothermal Research* in its wider aspects, to embrace volcanism, hydrothermal geology and heat flow generally, as distinct from the earlier Standing Committee for Volcanology, with undue emphasis on purely volcanic events.

If it be granted that an organization such as the Pacific Science Association can become topheavy with too many Committees, and it is desired to maintain elasticity as favoured by the

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† Presented by Mr. Arturo Alcaraz, University of the Philippines, Quezon City.

founder, the late Professor J.W. Gregory, then these committees or sub-committees could have a limited life. A specific committee could be formed to perform certain functions, or accomplish certain ends, and once that had proceeded to the stage where it became desirable to disband it in favour of another one, that could be done. It seems certain that some of the earlier Standing Committees may have outlived their necessity when considered in relation to new problems.

It is also suggested that the Standing Committee or Committees concentrate specifically on problems or projects for the following Congress.

Pacific Bibliography

As requested at the Seventh Pacific Science Congress, a report on the preparation of a bibliography of the geology of the Pacific was prepared and submitted by Charles G. Johnson at the Eighth Congress. It is published in Vol. 2 of the Proceedings of the 8th Pacific Science Congress (pp. 3-5). Mr. Johnson now reports that no further progress has been made on the bibliography. He is of the opinion that although there is still a need for a bibliography, that need is not as pressing as it was immediately after World War II, and that current bibliographies published by the Geological Society of America, the American Geophysical Union, the New Zealand Geological Survey and others, satisfy most needs. He suggests that the project be dropped or transferred to someone else in better position to negotiate for funds to support it.

Helen L. Foster prepared an annotated bibliography of the Geology and Soils Literature of Western North Pacific.

In addition to the regular bibliographic sections published in certain journals, attention is drawn to the following publications of interest:

Catalogue of translations of Japanese geological literature of the Pacific Islands. Prepared by Geological Surveys Branch, Intelligence Division, Office of the Engineer, HQ, United States Army Forces, Far East, with personnel of the U.S. Geological Survey. April, 1954.

Abstracts of papers on New Zealand geology published during

-1949.	N.Z. Jour. Sci. & Tech.	33B,	61-72,	1951
-1950.	,, ,,	33B,	234-244,	1951
-1951.	,, ,,	34B,	189-204,	1952
-1952.	,, ,,	35B,	284-297,	1953
-1953.	,, ,,	36B,	411-428,	1955
-1954.	,, ,,	37,	416-435.	

Bibliography of New Zealand Oceanography. *Geophysical Memoir* 4. N.Z. Oceanographic Institute, Wellington 1955.

Publications on the geology and geophysics of Indonesia and adjacent areas, 1952-1953. *Indonesian Jour. for Nat. Sci.*, Vol. 110 1954. Compiled by Th. Klompé. Addenda.... *Indonesian Jour. for Nat. Sci.*, Vol. 111.

Publications on the geology and geophysics of Indonesia and adjacent areas, 1954. *Indonesian Jour. for Nat. Sci.*, Vol. 111, 1955. Compiled by Th. Klompé.

Bibliography of Philippine Geology, Mining and Mineral Resources. Juan S. Teves. *Bureau of Mines, Bibliography Series* No. 1. 1953.

Report of the Standing Committee on Volcanology. Compiled by J. Healy. *Proc. 8th Pac. Sci. Cong.* Vol. II, 7-61, 1956. Contains references to most important volcanological papers published during period 1949-1953.

Report of the Standing Committee on Datum-planes in the Geological History of the Pacific Region. R.S. Allan. *Proc. 8th Pac. Sci. Cong.* Vol. II, 325-423. A Comprehensive account of stratigraphic correlation in the Pacific region, including a massive bibliography.

Stratigraphic Correlation

In view of the importance of this subject to Pacific geology, Dr. R.S. Allan was asked to compile an account of developments in stratigraphic correlation since the last Congress, and his report will be appended separately.

International Geophysical Year

Geophysicists in the Pacific region will spend a considerable amount of time during the next year or two on projects connected directly and indirectly with the International Geophysical Year. Conceived originally by a small bunch of scientists, this project has caught the imagination of peoples and governments the world over, and the next two years will see the amassing of an amount of data that will keep geophysicists and geologists on their toes for years to come. Arrangements have been made for the *Annals of the International Geophysical Year* to be published by the Pergamon Press Ltd., London.

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Dr. L.W. Morley, Chief Geophysicist, Geological Survey of Canada, Victoria Museum, Ottawa, Canada.

Professor W.H. Mathews, University of British Columbia, Vancouver 8, Canada.

The death of a former member of the Standing Committee for Volcanology, Dr. W.E. Cockfield, is recorded with regret.

VOLCANIC GEOLOGY

Professor Mathews has supplied the following information on volcanic geology in Canada since 1953. No volcanic activity has been Reported, and significant literature is confined to the study of late—and post-Pleistocene lavas and pyroclastics, concerning which three papers are worthy of mention.

Bostock, H.S., 1952, Geology of North-west Shakwak Valley, Yukon Territory. *Geol. Surv. Canada*, Mem. 267.

Contains a discussion (p. 36-39) of the character and distribution in Yukon Territory of a well-known deposit of volcanic ash approximately 1,400 years in age.

Rigg, G.B. and Gould, H.R., 1957, Age of Glacier Peak eruption and chronology of post-glacial peat deposits in Washington and surrounding areas. *Am. Jour. Sci.* 255, 341-363.

Describes an ash deposit about 6,700 years old, which may have extensions into southern British Columbia.

Mathews, W.H., 1957, Petrology of Quaternary volcanics of the Mt. Garibaldi map-area, Southwestern British Columbia. *Am. Jour. Sci.* 255, 400-415.

Recent reconnaissance work by the Geological Survey of Canada in the Stikine River area has discovered striking signs of postglacial volcanic activity. Nothing of this activity has as yet been published beyond a note by F.E. Wright (The Unuk River Mining region of British Columbia, Geol. Surv. Canada Summ. Rept, for 1905, 46-53, 1906). This includes the remark, "The volcanic ash from these eruptions can still be seen on the glaciers of the mountain peaks 8-10 miles distant".

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PACIFIC INVESTIGATIONS

The following notes have been prepared from a summary by Charles G. Johnson of U.S. Geological Survey activities in the Pacific since the 8th Pacific Science Congress in 1953. Most projects have been co-operative with other Government agencies, chiefly the Corps of Engineers, U.S. Army, Office of Naval Research, U.S. Navy, and U.S. Trust Territory of the Pacific Islands.

Systematic geologic mapping was completed for Guam and Pagan in the Marianas, Truk in the Carolines, and Ishigaki and Miyako in the Ryukyus, and in addition the soils were concurrently mapped on Guam, Ishigaki and Miyako. Soil mapping on Yap, in the Carolines, was also completed, geology having been previously mapped.

Topical studies have continued on several islands, covering a variety of subjects, and providing significant contributions to the knowledge of the structure and geologic history of the western north Pacific. *U.S.G.S. Professional Paper 260 A-R* has appeared as the first 18 chapters on the geology, oceanography, geophysics and paleontology of the atolls Bikini, Eniwetok, Rongelap, Rongerik, and Ailinginae, studied by a large group of investigators during Operation Crossroads. Four others (additional seismic studies, chemical erosion of beach rock, geothermal gradient, and fossil Foraminifera) are now in press proof, and several additional chapters are nearing completion. These deal mainly with results of deep drilling carried on at Eniwetok during 1951-52. A study of four species of fossil land shells recovered from drill-holes on Bikini, Eniwetok and Funafuti was completed, and geothermal measurements in the deep drillhole on Eniwetok are being continued in an effort to detect rate of change of heat flow with time.

U.S.G.S. Professional Paper 280 A-K is also under way as a similar project on Saipan. Chapter A on the geology has been published, and the succeeding ones will deal with the soils, petrology, and petrography of the volcanic rocks and limestones, calcareous algae, microfossils, echinoids, and submarine topography and shoalwater ecology.

From Okinawa, studies of fossil brachiopods and mollusks have been completed, and work continues on the microfossils in cuttings from deep holes drilled during World War II. A long term study of fossil mollusks from several island groups including the Marshalls, Marianas and Palau is continuing.

A petrologic study of the major soils of Guam was completed, including rapid chemical analyses, grain size distribution, pH, organic carbon, free iron oxide, mineralogic composition of sand-size material, and X-ray examination of silt and clay-size material. The limestones of Guam were examined by X-ray and microscope, and the beach sands and soils of the northern Marshall Islands were studied with respect to particle size distribution, mineral and trace element content, and relation of organic content to calcareous organisms that make up the bulk of the material.

Large bulk samples of unweathered volcanic rock were collected from scattered islands for the purpose of gathering and comparing geochemical data throughout the Pacific and surrounding areas. Emphasis will be placed on problems of differentiation and the variation of minor elements.

Construction of a laboratory in Kilauea on Hawaii was started and should be completed by February, 1958. It will be equipped for mass-spectrographic, chemical and spectrochemical analysis of volcanic rocks and their weathered products. The aim is the study of chemical volcanology and weathering. Systematic analyses will be made of volcanic and solfataric gases and residual volatiles in lavas. A project on chemical weathering, principally on the development of laterites, is being started.

In addition to carrying out research, the U.S.G.S. has aided Pacific countries by the training of professional personnel, the organization of geologic survey agencies, and the investigation of mineral deposits and water resources. Countries that have received such aid are Thailand, Taiwan, Indonesia, South Korea and the Philippines.

INTERNATIONAL GEOPHYSICAL YEAR

Reviews of the United States program of geophysical endeavour for the IGY are published in Bulletins Nos. 1 and 2, issued by the National Academy of Sciences in the *American Geophysical Union Transactions*, Vol. 38. No. 4. The program is planned and directed by the U.S. National Committee for the international Geophysical Year, with the co-operation and assistance of hundreds of scientists and many public and private institutions. Outstanding in the list of public institutions are the National Science Foundation and the Department of Defense.

In the Antarctic program, oceanographic observations were carried out during the 1955/56 operations. Continuous echo soundings of the ocean bed were made south of Panama, and bathythermograph observations were made in the Pacific and across the Antarctic Convergence. Gravity and geomagnetic observations were also carried out. In the 1956/57 period the IGY stations of Little America, South Pole, Byrd, Ellsworth, Wilkes and Adare were established and manned, and seismic, gravity and geomagnetic observations were commenced. A seismic profile, begun 200 miles out from Little America, has shown that the ice depths increase from 2,000 to 7,000 feet approaching the station. A profile in the immediate vicinity of the site has determined that this station, which is only 5,000 feet above sea level, is located upon 10,000 feet of ice; these data must be regarded as tentative pending more detailed studies.

Of interest also to Pacific science is the Arctic drift ice program, which called for the establishment of two stations on drifting sea-ice, to study the annual mass budget of the Arctic sea ice and its relation to total accumulation and ablation at the ice-ocean and ice-atmosphere interfaces respectively.

Accumulation and ablation of the upper surface of the ice pack will be measured by the combined use of stakes to determine the rise or fall relative to a fixed reference plane within the ice floe, together with measurements of weight differences over given time periods, by the taking of vertical cores through the surface snow and ice. Accretion or ablation of ice at the bottom of the ice pack will be determined from a series of cores taken through the ice pack every two or three months.

Oceanographic data will be gathered on current flow, temperature and salinity at different depths; age determinations will be made on water samples taken from various depths; bottom cores will be taken to permit comparison of Arctic Ocean sedimentation, stratigraphy and marine life with that in other oceans.

The earth satellite program may throw light on the distribution of the earth's.mass and possibly even the composition of its crust from observed perturbations in the satellite's orbit, provided the orbit is precisely known. It can also obtain synoptic data on the earth's magnetic field in space.

The seismological program includes, in addition to work on the thickness of the ice sheet in the Antarctic, the study of crustal structure there by seismographs, and seismic exploration will be carried on in the southeast Pacific by the Scripps Institution of Oceanography.

Simultaneous land and sea measurements are involved in the program of seismic exploration of coastal structures. In addition, measurements in sharply contrasting terrain — very high mountains and neighboring lowlands — will be carried on in the Andes. A crustal strain seismograph has been installed in Santiago, Chile, and a second installation is practically complete at Huancayo Geophysical Observatory, Peru, constructed and installed under the supervision of Hugo Benioff, California Institute of Technology. These will be used to collect data on the accumulation of strain, whose release causes earthquakes.

Data on long period and other surface seismic waves will be collected by a widespread network of instruments. One long period instrument is now installed at the Coast and Geodetic Survey Seismological Observatory in Honolulu, and instruments have been shipped to the Belgian Congo and Trinidad. Nine additional installations are scheduled.

In the Arctic and North Atlantic Ocean regions, as well as several western Pacific islands, the U.S. Coast and Geodetic Survey will conduct studies of wave velocities, the location of earthquakes, crustal structure, and the relation of microseisms to storms. Pacific stations are at Guam, Truk and Koro. A seismograph is being installed at Palmyra Island in cooperation with Scripps Institution of Oceanography.

For a discussion on Antarctic Seismology, reference may be made to an article of that title by Frank Press in *Engineering and Science Monthly*, June 1957, published at the California Institute of Technology.

The gravity programme basically includes an extension of the existing network of pendulum base stations and gravimeter measurements extending from them, especially in the southern hemisphere and polar regions. The program calls also for improved determination of the rigidity of the earth at the tidal periods of approximately 12 and 24 hours. A highly sensitive gravimeter has been designed for this, and Louis B. Schlichter, Director of the Institute of Geophysics, Univeristy of California, who helped to develop it, recorded a maximum amplitude of tidal motion of the earth of about four inches in November 1956 in Honolulu. Submarine gravity measurements are also projected.

In oceanography, sea-level stations have been installed in the Pacific by Scripps Institution of Oceanography at Marcus, Pitcairn, Rurutu, Canton, Johnston, Wake and Napuka island, and others are being equipped. Many island observatories will also observe ocean temperature and salinity to depths of 1,000 ft. to help determine to what extent changes in sea level are owing to volumetric changes, and to what extent they are caused by movements of water mass. Equipment at many stations will record various waves of 5- to 15-minute duration. Deep-water ship operations will study deep circulation, and bottom topography and composition. A comprehensive study of the amount of CO_2 in the atmosphere and ocean will establish bench marks for future trends.

HAWAIIAN VOLCANO OBSERVATORY

A brief eruption of Kilauea Volcano occurred from 31st May to 3rd June, 1954. This has been described by Macdonald and Eaton (*Volcano Letter* No. 524, 1954). The volcano continued in an uneasy state, until finally in late February, 1955, earthquake activity increased greatly and centred in eastern Puna, where an eruption commenced on February 28. It continued intermittently until May 26, when it ceased suddently. This was the first flank eruption of Kilauea since 1923, and the first in the eastern Puna district since 1840.

The eruption was described by Macdonald and Eaton (*Volcano Letter* No. 529 & 530, 1955). Of special interest was the observation and photographing for the first time in history the complete sequence of the development of new volcanic vents.

"First, hairline cracks opened in the ground, gradually widening to 2 or 3 inches. Then from the crack there poured out a cloud of white, choking sulfur dioxide fume. This was followed a few minutes later by the ejection of scattered tiny fragments of red hot lava, and then the appearance at the surface of a small bulb of viscous molten lava. The bulb gradually swelled to a diameter of 1 to 1.5 feet, and started to spread laterally to form a lava flow. From the top of the bulb there developed a fountain of molten lava which gradually built around itself a cone of solidified spatter. The same general sequence was observed at three separate points during the day" (p. 6).

A temperature of close to 2000°F was measured in a lava fountain, but in a pit near the Kalapana Road a temperature estimated to be at least 100°F higher was noted, and the walls were seen to be covered by stalactites formed by fusion of the old rock under the intense heat of the burning gas.

The account also includes graphical representation and discussion of the relations between tilt, tremor and strain release index of earthquakes before and during this eruption.

"Publication of the *Volcano Letter* will be discontinued with this issue. Beginning in January, 1956, the quarterly report of the Hawaiian Volcano Observatory will be published by the United States Geological Survey." With this brief notice in the Volcano Letter No. 529 & 530 the world's best known volcano publication came to an end, when its publication by the University of Hawaii ceased. Simultaneously Dr. G.A. Macdonald severed a long connection with the Observatory, and Dr. J.P. Eaton was appointed Director in his place. Quarterly accounts of observations are now published in the *Hawaiian Volcano Observatory Summary*, of which Nos. 1 to 4 have already appeared.

Publications of particular interest since 1953 are:

Wentworth, C.K. and Macdonald, G.A., 1954, Structures and Forms of Basaltic Rocks in Hawaii. *U.S.G.S. Bull.* 994.

Wentworth, C.K., 1954, The Physical Benaviour of Basaltic Lava Flows. *Jour. Geol.* **62**:425-438.

Macdonald, G.A. and Eaton, J.P, 1955, Hawaiian Volcanoes during 1953. *U.S.G.S. Bull.* 1021–D.

Macdonald, G.A., 1954, Activity of Hawaiian Volcanoes during the years 1940-1950. *Bull. Volc. Ser. II*, **15**: 119-179.

———, 1956, The structure of Hawaiian Volcanoes. Reprint from the Gedenkboek H.A. Brouwer. *Verh. Kon. Ned. Geol. Mynb. Gen.* **16**: 1956.

Richards, A.F., 1954, Volcanic eruptions of 1953 and 1948 on Isabela Island, Galapagos Islands, Ecuador. *Volcano Letter* **525**: 1-3.

McBirney, A.R., 1955, Recent volcanic activity in Central America. *Volcano Letter* **527**: 1-2.

———, 1956, The Nicaraguan Volcano Massaya and its caldera. *Trans. Am. Geophys. Un.* **36**: 1-2.

Bullard, F.M., 1956, Volcanic activity in Costa Rica and Nicaragua in 1954. *Trans. Am. Geophys. Un.* **37**: 75-82.

Juhle, W. and Coulter, H., 1955, The Mt. Spurr eruption, July 9, 1953. *Trans. Am. Geophys. Un.* **36**: 199-202.

(This includes an account of a flash flood caused by torrential rain accompanying the eruption in the vicinity of the volcano. Gorges normally carrying water 1 ft. to 2 ft. deep were filled to 40 ft. to 50 ft. with a flood carrying boulders, ice and debris that blocked the Chakachatna River and formed a lake 5 miles long).

GEOPHYSICS

A report of the Special Committee of the American Geophysical Union on the geophysical and geological study of continents (G.P. Woollard, Chairman, *A.G.U.* 36, 695-708, 1955) includes mention of gravity, radioactive, geothermal, magnetic, electrical and tectonic studies of the American continent, and references to published work. Thicknesses of the crust are quoted for 21 localities, and range from 19 km. to 38 km.

Gutenberg (Verschiebung der Kontinente, Eine kritische Betrachtung. Geotektonisches Symposium zu Ehren von Hans Stille, Stuttgart, 1956.) reviewed evidence for horizontal displacements of land masses at a speed roughly 1 mile in 100,000 years in recent geological time, and states that the viscosity is not too great to permit apparent polar movements by wandering of continental blocks 100 kms. thick. He also pointed out that if the Mohorovicic discontinuity is due to a phase change, then appreciable changes in its depth could be expected where the temperature beneath the crust is changing by even small amounts.

Benioff (Orogenesis and deep crustal structure-additional evidence from seismology. *B.G. S.A.* 65, 385-400, 1954) has studied the seismic evidence from eight orogenic regions, and determined that the structures responsible for the great linear and curvilinear mountain ranges and oceanic trenches are complex reverse faults. He has classified them into two types — oceanic and marginal. Oceanic faults, typified by the Mindanao, Tonga and Kermadec structures, have an average dip of 61°, and two components extending from the ocean bottom to 60 km. and from there down to 700 km. Marginal faults, typified by the New Hebrides, Aleutian, Sunda, Kurile-Kamchatka, Peru-Ecuador and other structures, have shallow and intermediate members extending with an average dip of 33° to 60 km. and 300 km. respectively, and a third component with dip of 60° extending down to 650 ± km. The elastic-strain rebound characteristics of the marginal faults show that the three components move as separate units.

He also offered a hypothesis for the origin of the volcanoes associated with these structures, by assuming that the inelastic components of the repeated to-and-fro strains involved in the generation of the sequences of earthquakes and after-shocks generate heat. In the case of South America he calculated that roughly 10^{23} ergs per year is the amount of energy liberated. (Benioff stated that he did not know if this would be equivalent to the volcanic energy required to maintain the South American system of volcanoes. It is for example about half of the energy released by natural thermal activity at Wairakei hot springs, New Zealand, and is thus a small fraction of New Zealand's discharge of volcanic energy. J. Healy).

Progress reports of the Seismological Laboratory of the California Institute of Technology have been published in the Transactions of the American Geophysical Union. They contain complete lists of publications. Reports are as follows:-

1953.	*A.G.U.*	**35,**	979 - 987,	1954.
1954.	*A.G.U.*	**36,**	713 - 718,	1955.
1955.	*A.G.U.*	**37,**	232 - 238,	1956.
1956.	*A.G.U.*	**38,**	248 - 254,	1957.

OCEANOGRAPHY

At the 8th Congress R.S. Dietz presented a paper on the marine geology of the northwestern Pacific, based on the Japanese Bathymetric Chart 6901. The paper has now been published (Dietz, 1954), and is another important addition to the growing list of literature describing the hidden morphology of the Pacific basin. The Structural features of this large fraction of the earth's surface are gradually being pieced together. The echograms obtained on the Scripps Institution — U.S. Navy Mid-Pacific Expedition of 1950 have been published by Dietz, Menard and Hamilton (1954). This expedition obtained data continuously between San Diego and the Marshall Islands, and considerable new information was obtained.

The Hawaiian Islands are located on a broad swell bounded by a trough and an arch believed to be formed by crustal yielding due to the weight of the Hawaiian Ridge. Between Hawaii and the Marshall Islands is a mountainous region termed the Mid-Pacific Mountains. It includes guyots, and from the mile-deep top of two of them were dredged Cretaceous reef fossils. The Medocino escarpment was crossed at several places. Much of the sea floor is rough, but there are flat basins, and it seems necessary to assume the existence of currents along the sea floor to explain the erosion and existence of currents along the sea floor to explain the erosion and redistribution of sediment once it has been deposited.

Menard (1955) has summarized information on the bathymetry of the north-eastern Pacific basin, where four great fracture zones trending east and west for distances ranging from 1400 to 3300 miles in length are now known. He has tentatively ascribed their formation to plastic, deformation of the crust because of stress induced by an annular convection current that rises near the Hawaiian Islands and sinks near North America. Associated with the fracture zones are large numbers of guyots, some of which at least are known to be volcanic.

A detailed account by Hamilton (1956) of the guyots of the Mid-Pacific Mountains investigated in the 1950 Mid-Pacific Expedition has been published by the Geological Society of America. Five of the flat-topped seamounts at depths of 700 to 900 fathoms are described in detail. The Mid-Pacific Mountains are interpreted as a series of basaltic ridges and volcanoes formed by the extrusion of basalt on a broad swell, similar to the present Hawaiian structure. The ridges and volcanoes were planed off and sank beneath the sea during the Cretaceous. To account for this, subsidence of the Pacific basin in the area of the

Mid-Pacific Mountains is favoured, preferably by the action of subcrustal convection currents, but possibly by foundering due to the weight of the mountains themselves.

Menard has discussed (1955, 1956) some details of seabottom topography in relation to sedimentation. In particular he has described archipelagic aprons surrounding groups of existing or drowned islands. These are believed to be accumulations at least 1000 ft thick of submarine lava flows and ash.

Dietz, R.S., 1954, Marine geology of Northwestern Pacific: Description of Japanese Bathymetric Chart 6901. *B.G.S. Am.* **56**: 119-1224.

Dietz, R. S., Menard, H. W. and Hamilton, E. L., 1954, Echograms of the Mid-Pacific Expedition. *Deep-Sea Res.* **1**: 258-272.

Hamilton, E.L., 1956, Sunken islands of the Mid-Pacific Mountains. *Geol. Soc. Am. Mem. 64.*

Menard, H.W., 1955, Deformation of the Northeastern Pacific Basin and the West Coast of North America. *B.G.S. Am.* **66**: 1149-1198.

— 1955, Fractures in the Pacific Floor. *Scientific American*, **193**: 36-41.

— 1955, Deep-sea channels, topography and sedimentation. *Bull. Am. Ass. Pet. Geol.* **39**: 236-255.

— 1956, Archipelagic aprons. *Bull. Am. Ass. Pet. Geol.* **40**: 2195-2210.

VOLCANOLOGY (1954-1957, information supplied by Dr. Donald E. White)

The work of Bullard and his associates (reviewed in Bullard, Maxwell, and Revelle, 1956) indicates that the heat flow in the ocean basin is at least as high as average heat flow in the continents in spite of the much greater thickness of matter of relatively high radioactivity under the continents. This work is with little doubt most significant to an understanding of the crust and mantle of the earth and to the ultimate causes of volcanism.

A review of basaltic provinces (Green and Poldervaart, 1955) in space and time concludes: 1) The bulk of oceanic basalts are unsaturated in silica; 2) There is no consistent variation in, composition with time; 3) There are no distinct types of basaltic magma but rather a continuous series from silica-saturated (tholeiitic) to silica-unsaturated (olivine basaltic) rocks. This seems in accord with origin by partial melting of the upper mantle.

Nockolds (1954) has revised the averages of chemical compositions of the major types of igneous rocks, based on modern analyses.

Williams (1954) has reviewed problems and progress in volcanology and Waters (1955) suggests an explanation for the origin and interrelationships of plateau basalts, the andesites and batholithic rocks of mountain belts, serpentines and amphibolites.

Many papers discuss detailed relations of volcanic rocks of specific areas, and a few are concerned with compositions of fumarolic gases and condensates.

HOT SPRINGS

Important progress has been made on the problems of the content of volcanic water, and heat supply of hot springs closely associated with volcanism. It has been long suspected that meteoric water was dominant in these mixtures. This view is definitely confirmed by stable isotopes (Craig, Boato, and White, 1956). Isotopic fractionation from evaporation and precipitation causes major and easily detected differences in the stable isotopes of meteoric water. The isotopes of each volcanic hot springs area so far investigated are closely related to the meteoric water of that particular area. No volcanic contribution has been positively identified; isotopic relations suggest that the upper limit of volcanic water is not more than about 5 percent. If true, most of the heat must be supplied by rock conduction from the magma.

Due to recent work, the Wairakei area in New Zealand is the most thoroughly studied thermal area in the world (See under New Zealand section).

White (1951a) has attempted to explain the origins of the greatly differing compositions of thermal waters that are commonly closely associated with each other in areas of recent or active volcanism. He emphasizes physical environment of the emanations. The sodium chloride type is believed to result from condensation at considerable depth by meteoric water of emanations with nonvolatile substances in solution in a dense vapor phase. Most other types of water are believed to evolve from the sodium chloride type. In an accompanying paper (White, 1957b) volcanic waters of the sodium chloride type are compared with waters of connate and of possible metamorphic origin. Tentative chemical and isotopic criteria are suggested to distinguish these waters.

G.A. Waring has completed a bibliographic summary of the thermal springs of the world. This will be published in the near future by the U.S. Geological Survey.

Many individual thermal spring areas have been studied in detail, and much attention has been given to the geochemistry of specific components.

REFERENCES

Bullard, E. C., Maxwell, A. E. and Revelle, R., 1956, Heat flow through the deep sea floor, p. 153 - 181 *in* H.E. Landsberg (*Editor*), *Advances in geophysics*, **3**: p. 1 - 378, New York: Academic Press, Inc.

Craig, H., Boato, G. and White, D. E., 1956, Isotopic geochemistry of thermal waters. *Nat. Research Council Nuclear Sci. Ser.*, Rept. No. 19, Nuclear processes in geologic setting, p. 29 - 44.

Green, J. and Poldervaart, A., 1955, Some basaltic provinces, *Geochim. et Cosmochim. Acta*, **7**: p. 177 - 188.

Nockolds, S.R., 1954, Average ehemical compositions of some igneous rocks *Geol. Soc. Am. Bull.*, **65**: p. 1007 - 1032.

Waters, A.C., 1955, Volcanic rocks and the tectonic cycle. *Geol. Soc. Am., Sp. Paper 62*: p. 703 - 722.

White, D.E., 1957a, Thermal waters of volcanic origin. *Geol. Soc. Am. Bull.*, **68**: Nov.

————, 1957b, Magmatic, connate, and metamorphic wates. *Geol. Soc. Am. Bull.*, **68**: Nov.

Williams H., 1954, Problems and progress in volcanology. *Quat. Jour. Geol. Soc. London*, **109**: p. 311 - 332.

NEW ZEALAND

STANDING COMMITTEE MEMBERS

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Professor R.S. Allan, Canterbury University, Christchurch.

Reference to bibliographic publications has already been made in the early part of this report. A list of all geological publications on New Zealand is prepared annually and published in the Journal of Science and Technology. As from the end of 1957, the present form of the Journal will be changed, and geological and geophysical papers will be published in the N.Z. Journal of Geology and Geophysics.

GEOLOGICAL MAPS

To replace the existing 1:1,000,000 geological map of New Zealand an improved map on a scale of 1:2,000,000 has been assembled and is now being prepared for publication.

A new project has been commenced to map New Zealand on a scale of 4 miles to an inch by the end of 1962. For this purpose New Zealand has been divided into 28 sheets, and a schedule has been prepared. The first maps will appear in 1958.

QUATERNARY RESEARCH

The last few years has seen an increasing interest in Quaternary geology, culminating in a special conference held by the Geological Survey in 1957 to discuss this subject alone. Interest was probably sparked by Fleming (1953) by his comprehensive account of the Pliocene and Pleistocene geology of the Wanganui district. Current investigations are proceeding on sea-level changes, glaciation, peri-glacial features, and volcanic ash shower chronology.

The correlation problem, which has been the greatest one hampering progress in Quaternary research is now being in part at least overcome. Dating by C^{14} now covers the range back to 40,000 years, and Geological Survey holds records for 112 samples dated by this method. Of these most results have already been published by Fergusson and Rafter. Paleontology is still the basis of dating earlier events, though recently work has commenced on pollen study, and it is hoped that this will greatly improve correlation and climate study, especially in the late middle Pleistocene.

Recent papers of particular interest are as follows:

Brodie, J. W., 1957, Late Pleistocene beds, Wellington Peninsula. *N.Z. Jour. Sci. Tech.* **36B**: 632-643.

Cotton, C.A. and Te Punga, M.T., 1955, Solifluxion and periglacially modified landforms in Wellington, New Zealand. *Trans. Roy. Soc. N.Z.* **82**: 1-1031.

Couper, R.A. and McQueen, R., 1954, Pliocene and Pleistocene plant fossils of New Zealand and their climatic interpretation. *N.Z. Jour. Sci. Tech.* **35B**: 398-420.

Fleming C.A., 1953, The Geology of the Wanganui Subdivision. *N.Z.Geol. Surv. Bull.* **52.**

—— ——1955, Quaternary Geochronology in New Zealand. *Act. IV Cong. Int. Quat. 1953*: 925-930.

Gage, M., 1953, The study of Quaternary strandlines in New Zealand. *Trans. Roy. Soc. N.Z.*, **81** : 27-34.

Stevens, G.R., 1957, Solifluxion phenomena in the Lower Hutt Valley. *N.Z. Jour. Sci. Tech.* **38B** : 279-296.

Brothers, R.N., 1954, The relative Pleistocene chronology of the South Kaipara district, New Zealand. *Trans. Roy. Soc. N.Z.* **82** : 677-694.

Fergusson, G.J. and Rafter, T.A.; New Zealand C^{14} age measurements.

—1. *N.Z. Jour. Sci. Tech.* **35B**, 127-8, 1953.

—2. *N.Z. Jour. Sci. Tech.* **36B**, 371-374, 1955.

—3. *N.Z. Jour. Sci. Tech.* **38B**, 732-749, 1957.

GEOTHERMAL INVESTIGATIONS

A power station to generate 69,000 KW of electricity from geothermal steam is now under construction at Wairakei, and an increase to 151,000 KW is planned to use steam already in production.

Since the last Congress drilling at Wairakei has been for production only. Geological work was concentrated on the mapping of fault traces on aerial photographs, and four were identified that seem to be important feeding fissures in the Wairakei thermal area (Grindley, 1957). Fair success has been obtained by drilling to intersect these steeply-dipping fissures at about 2,000 ft. depth from the surface, and the best production wells in the fissured zones discharge about 80,000 lb of steam and 500,000 lb of water per hour at a well-head pressure of 200 lb/sq in.

Some wells have shown a gradual decline in production, and in some cases at least this seems to be due to deposition of minerals, chiefly calcium carbonate, in the wells, which return to full production when drilled out again.

Geophysical work at Wairakei has included a detailed temperature survey, using thermocouple probes to a depth of 3 ft. as well as in deeper drilled holes, to determine the full extent of the warm area, its surface thermal pattern and relation to geological structure. Results of this survey are not yet available.

Chemical work on the well discharges has been continued and extended, and a research project on high temperature chemical equilibria in volcanic gases and steam (Ellis, 1957) was commenced.

At Waiotapu, thermal area some 30 miles north-east from Wairakei, another investigation is under way. Geophysical work was done some time ago, but a detailed temperature survey, combined with drilling and geological and hot spring surveys, is now being completed.

The following comments on geothermal investigations are supplied by Mr. C.J. Banwell, of Dominion Physical Laboratory, N.Z. Dept. of Scientific and Industrial Research.

"In the course of an intensive drilling program for power production, approximately 50 holes have been drilled in an area measuring roughly 1½ miles by ½ mile. One of these holes has reached a depth of approx. 1 kilometre, and most of the more recent holes have depths of 600 to 700 metres. Practically all the holes produce a mixture of steam and water in proportions corresponding rather closely with the temperatures measured in their lower sections. The physical and geological data obtained from these holes are consistent with the idea that the region tapped by them, consisting largely of permeable volcanic breccias, is fed by hot water at a temperature of about 260°C rising through joints or fissures in a much less permeable formation which underlies most of the area so far explored at a depth of the order of 600-700 metres. No hole has yet been drilled deep enough to reach the bottom of this impermeable formation (an ignimbrite), which must have a minimum thickness of some 300 metres, and there is little evidence available to indicate what its true thickness may be. Some of the holes drilled into it have shown temperatures falling with depth in their lower sections, suggesting that the regions beneath are not uniformly hot, but apart from this, not very much can be said about the nature of the hot fluid below the ignimbrite; it could equally well be steam or hot water. An attempt is being made to drill into one of the supposed feeding fissures at some depth in the ignimbrite, and if this is successful, much new information about the mode of heat transfer through this formation, and the hot fluid below, should be obtained.

Regarding the origin and mode of transfer of heat at still greater depths, Banwell (1957) has discussed some of the physical implications of heat transfer models involving either convection (by steam and magmatic gases) or conduction (from a mass of hot rock to circulating ground water) and discussed some of the theoretical difficulties associated with a simple conductive model. However, the results of recently published work with stable isotopes in other thermal areas (Craig, Boato and White, U.S.A.) indicate such small proportions of primary (magmatic) gases, including water, that the initial temperature of these gases would need to be improbably high if they were responsible for most of the initial heat transfer. Although not a great deal of this kind of isotope work has so far been done at Wairakei, the results of some preliminary observations of Carbon 14 content, based on a greatly improved technique for the determination of this isotope, indicate that both the emissions of the White Island[1] fumaroles and some of the natural steam vents at Wairakei must contain a major proportion of water of surface origin (G.J. Fergusson, pers. comm.). Thus, it would appear that some kind of conductive process must be called upon to provide much of the observed heat transfer, and the devising of physically workable and geologically acceptable conductive models offers some interesting problems."

Recent publications of geological interest on geothermal investigations are as follows:-

Hamilton, W.M., 1954, Geothermal energy. *Cawthron Lecture Series*, No. 27.

Grange, L.I. (compiled by), 1955, Geothermal steam for power in New Zealand. *N.Z.D.S.I.R. Bull.* 117.

Ellis, A.J. and Wilson, S.H., 1955, The heat from the Wairakei-Taupo thermal region calculated from the chloride output. *N.Z. Jour. Sci. Tech.* **36B**: 622-631.

Steiner, A., 1955, Wairakite, the calcium analogue of analcime, a new zeolite mineral. *Min. Mag.* **30**: 691.

Coombs, D.S., 1955, X-ray observations on Wairakite and noncubic analcime. *Min. Mag.* **30**: 699.

Healy, J., 1956, Preliminary account of hydrothermal conditions at Wairakei, New Zealand. *Proc. 8th Pac. Sci. Cong.* II, 214-227.

Grindley, G.W., 1957, Geothermal power. *Science in New Zealand*, Ed. F.R. Callaghan, 112-122.

Banwell, C.J., 1957, The New Zealand thermal area and its development for power production. *Trans. A.S.M.E.*, **79**: 255.

Studt, F.E., 1957, Wairakei hydrothermal system and the influence of ground water. *N.Z. Jour. Sci. Tech.* **38B**: 595-622.

Ellis, A.J., 1957, Chemical equilibrium in magmatic gases. *Am. Jour. Sci.* **255**: 416-431.

STRATIGRAPHIC LEXICON

The preparation of material for the New Zealand section of the international stratigraphic lexicon by New Zealand geologists has been completed, and the huge task of editing and preparing this for publication, undertaken by Dr. C.A. Fleming, is almost finished. Its preparation was in the first place considerably simplified by the earlier appearance of the *Bibliographic Index of New Zealand Stratigraphic Names* by G.L. Adkin (*N.Z.G.S. Mem.* 9, 1954), but the greatly increased scope of the Lexicon will make it an invaluable asset to New Zealand geology.

GEOLOGICAL STRUCTURE

H.W. Wellman, 1956. Structural outline of New Zealand. *N.Z. D.S.I.R. Bull.* 121.

This bulletin is a concise statement of the dominant structural features of New Zealand. For this purpose New Zealand has been divided into 20 structural regions based on natural divisions. Each is described separately, and in addition there is an account of the rocks of New Zealand and their structures in period groups. The Bulletin is accompanied by five maps and 151 references.

INTERNATIONAL GEOPHYSICAL YEAR

Preliminary organization of New Zealand's effort for the I.G.Y. was by a National Committee of the Royal Society of New Zealand, but for the co-ordination and execution of the program an Interdepartmental Committee was formed.

Geomagnetic work will include observations of the earth's magnetic field at stations in New Zealand, Rarotonga, Samoa, Campbell Island,

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[1] **White Island is the top of a large and mostly submerged volcanic mass located in the Bay of Plenty about 100 miles NE of Wairakei.**

and Cape Adare and Scott Base, McMurdo Sound. Earth currents will be observed along two lines near Christchurch.

In glaciology, geological work is already in hand for the measurements of shrinkage and movement on the Tasman and Franz Josef glaciers. In the Antarctic the New Zealand party will make gravity and seismic surveys of ice thickness up to and on the polar plateau between McMurdo Sound and the South Pole.

The oceanographic program includes the installation and operation of tide gauges in New Zealand and outlying islands, the operation of a long wave recorder at North Cape, and ocean measurements at stations in the South Pacific and Southern oceans.

For studies in seismology, instrumentation in New Zealand and Samoa have been improved, and new stations have been established at Raoul Island, Scott Base and Adare (with the Americans). A better understanding of the seismicity of a much larger and partly unknown area is sought.

Gravity measurements will be extended from a new base at Scott Base, McMurdo Sound, in the Ross Sea Dependency and inland towards the South Pole.

PACIFIC ISLANDS

Assistance has been given to various Pacific islands. Geological surveys have been made at Niue, Samoa and the Cook Islands, and a survey of hot springs to assess geothermal potential in Fiji was carried out.

SEISMOLOGY

The continuous recording and analysis of earthquake data has been continued, with special attention to various aspects of New Zealand earthquakes. A special project of interest has been the crustal studies in the Wellington area. These have now been extended into the Auckland area, and other work is planned.

Eiby, G.A. and Dibble, R.R., 1957, Crustal Structure Project. *N.Z. D.S.I.R. Geophysical Mem. 5.*

OCEANOGRAPHY

The N.Z. Oceanographic Institute has carried out studies of Pleistocene and Recent sediments in Hawke Bay and elsewhere. A considerable amount has been done on the assembling information on the sea bottom round New Zealand, and on the structural significance of the physical forms. A bibliography has been published of oceanographic work in New Zealand (Geophysical Mem. 4, 1955), and there is an account of post-war oceanography in *Science in New Zealand* (Ed. F.R. Callaghan, 1957) by R.M. Cassie.

AUSTRALIA

STANDING COMMITTEE MEMBERS

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VOLCANOLOGY

The following information on volcanology is compiled from the 1954-56 report of the Sub-Committee on Volcanology, of the Australian Committee on Geodesy and Geophysics.

Volcanological work was confined to the New Guinea area, including the Solomon Islands, and was carried out mainly from the Volcanological Observatory at Rabaul. M.A. Reynolds was officer in charge of the Observatory for most of the period under review. Field and aireal observations of other volcanoes were also carried.

The observatory at Rabaul functioned continuously. Instruments at the observatory are a three-component short period Benioff seismograph, and a two-component tiltmeter. An Omori-type two component seismograph is maintained at Rapindik, 5.5 km south-south-east of the observatory and 2.5 km west-north-west of Matupi volcano. The following reports are prepared regularly:

Weekly	: Provisional seismological Bulletin
Monthly	: Volcanological report
,,	: List of tremors reported to the Observatory
Quarterly	: Seismological Bulletins
Irregularly	: Reports on investigations of volcanic centres, volcanic eruptions or seismic phenomean.

Volcanic activity since January, 1954, has been summarized.

Tuluman. Submarine activity at this "new" centre continued, and two small islands were built up above sea level, but their shape is continually changing, due to eruption and erosion. The lava is basaltic in composition.

Bam. Mild explosive eruptions began on 3 August 1954, and continued intermittently at intervals through 1955 and 1956.

Manam. Ejections of dust began in December 1956. Activity continued during January and February 1957 with explosive eruptions and extrusion of lava.

Long Island. Eruptions from the island crater on Lake Wisdom continued intermittently from 8 May 1953 till 7 January 1954. Further eruption, with the ejection of incandescent ash occurred from 5 to 13 June 1955.

Langila. After earlier premonitory signs, the more northerly crater burst into eruption on 18 May 1954 and continued with intervals until June 1955, with a further period of mild eruptions towards the end of March 1956.

Lamington. Dome building continued quietly at least until September 1956, with some breaking up and collapse of the upper part of the lava dome. An "explosion" was reported on 27 March 1956.

D'Entrecasteaux Islands. Earthquake swarms were experienced in the area about Dobu, between Fergusson and Normanby Islands, from July to September 1955, and again in the first months of 1957. In the intervening period earth tremors were more frequent than normal. Several craters exist in the area and are being kept under observation for possible volcanic eruption, though none has been recorded previously.

Savo. Local investigations established that this volcano is definitely of the Pelean type, so arrangements were made for the establishment of a system of warning of any increase in temperature or local seismic activity.

Tinakula (Santa Cruz Is.) This very active volcano is reported to have become quieter since 1951.

Yasour (Tanna). This volcano is continually active with small explosions from a pool of liquid lava in the bottom of the crater, but with exceptionally violent activity in January 1956.

Both G.A. Taylor and M.A. Reynolds have devoted a considerable amount of attention to research on the relationship between volcanic eruptions and seismic activity, and to the influence of luni-solar factors on such activity. Petrological examinations of lavas from the Melanesian volcanic centres have been made in the laboratory at the Bureau of Mineral Resources, and 18 chemical analyses of rock types from Mt. Lamington were completed.

Samples of burned wood from Rabaul, Long Island and Lamington were sent to New Zealand for C^{14} dating. Recent publications are as follows:-

Best, J.C., 1956, Investigations of recent volcanic activity in the territory of New Guinea. *Proc. 8th Pac. Sci. Cong.* II, 180-204.

Fisher, N.H., 1954, Report of the sub-Committee on Vulcanology 1951. *Bull. Volc. Ser. II*, **15**: 71-79.

Grover, J.C., 1955, Geology, Mineral deposits and prospects of mining development in the British Solomon Islands Protectorate. *Interim Geol. Surv. Sol. Is. Mem.*

Taylor, G.A., 1956, Report of the Sub-Committee on Vulcanology 1953. Review of volcanic activity in the Territory of Papua-New Guinea, the Solomon and New Hebrides Islands, 1951-53. *Bull. Volc. Ser. II* **15**: 81.

Taylor, G.A., 1954, Vulcanological observations at Mt. Lamington 29th May 1952. *Bull. Volc. Ser. II*, **15**: 81-89.

Taylor, G.A., 1956, An outline of Mt. Lamington eruption phenomena. *Proc. 8th Pac. Sci. Cong. II*, 83-88.

The following publications were in press or ready to go to the press at March, 1957.

Fisher, N.H. Catalogue of the active volcanoes and solfatara fields of Melanesia. Part V of the *Catalogue of the active volcanoes of the world* edited by the International Volcanological Association.

Grover, J.C. *Interim Geol. Surv. Brit. Sol. Is.* Mem. 2.

Reynolds, M.A. and Best, J.C. The Tuluman volcano, St. Andrew Strait, Admiralty Islands, *Bur. Min. Res. Aust. Bull.* **38**.

Taylor G.A. The Mt. Lamington eruption of 1951. *Bur. Min. Res. Aust. Bull.* **38**.

Taylor, G.A., Reynolds, M.A. and Best, J.C. Eruptive activity and associated phenomena, Mt. Langila, New Britain, 1952-1956. *Bur. Min. Res. Aust. Rept. 26.*

INTERNATIONAL GEOPHYSICAL YEAR

The Australian Academy of Science is the planning organization, but there is appointed an Australian National Committee for the International Geophysical Year, to co-ordinate the Australian projects. There are in addition sub-Committees to deal with individual aspects.

Geomagnetic observations will include measurements of the earth's field, especially near the equator and in the auroral zones, and during magnetic storms.

Ice depth determinations will be made and general glaciological investigations carried out on the Antarctic continent inland from Mawson.

Ocean movements—tides and long waves—will be recorded at Norfolk Island and Willis Island, and tides will be recorded also at sites on the western shores of the Tasman and Coral Seas. Microseisms will be investigated on the Queensland coast.

The number of standard seismograph stations will be increased from two to seven in continental Australia, and others will operate at MacQuarie Island and Mawson.

HYDROLOGY

The Australian Academy has now established a Standing Committee for Hydrology, with convener Professor E. S. Hills of the University of Melbourne. This replaces the former sub-Committee for Hydrology of the National Committee for Geodesy and Geophysics.

SEISMOLOGY

The Report on Seismology in Australia, 1954-57, published by the Secretary of the Sub-Committee on Seismology, contains a description of the active seismograph stations in Australia.

Under the aegis of Professor Jaeger, of the Australian National University, Canberra, and Professor Bullen, of the Department of Applied Mathematics, University of Sydney, new research is being carried on with a view to the revision of travel time-tables of near earthquakes in the Australian region. Some of the data used in this research have come from the study of seismograms of controlled explosion in the Snowy Mountain area.

Research at stations under the control of the University of Queensland includes investigations into local tremors and into microseisms, with special references of the relation of these to cyclonic disturbances; investigations into the direction of faulting; into the nature of the crust in the S.W. Pacific; theT-phase, as recorded at Brisbane. A study of L_g from the New Guinea region has recently been initiated.

At Canberra recent research includes determinations of the depth of the crustal layer, use being made of recordings of controlled explosions.

At Riverview College, Sydney, investigations of teleseisms, with special reference to core phases, are carried out. Also research into local tremors, with a view to determining epicentres, so that a revision of travel-time-tables for near earthquakes may be possible. Recent research includes an investigation into the travel times of waves generated by "nuclear explosions".

Recent investigations by the Bureau include determinations of crustal thickness, using data obtained from controlled explosions. The following bibliography ends the above report:

Bolt, B.A., 1956, The Epicentre of the Adelai de Earthquake of 1954, March 1. *J. and Proc. Roy. Soc. of N.S.W.* **90** : 39-43.

Bullen, K.E., 1954, Composition of the Earth's outer core. *Nature* **174** : 505.

———, 1954, Euler's equation and (p,r) coordinates. *Math. Gazette* **38** : 172-174.

———, 1954, Conversion of variation problems into isoperimetrical problems. *Math. Gazette* **38** : 249-252.

———, 1954, On the homogeneity, or otherwise, of the Earth's upper mantle. *Trans. Amer. Geophy. Un.* **35** : 838-841.

———, 1955, On the size of the strained region prior to an extreme earthquake. *Bull. Seis. Soc. Amer.* **45** : 43-46.

———, 1955, Note on New Zealand crustal structure. *Trans. Roy. Soc. of N.Z.* **82** : 995-999.

———, 1955, Some trends in modern seismology. *Science Progress,* **170** : 211-227.

———, 1955, Physical properties of the Earth's core. *Ann. Geophys.* **11** : 53-64.

———, 1955, The Interior of the Earth. *Scientific American* **193** : 56-61.

———, 1955, Proposal for the use of atom bombs for seismological purposes. *Bull. d'Information de l'U.G.G.I.*, **12** : 550-552.

———, 1955, Features of seismic pP and PP rays. *M.N. Roy. Astr. Soc., Geophys. Supp.* **7** : 49-59.

Bullen, K.E., 1956, Seismic wave transmission. *Encyclopedia of Physics* **47** : 74-118.

————, 1956, Seismology and the broad structure of the Earth's interior. *Physics and Chemistry of the Earth* **1**:68-93. Pergamon Press.

————, 1956, Seismology and the Earth's deep interior. *Aust. J. Sci.* **19** : 99-100.

————, 1956, The influence of the temperature gradient and variation of composition in the mantle on the computation of density values in Earth Model A. *M.N. Roy. Astr. Soc., Geophy. Supp.* **7** : 214-217.

————, 1956, Note on the phase PKJKP. *Bull. Seism. Soc. of Amer.* **46** : 333-334.

————, 1957, The International Geophysical Year. *Australian Quarterly* **29** : 16-25.

Bullen, K.E. and Bolt, B.A., 1956, The South Australian Earthquake of 1939, March 26. *J. and Proc. Roy. Soc. of N.S.W.* **90** : 19-28.

Burke-Gaffney, T.N., 1954, The T-phase from the New Zealand Region. *J. and Proc. Roy. Soc. of N.S.W.* **88**:50-54.

Burke-Gaffney, T.N. and Bullen, K.E., 1957, Seismological and related aspects of the 1954 Hydrogen Bomb explosions. *Aust. J. of Phys.*, **10**:130-136.

Kerr Grant, C., 1956, The Adelaide Earthquake of 1st March, 1954. *Trans. Roy. Soc. of S.A.* **79**:177.

Upton, P.S., 1956, Cyclone Microseisms at Brisbane. A new method of analysis. *Bull. Dept. Geol., Univ. of Queens.*, **4**:14.

————, 1956, Microseisms associated with Tropical Cyclones over the North-East Australian Region. *Tropical Cyclone Symposium*, Brisbane.

GRAVIMETRY

The National Report on Gravity Surveys for the period 1954-1956 lists the gravity surveys carried out during that period, and illustrates them on a map. The following publications are listed:

Marshall, C.E., and Narain, H., 1954. Regional gravity investigations in the eastern and central Commonwealth. Dept. Geology and Geophysics, University of Sydney.

Thyer, R.F. and Everingham, I.B., 1956, Gravity survey of Perth Basin, Western Australia. *Bur. Min. Res. Aust. Bull.* **33**.

The National Reports on Precision Levelling and Triangulation for the same period also include accounts of the work completed. The above reports were published by the International Association of Geodesy, Eleventh General Assembly, at Toronto, 1957.

INDONESIA

STANDING COMMITTEE MEMBER

Dr. Th. H.F. Klompé. Geological Institute, University of Indonesia, Djl. Ganeca 10, Bandung, Java.

THE STATUS OF GEOLOGICAL MAPPING IN INDONESIA

This is the title of a report prepared by Th. H.F. Klompé for the Ecafe meeting in Bangkok in 1954, but brought up to date in October, 1957[2]. The Indonesian archipelago occupies about 4% of the area of the earth, and there are altogether about 7,000 publications on the geology and geophysics of the region. Owing to the considerable amount of work done by the joint effort of Geological Survey and oil and mining companies, and by private research, a fair area has been mapped in detail. Altogether about 80% has been mapped on a reconnaissance scale.

The historical aspects of geological mapping are described, and there is a list of the published maps available. The general geological map of Indonesia on a scale of 1: 1,000,000 will consist of 21 sheets, of which 12 have already been published, all accompanied by an explanatory note.

Of 131 sheets of the geological map of Java on a scale of 1:100,000, 11 have been published with explanatory notes and detailed maps, sections and photographs. 13 sheets of 43 have been published of the 1:200,000 map of South Sumatra.

For the geological maps of Java and South Sumatra a system of colours and symbols are used as described by Ir. A.C. de Jongh (*J.v.h.M.* vol. 59, 1930, Part III, 56-71). The report contains a discussion on the colours and symbols.

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[2] Published in: *Indonesian Journ. f. Natural Science.* Vol. 113. 1957.

A new general geological map of Indonesia in four sheets has been prepared on a scale of 1:2,000,000, using 20 shades of colours and 7 symbols of dots and crosses. The map is compiled from existing maps, which are listed.

In 1953 detailed geological mapping was commenced in the crystalline schists of the Lalan-Assu area in West Timor. Another sequence of overthrust masses was found, as established by Brouwer, but the orogenic phase is younger (Middle Miocene) than formerly suggested, and corresponds to the main phase of diastrophism in the Outer Banda Arc. The area being mapped has been extended, and the work has included some gravity and magnetic measurements.

Mapping was started in 1953 in Central Sumatra in the granite massive of Solok, and will be extended northeast and southwest to complete a section across Sumatra. Since 1954 the area of mapping has also been extended west and north-west, where a remarkable Permian volcanic-sedimentary series has been mapped.

Detailed mapping was started in 1954 in the Dwijo Hills and the northern part of the "Zuidergebergte" (Southern Mountains) east of Djokjakarta. The area has pre-Tertiary metamorphics unconformably overlain by Eocene, with both frequently interfolded. There are a number of sedimentation cycles and a flysch facies.

Detailed mapping was also started in the Duizendgebergte (Thousand Mountains) on the southcoast of Central Java, with a sequence of almost undisturbed middle and upper Miocene sediments. The name of this area derives from its morphologic character, and results to date indicate that the individual hills owe their location to the presence of bioherms.

In east Java geological mapping was started in 1957 in the Ringgit-Beser complex of younger volcanics belonging partly to the Mediterranean suite, covered in the south by young volcanic sediments.

The report is accompanied by maps and figures to illustrate the maps mentioned above and the areas in which mapping has been carried out.

GEOLOGICAL PUBLICATIONS FOR THE YEARS 1953-1957:

Marks, P., 1953, Preliminary note on the discovery of a new jaw of Meganthropus von Koenigswald in the lower middle pleistocene of Sangiran, Central Java. *Indonesian Journ. f. Nat. Sc.* **109**:26-34, 1 fig. 2 plates, 1 map, Bandung.

Klompé, Th. H.F., 1954, The structural importance of the Sula Spur (Indonesia). *Indonesian Journ. for Nat. Sc.* **110**: 21-41, 8 figs.

Marks, P., 1954, Contributions to the Geology of Timor. III. An occurrence of Miogypsina (Miogypsinella) Complanata Schlumberger in the Lala Asu Area Timor. *Ind. Journ. f. Nat. Sc.* **110**: 77-78, 4 figs.

Osberger, R., 1954, Contributions to the Geology of Timor. IV. Notes on Plio-Pleistocene Corals of Timor. *Indonesian Journ. f. Nat. Sci*, **110**: 80-82.

Waard, D. de, 1954, Contributions to the Geology of Timor. I. Geological research in Timor, an introduction. *Indonesian Journ. f. Nat. Sci*, **110**: 1-9, 5 figs. and map.

———, 1954, Contributions to the Geology of Timor. II. The orogenic main phase in Timor. *Ind. Journ. f. Nat. Sc.* **110**:9-21, 10 figs. and map.

———, 1954, Contributions to the Geology of Timor. V. Structural development of the crystalline schists in Timor, tectonics of the Lalan Asu Massif. *Indonesian Journ. f. Nat. Sc.* **110**: 143-154, 12 figs.

———, 1954, Contributions to the Geology of Timor. VI. The second geological Timor Expedition, preliminary results. *Indonesian Journ. f. Nat. Sc.* **110**: 154-161, 5 figs.

Klompé, Th. H.F., 1955, On the supposed upper Paleozoic unconformity in North Sumatra. *Indonesian Journ. f. Nat. Sc.* **111**: 151-166, 3 figs.

Kraëff, A., 1955, A contribution to the petrology of the young extrusive and intrusive and intrusive rocks of the river-basin of S. Kajan. (N.E. Borneo). Djawatan Geologi, Bandung *Publikasi Keilmuan, seri Petrologi*, No. 29: 11-19, figs and locality map.

Waard, D. de, 1955, Contributions to the Geology of Timor. VII. On the Tectonics of the Ofu Series. *Indonesian Journ. f. Nat. Sc.* **111**: 137-144, 6 figs.

———, 1955, Contributions to the Geology of Timor. VIII. Tectonics of the Sonnebait Overthrust Unit near Nikiniki and Basleo. *Indonesian Journ. f. Nat. Sc.* **111**: 144-151 5 figs. 1 pl.

Marks, P., 1956, Smaller Foraminifera from Well No. 1 at Kebajoran, Djakarta. *Publikasi Keilmuan* No. 30, Seri Paleontologi, Bandung 1956.

———, 1956, *Lexique Strátigraphique International.* Vol. III, *Asie, Faxicule* 7, *Indonesia*, Paris 1956.

Obserger, R., 1956, Korallen als Hilf smittel der Tertiär und Quartär Stratigrafic Indonesiens. *Publikasi Keilmuan* No. 32, *Seri Paleontologi*, Bandung 1956.

Laufer, F. and Kraeff, A., 1957, The Geology and Hydrology of West-and Central-Sumba and their Relationship to the Water-supply and the rural Economy. *Publikasi Keilmuan* No. 33, *Seri Geologi*, Bandung 1957.

NATIONAL REPORT OF WORK ON SEISMOLOGY (1951-1956)

(Published by the Seismological Department, Meteorological and Geophysical Institute, Djakarta, April, 1957).

SEISMOGRAPH STATIONS

Djakarta Lat. 06°11′ S. Long. 106°50′ E h=8m (inaugurated 1898) Foundation: River quaternary. Seismograph: Wiechert Z 1300 kg Wiechert N & E 1000 kg

Bandung Lat. 06°54′S. Long. 106°37′E h=726 m (inaugurated 1948) Foundation: Quaternary volcanics. Seismograph: Wiechert N & E 1000 kg

Lembang Lat. 06°50′ S. Long. 107°37′ E h= 1295 m (inaugurated 1953) Foundation: Quaternary volcanics. Seismograph: Sprengnether Z (T = 1.4 sec) Sprengether N and E (T_0 = 15 sec)

Medan Lat. 03°33′ N. Long. 98°41′E h=32 m (inaugurated 1956) Foundation: Young marine sediments. Seismograph: Sprengnether Z,N and E (T_0 = 1.5 sec).

Because of serious difficulties in the construction sector (building of adequate housing) it has still not been possible to install the seismographs in Kupang (Timor) and Menado (N. Celebes). Both stations are going to be equipped with a set of short-period Sprengether seismographs.

MACROSEISMIC WORK

The macroseismic bulletin for the years 1948-1955, prepared under the direction of R. Soetadi and A.R. Ritsema, is now in print. It will not be possible to bridge the gap between the years 1942 and 1948; during these years no data of felt earthquakes have reached the Institute.

The drafting of new blanks has been successful in so far that there is a marked improvement in number of reported shocks. The diligence of the voluntary observors, however, has not yet reached the pre-war level, seeing that the number of reported shocks has not yet reached the average of the last years before the war.

From 1956 onward the bulletin will be published yearly, all reports than being based on the Modified Mercalli Intensity Scale.

Important damage was caused by the Sumbawa earthquake of November 2, 1954. A local shock with a very small macroseismic area caused considerable damage in Sumedang (W. Java) on August 14, 1955.

MICROSEISMIC OBSERVATIONS AND RESEARCHES

Preliminary readings are executed at every stations, and if necessary results are cabled to the Institute in Djakarta. Seismic bulletins of all Indonesian stations are prepared by W.F. Smeets. All seismograms are stored in Djakarta.

Since January 1, 1957 also microseisms are read from the Djakarta seismograms under the direction of R. Soetadi. Results are published monthly as an annex of the Seismic Bulletin.

Some focal mechanism studies of SE Asian earthquakes have been executed. These investigations will be continued during the next years. The method used so far is extended, so as to include also the initial motion of the S waves.

BIBLIOGRAPHY

Ritsema, A.R.—A strong earthquake near Bima (Sumbawa) *Indon. Jour. Nat. Sc.*, **110**: 214-215 (1954).

———, The fault plane technique and the mechanism in the focus of the Hindu Kush earthquakes. *Indian Jour. Meteor. & Geoph.* **6**: 41-50 (1955).

———, Amplitudes of bodily seismic waves *Indon. Jour. Nat. Sc.*, **112,** (1956).

Ritsema, A. R., The mechanism in the focus of 28 SE Asian earthquakes. *Verhand.* **50**, *Meteor. & Geoph. Inst.*, Djakarta, (1956).

———, Stress distributions in the case of 150 earthquakes *Geol. & Mijnb.*, *Nw. Ser.*, **19**:36-40 (1957).

———, Pacific and Mediterranean earthquake mechanisms *Trans. Am. Geoph. Un.* **38**, (1957).

———, Earthquake generating stress systems in SE Asia *Bull. Seism. Soc. Am.*, **47**, (1957).

———, On the use of transverse waves in earthquake mechanism studies. *Verhand.* **52**, *Meteor. & Geoph. Inst.*, Djakarta (1957).

Soetadi, R. and A.R. Ritsema -The earthquake of November 2, 1954 near Sumbawa Island. *Verhand.* **47**, *Meteor. & Geoph. Inst.*, Djakarta (1955).

THAILAND

STANDING COMMITTEE MEMBER

Mr. Vija Sethaput, Royal Department of Mines, Bangkok.

SUMMARY OF GEOLOGICAL DEVELOPMENT IN THAILAND SINCE 1953.

(*Report received from Geological Survey Division, Bangkok*).

During the past three years routine reconnaissance survey uncovered tremendous amounts of fossils in diverse localities. Notable among these are the fossils collected during the joint Malay-Thai investigation (for mutual correlation purposes) along the adjoining border areas. This work was done from November 1955 till February 1956 and Upper Cambrian, Middle Ordovician, Lower Silurian, Carboniferous and Permian fossils were discovered.

In 1954 the Central Plain of Thailand, an area of some 26,000 square kilometers, was covered with an aeromagnetic survey and four anomaly closures were found. One of these was explored by terrestric gravitymeter surveying and drilling is being done to test the underlying formations for possible economic development. Further aerial survey work, including magnetometer, scintillation counter and perhaps electromagnetic induction instrument, is expected to be undertaken over three known mineralized areas. The flights will be made under contract and will start early next year.

Radio-active minerals of doubtful economic value were discovered in tin mines in the south. Iron, tin, tungsten, manganese, gypsum, salt and fluorite deposits were surveyed during this period.

A groundwater project has been carried out since 1955 with the aim to help develop water resources for the NE., in an area about one third of Thailand. This is in the plateau area, where surface water is usually very scant, due to absorption by the underlying sandstone formations. Many holes have been drilled with a coverage about 60 per cent. Most failures are due to the occurrence of salt water.

The lack of reasonably good maps has been an important problem to the Geological Survey. Compilation of geological information has to be done on a reconnaissance base. Fossil localities are specially emphasized so that when good maps will become available, the strata can be readily traced in a proper way. Beside, identification of the fossils may indirectly be used for generalisation of the stratigraphy of Thailand.

The Geological Survey is also faced with the lack of personnel. This may be due to the public feeling that geologists are confronted with personal risk and a hard occupation, while getting paid the same as other technicians who work in town. Last but not least, is the meagre yearly budget resulting in only a few short trips each year. However, since the last few years, we received aid from the U.S. Government through ICA and many of our needs were realized. Material and monetary aids are very substantial, and geologists have the chance to be selectively trained abroad.

It is very gratifying to know that the Government is now really becoming interested in the work of the Geological Survey and intends to enlarge its budget in the future.

Owing to lack of funds and personnel, the Survey has not participated in this International Geophysical Year.

PHILIPPINES

STANDING COMMITTEE MEMBER

Mr. Arturo Alcaraz, Commission on Volcanology, University of the Philippines, Quezon City.

PROGRESS OF GEOLOGIC SURVEY IN THE PHILIPPINES SINCE 1953

(*By Elpidio Vera and Arturo Alcaraz*).

The Philippine Bureau of Mines conducted detailed geologic surveys mainly in areas of known mineral deposits. Little or no regional geology was attempted. However, reconnaissance mapping covered 1.7 million hectares in 33 provinces. There is also in progress a project of measurement of stratigraphic sections in the Cagayan Valley covering 50,000 hectares. An airborne magnetometer survey of six principal iron areas in Luzon, Visayas and Mindanao was completed by Hunting Geophysics, Ltd. of London in 1954 for the Philippine Government. Since the last couple of years or so oil concessionaires have conducted geophysical surveys in their respective concessions, covering in particular, the Cagayan Basin, parts of Panay island, and Cotabato. Some of these oil companies also made ground reconnaissance surveys in a number of provinces.

Paleontologic and stratigraphic studies have advanced considerably as a result of close cooperation between the technical staffs of the petroleum companies and the Bureau of Mines.

In the past four years significant contributions have been made to the geology of the coal deposits of Central Cebu, Malangas (Zamboanga del Sur), Batan Island (Albay), Catanduanes, Semirara (Antique), Bulalacao (Mondoro), Bislig (Surigao) and Polillo (Quezon); the geology of copper deposits in Antique, Cebu, Repu-Rapu Island (Albay), Botolan (Zambales), Sipalay (Negros Occidental); and the geology of chromite deposits in Zambales and of manganese deposits in the Anda Peninsula (Bohol).

The coal and strategic minerals investigations conducted by the Philippine Bureau of Mines in cooperation with International Cooperation Administration and the results of exploration work of the petroleum companies brought out much information leading to a clearer understanding of the Tertiary formations, structures, and stratigraphic sequence in the Philippines.

The results of detailed surveys by the Bureau of Mines are published under the *Special Projects Series* of which 10 volumes are now available.

With but few exceptions all additional geologic data gathered from various sources up to the time of writing have been incorporated in a geologic map of the Philippines that is to be submitted to the ECAFE Convention in India this coming November.

Volcanological Observations and studies of the active volcanic areas of the Philippines were continued by the Commission on Volcanology. Two-component seismographs have been installed at Taal, Mayon, Hibok-Hibok, Canlaon, and Apo. A water tiltmeter of the type being used in Hawaii has also been installed in the Mayon area, with others due to be set up at other volcanological stations during the year. Magnetic and petrographic studies are also being undertaken by the Commission on Volcanology.

INTERNATIONAL GEOPHYSICAL YEAR

The Bureau of Coast and Geodetic Survey and the Philippine Geodetic and Geophysical Institute will carry out measurements of the earth's magnetic field. Observations are now being made at the Muntinlupa Magnetic Observatory.

In oceanography the Bureau of Coast and Geodetic Survey will carry out measurements of tide, temperature and salinity at five regular stations and two additional ones established for IGY. C & GS ships have been instructed to take oceanographic measurements wherever they should happen to be during the IGY.

The Manila Observatory and the Geophysical Division of the Weather Bureau will participate. The Manila Observatory will continue its regular program of seismic recordings from its five Sprengnether seismometers. Microseismic studies will also continue. Geophysical Division will also continue its regular program of seismic recording and microseismic work, and studies on the relation of microseisms to ocean storms will continue.

There will be no Philippine work on gravity measurements, but a United States party will make some during the latter part of 1957.

OBITUARY

The death of Dr. Jose M. Feliciano on 22 February 1955 is recorded with regret. He attended the 7th Congress in New Zealand, and was Chairman of the Division of Geology and Geophysics at the 8th Congress, as well as a member of the Standing Committee on Volcanology. His unassuming manner and cheerful personality will be remembered by all who knew him.

TAIWAN

STANDING COMMITTEE MEMBER

Dr. V.C. Juan, Head of the Department of Geology, National Taiwan University, Taipei, Taiwan, China.

RECENT DEVELOPMENT IN GEOLOGY IN TAIWAN

In the preparation of this report, the first task is to have a survey of the relevant literature on the geology of Taiwan and then compile the bibliographies grouped in the following four categories: (1) general and structural geology, (2) stratigraphy and palaeontology, (3) mineralogy and petrology, and (4) mineral resources. It is intended to provide a background for the work of this Standing Committee and a guide in initiation and encouragement of co-operative research on the geological problems of the Pacific region. It helps in an assessment of the past achievement and points the way to fruitful advance.

GENERAL AND STRUCTURAL GEOLOGY

The origin of the island of Taiwan has been the subject of theories and hypotheses. A hypothesis of coastal range of the Asiatic continent has been expressed by Juan (1955). He has attempted to attack the problem from various angles such as structural correlation between the continent and the island, the ill comparison between Riukiu arc and Philippine Archipelago and the island, the origin of Formosa Channel, the causes of present simple shore line, and the submarine topography around the island, and concluded that the island of Taiwan has long been in existence and is actually a part of the old land of Fukien province. Taiwan island should be regarded as the coastal range of the continent.

In connection with the study of oil possibilities of Taiwan, Biq (1956), taking the East Indies as a perfect example, advocated an origin of a double island are with morphotectonic elements from east to west of (1) a volcanic inner arc, represented by the submarine ridge on which two off-shore island, Lutao and Lanhsu are situated, (2) non-volcanic outer arc of Central Mountain of the island, and (3) a foredeep, now occupying the coastal plain of western Taiwan and a part of Taiwan Strait. However, he failed to explain, just like most of the Japanese geologists who advocated the origin of an island arc before, the reverse direction of the curvature of the island which has a convexity facing the continent, and disregarded the absence of epicontinental seas behind the arc, an important feature of all arc structures, and thus contradicting the theory of formation of arcs by the underthrusting of a simatic layer from the ocean toward the continent.

Although there are different views about the origin of the island, it is the consensus of opinion that the island is mainly occupied by Tertiary geosynclines. The eugeosynclinal nature of the sediments in the East Coastal Range of the island is especially clear after the detailed study by Hsu (1956).

However, more extensive studies on sedimentation, igneous activities and orogenies of such geosynclines are needed before we can agree on the origin of the island. An outline of such studies was published by Juan (1957) quite recently.

A geological map of Taiwan on a scale of 1 to 300,000 was published by the Geological Survey of Taiwan in 1953.

RELATED BIBLIOGRAPHY, 1953-1957

Biq, C.C., (1956), The tectonic framework and oil possibilities of Taiwan. *Mem. National Taiwan Univ.*, 95-105.

Hsu, T.L., (1954), On the geomorphic feature, and the recent uplifting movement of the Coastal Range, Eastern Taiwan. *Bull. Geol. Surv. Taiwan*, **7**: 51-57.

Hsu, T.L., (1956), Geology of the Coastal Range, Eastern Taiwan. *Bull. Geol. Surv. Taiwan*, **8**: 39-63.

Juan, V.C., (1955), Physiography and geology of Taiwan. *Annals of Academia Sinica*, **2.** I: 59-90.

Juan, V.C., (1957), Continental rifting and igneous activities in the Neogene marginal geosynclines of Taiwan. *Proc. 9th Pacific Science Congress* (MS).

Wang, C.S., (1956), The structural evolution and oil accumulation in Taiwan. *Mem. National Taiwan University*, 106-109.

STRATIGRAPHY AND PALEONTOLOGY

The geologic age of the metamorphic rocks in the Central Mountains has been a much disputed problem among the geologists in Taiwan. Most of the fossils found in this metamorphic complex are very poorly preserved and deny accurate determination. Recent collecting from the fusuline limestone by Yen (1953), however, suggest *schwagerinids* or *neoschwagerinids* and also *Waagenophyllum* among coral specimens. Thus both fusulines and corals point to a late Palaeozoic age.

Encouraged by these findings, geologists began to suspect that there may possibly be a Mesozoic formation between the late Palaeozoic and the Paleogene rocks. It is reported (Yen et al., 1956) that in the lower part of the Paleogene slate formation, traces of organisms, such as spines of echinoids and *Orbitolina*, have been noted in the basal conglomerate layers. Thus there is a possibility these may be of Cretaceous age; and only the upper portion of the slate formation, in which *Discocyclina*, *Camerina*, *Assilina* and *Pallatispira* (?) of a middle and late Eocene fauna have been found, belongs to the Paleogene. This certainly poses as an important problem that calls for attention.

A discovery of ammonite-fossils was made in a bore-hole for petroleum in 1956, in the western marginal belt of the western coastal plain. The age of this fossiliferous bed is tentatively fixed as Upper Jurassic (Lin, 1957). Further verification of the presence of Jurassic in the central area of the island is thus urged.

Geologists generally now agree that Oligocene formations are definitely present in the island. Wang (1953) suggested that a part of Mushan coal formation, which lies disconformably below the Kungkuan tuff formation of early Miocene age, may belong to the Oligocene; based on his careful stratigraphical and sedimentological studies of the latter formation in northern Taiwan. The problem of ocurrence of the Oligocene formation is further elucidated by Chang (1954a) in his study on smaller foraminifera collected at Yuhang. According to Chang, the Suichangliu (Suichoyu) and Suo formations, both had been formerly included in the "Slate formation", are more closely related to formations of the Urai and Suo group containing smaller forms of *Camerina*, *Assilina* and *Discocyclina* rather than to the lower to middle Miocene Hsichih group, and that the Aoti coal measure, the lowest coal measure in Taiwan, may also be of lower Oligocene age. A re-study of the fossils of *Cyclamina*, collected from Suo and Urai groups, led to the conclusion that the rocks containing them are of Oligocene, rather than of Eocene age (Chang, 1953).

Stratigraphic correlation of Miocene and Pliocene formations between northern and southern Taiwan has long been a vexing problem for many geologists. It is grateful to note that an attempt has been made by Ho (1956), thus knowledges of sedimentation, ecology and facies concept find wider application to stratigraphy. According to Ho, the shelf-type Miocene sediments are predominant in northern Taiwan, while the sedimentation in southern Taiwan appears to be exclusive development of a basinward or geosynclinal facies. A number of rock-stratigraphic or lithologic units are re-classified. However, the importance of biostratigraphic subdivision has also been stressed by Oinomikado (1956).

RELATED BIBLIOGRAPHY, 1953-1957

Chang, L.S., (1953), Tertiary *Cyclamina* from Taiwan and their stratigraphic significance. *Bull. Geol. Surv. Taiwan*, **4**: 27-37.

Chang, L.S., (1954a), The lower Oligocene Yuhangian foraminiferal fannule and its stratigraphic significance in Taiwan. *Bull. Geol. Surv. Taiwan*, **5**: 101-116.

Chang, L.S., (1954b), Two new species of smaller foraminifera from the Miocene of Taiwan: *Gaudryina (Pseudogaudryina) Kokuseiensis* and *Karreriella Shangtaoensis*. *Bull. Geol. Surv. Taiwan*, **7**: 59-61.

Chang, L.S., (1956a), On the correlation of the Neogene formations in western Taiwan and some diagnostic species of smaller foraminifera. *Mem. Nat'l Taiwan Univ.* 113-121.

Chang, L.S., (1956b), Two species of *Lingulina* from the Miocene of Taiwan. *Bull. Geol. Surv. Taiwan*, **8**: 65-66.

Chang, L.S., (1956c), A new *Spiroplectammina* from the Miocene of Taiwan. *Bull. Geol. Surv. Taiwan*, **8**: 67-68.

Ho, C.S., (1956), Miocene rocks of the Chutouchi oil field. Taiwan. *Bull. Geol. Surv. Taiwan*, **8**: 15-38.

Lin, C.C., (1957), Personal communication.

Oinomikado, T., (1956), Problems of biostratigraphic correlation in Taiwan. *Mem. Nat'l Taiwan Univ.*, 110-112.

Wang, Y., and Huang, T.C., (1953), A stratigraphic study of the Kungkuan tuff formation, Northern Taiwan. *Acta Geologica Taiwanica*, **5**: 35-46.

Yen, T.P., (1953), On the occurrence of the late Palaeozoic fossils in the metamorphic complex of Taiwan. *Bull. Geol. Surv. Taiwan*, **4**: 23-26.

Yen, P.T. et al., (1956), Some problems on Mesozoic formation of Taiwan. *Bull. Geol. Surv. Taiwan*, **8**: 1-14.

MINERALOGY AND PETROLOGY

In the field of mineralogy and petrology, great progress has been made in recent years. Huang (1953) has made a detailed morphological study of the adularia crystals collected from quartz veins in the schists. He has also made a genetic study of the basaltic hornblende in andesite from Tatun volcanoes and concluded that the black hornblende may have been derived from a green variety by heating, and the brown varieties from black ones by reheating, in which the transition of magnetite to hematite may have also occurred, resulting in the pale reddish colour of the andesites (Huang, 1954).

In 1953, one of a series of studies of basic and ultrabasic rocks of the East Coastal Range, undertaken by Juan (1953) and his co-workers, was published. A new basaltic glassy rock was named as Taiwanite representing a distinct magma-type. According to Juan, the magma that produced Taiwanite, a liquid massed with olivine and plagioclase crystals, accumulating at the time of intrusion, is the parental magma of the plateau basalts recognized by Washington. The chemical laboratory of the Department of Geology, National Taiwan University, has also published 98 complete analyses of basic and ultrabasic rocks in Taiwan, a valuable contribution to the science of geochemistry (Juan, et al., 1955).

In the field of petrology of sedimentary rocks, an excellent contribution was made by Wang (1954) on the study of graywacke from Nankangshan near Taipei. Is mineralogical composition is given and its genesis is discussed. Thus the geosynclinal nature of the Tertiary sedimentation in western Taiwan is clearly demonstrated. Slump features associated with graded bedding in the Miocene sediments of the East Coastal Range were also carefully studied. Since such contemporaneous deformational features are quite common in the active volcanic belts, bordering the continents, not necessarily a record of ancient earthquakes, as so interpreted by Hsu (1954), the eugeosynclinal nature of the sediments, distinctive to those found in the miogeosynclines, is indicated.

The metamorphic complex of the Central Mountain Range that occupies nearly half of the area of the island is still a virgin ground for study. However, a good start has been made on the petrography of the gneisses (Yen, 1954a), thus rough sketch of the process responsible for the formation of these rocks could be outlined. Yen (1954b) also showed that the green rocks, including chlorite schists, amphibolites, serpentine and meta-diabase, have closer genetic relations to one another and they were formed commonly from basic igneous rocks or their pyroclastic equivalents by low grade metamorphism. Since the geohistory of the whole complex is not yet clear, the present data on hand are not adequate to formulate a sequence of the formation of such rocks petrologically and geologically. Further field study is neecded.

Some geological problems posed by the schist formations in the Central Mountain Range have also been recognized (Yen, 1954c). These involve mainly the principal rock types and geological structures of the schist formations.

RELATED BIBLIOGRAPHY, 1953-1957

Hsu, T.L., (1954), On the contemporaneous deformation of the sedimentary rocks in the Coastal Range, Eastern Taiwan. *Bull. Geol. Surv. Taiwan*, **6**: 61-56.

Huang, C.K., (1953), Adularia from Kukutzu, Taiwan. *Acta Geologica Taiwanica*, **5**: 27-34.

Huang, C.K., (1954), Basaltic hornblende from the Tatun volcanoes, Taiwan. *Acta Geological Taiwanica*, **6**: 113-124.

Juan, V.C., Tai H. & Chang, F.H., (1953), Taiwanite, a new basaltic glassy rock of East Coastal Range, Taiwan and its bearing on the parental magma-type. *Acta Geologica Taiwanica*, **5**: 1-25.

Juan, V.C. Tai, H. & Hsu T.C., (1955), Chemical analyses of igneous rocks—a progress report of the chemical Laboratory. *Acta Geologica Taiwanica* **7**: 43-65.

Wang, Y., (1954), Graywacke from Nankangshan and its vicinity, east of Taipei

City. *Acta Geologica Taiwanica*, **6**: 125-131.

Yen, T.P., (1954a), The gneisses of Taiwan. *Bull. Geol. Surv. Taiwan*, **5**: 1-100.

Yen, T.P., (1954b), The green rocks of Taiwan. *Bull. Geol. Surv. Taiwan*, **7**: 1-46.

Yen, T.P., (1954c), Some geological problem on the Tananao schist. *Bull. Geol. Surv. Taiwan*, **7**: 47-50.

MINERAL RESOURCES

The most important mineral resources under exploration and mining in the island are coal, petroleum and gold-copper deposits.

Coal fields are exclusively located in the northern part of Taiwan and have been worked for many years. However, for the purpose of increasing production, a new field, the Nanchung coal field, has recently been mapped in detail. It covers an area of 162 sq. km. and includes 3,000 m of Miocene sediments. Although there are three coal-bearing formations in the Miocene strata, the Middle coal-bearing formation is by far the most important, consisting of three coal seams. The coal produced is medium-volatile bituminous, low in ash and sulphur. It possesses good heating properties and is excellent for making metallurgical coke (Ho, et al., 1954). Another brown coal field in the upper coal-bearing formation of Miocene age in Miaoli has also been surveyed (Ho, 1953).

A program to re-estimate the coal reserves of the whole island, initiated by the Ministry of Economic Affairs, is now under way.

Although the gold-copper deposits of Chinkuashih and Chiufen districts have been mined extensively for a long time in the past, the first published account of the geology of the deposits appeared only very recent (Wang, 1953). This report covers the general stratigraphy of the area, the mode of occurrence of the deposits and the age of dacite intrusions in which gold-copper deposits are found. The fracture pattern of the mining areas which directly controls the localization of the ore-forming solutions has also been analyzed (Wang, 1955). Among the complicated folding and thrusting, normal faulting is said to be followed by the mineralization of gold and copper. The mineralogy of the ore bodies, their genesis, and the associated wall rock alterations have further been investigated (Huang, 1955). All this detailed work should be of value to future exploration of new ore bodies in the said mines.

Though Taiwan is known to produce a small quantity of oil, the petroleum potentialities of the island have long been a subject of discussion. In recent years, the Chinese Petroleum Corporation embarked on an expanded program of systematic oil exploration. Considerable progress has been made by the Corporation in building up efficient technical organizations to increase the pace and scope of exploration survey activity. Attention has been concentrated not only on a more detailed survey of known shallow structures along the foothill region, but also on the establishment of deep drilling projects in the coastal plain (Meng, 1957).

During 1953-1954, re-evaluation of the shallow structures of previous test drilling was made. Based on detailed sub-surface studies, extension wells were selected in Chuhuangkeng oil field and Chinshui gas field and a wildcat was located on the southern plunge of the large Chutouchi structure. All these wells were successful in finding production and a new oil field was discovered in January 1954 at the Chutouchi south culmination. Small production has also been proved on the Shantzechio structure, near Taipei. Selection of locations for deep tests on the coastal plain began in 1957 (Stach, 1957).

Two symposia on petroleum geology of Taiwan were successfully conducted by the Department of Geology, National Taiwan University in November, 1955, and the Chinese Petroleum Corporation in June, 1956. In the first meetings, discussion was centered on the problem of potentialities of oil in the coastal plain and in the second gathering, past achievements were reported and a future plan of exploration was presented. In summing up the opinion of geologists towards the prospects of oil in Taiwan, Prof. H.G. Schenck (1957) has remarked that "exploration for petroleum requires thorough and systematic teamwork over a considerable period of time and, where the geological conditions appear to be as favourable as they are in Taiwan, success should ultimately be achieved".

An investigation of monazite and zircon sands occurring along the beaches and streams in western Taiwan has been carried out. The mineral components of the heavy sands are estimated to be no less than 20 different species among them: monazite (1-2%), zircon (0.3-55%), ilmenite (14-45%) and magnetite (5-80%), are the four important ones (Chen, 1953). An investigation of ground water resources in Changhua and Yunglin districts has also been made (Wang & Chen, 1955).

RELATED BIBLIOGRAPHY, 1953-1957

Bien, Edward, H.N., 1957, The importance of the things we do not know. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 42-24.

Chang, S.L., 1957, Preliminary results of sedimentation study of the white sandstone member of the Nanchuang coal-bearing formation in the vicinity of Miaoli. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 122-126.

Chang, S. and Chung, C.T., 1957, Geology of the Chutouchi structure, Tainan district. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 245-249.

Chen P.Y., 1953, Heavy mineral deposits of western Taiwan. *Bull. Geol. Surv. Taiwan*, **4**: 13-21.

Chiu, H.T., 1957, Geology of the Yangmeipai (Pakuali) structure Miaoli district. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 161-163.

Heh, Kenneth, 1957, Subsurface geology of Chinshui gas field and correlation with the stratigraphic sequence on the western flank of Chuhuangkeng structure. *Symp. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 106-108.

Heh, K. and Hsiao, P.T., 1957, Geology of the Tunghsiao anticline, Mioali district. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 139-141.

Ho, C.S. and Keng, W.P., 1953, Geology and mineral deposits of the area between peipu, Hsinchu and Nanchuang, Miaoli. *Bull. Geol. Surv. Taiwan*, **4**: 1-12.

Ho, C.S. et al., 1954, Geology of the Nanchuang coal field, Miaoli, Taiwan. *Bull. Geol. Surv. Taiwan*, **6**: 1-59.

Hsio, P.T., 1957, Subsurface data from well st-1 on the Shantzechiao structure, Taoyuan district. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 170-173.

Huang, C.K., 1955, Gold-copper deposits of the Chinkuashih mine, Taiwan. *Acta Geol. Taiwanica*, **7**: 1-20.

Lin, C.C., 1956, A stratigraphical interpretation of the Miocene oil bearing formations of western Taiwan. *Mem. Nat'l Taiwan Univ.* 123-125.

Ma, T.Y.H., 1957, The relation between Cenozoic diastrophism and petroleum resources beds of the western Pacific (Summary). *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 13-14.

Meissner, C.R., 1957, Oil and gas prospects of Taiwan. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 35-39.

Meng, C.Y., 1957, Review of recent petroleum exploration surveys in Taiwan (Summary). *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 53-62.

Oinomikado, T., 1957, Micropaleontological investigation of subsurface samples from seismic survey shot holes in Tainan district. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 272-282.

Oinomikado, T. and Huang, T.Y., 1957, Micropaleontological investigation of the Kueitauchi section near Chutaochi oilfield. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 257-263.

Oinomikado, T. and Huang, T.Y., 1957, Micropaleontological investigation of subsurface samples from Chutaochi oilfield. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 267-270.

Pan, P.H., 1957, Seismic survey of Tunghsiao anticline, Miaoli district, *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Crop.*, 145-146.

Schenck, HG.G., 1957, Petroleum exploration policy in Taiwan. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 5-8.

Stach, L.W., 1956, Problem of petroleum geology in Taiwan. *Mem. Nat'l Taiwan Univ.* 84-94.

Stach, L.W., 1957a, Petroleum potentialities and exploration for oil in Taiwan. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 15-28.

Stach, L.W., 1957b, Stratigraphic subdivision and correlation of the upper Cenozoic sequence in the foothill region east of Chiayi and Hsinying. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 178-213.

Sun, S.C., 1957, Subsurface geology of Chu-

touchi south culmination oil field. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.* 254-256.

Wang, C.S. and Chen, C.S., 1955, Geological investigation on the ground water resources in and around Tachushuichi fan between Changhua and Yunglin district. *Acta Geologica Taiwanica* **7** : 35-43.

Wang, Y., 1953, Geology of the Chinkuashih and Chiufen district, Taiwan. *Acta Geologica Taiwanica*, **5**: 47-64.

Wang, Y., 1955, Fracture patterns in Chinkuashih area, Taipei-Hsien, Taiwan *Acta Geologica*, **7** : 21-34.

Wang, Y. and Wang, C.M., 1957, Cementing materials in some Tertiary sandstones from Taiwan. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 65-80.

Wang, Y.L. and Chang, S., 1957, Coordination of data drom the Chungchou wildcat and seismic surveys in the Tainan. *Sympo. Petrol. Geol. Taiwan, Chinese Petrol. Corp.*, 297-298.

JAPAN

STANDING COMMITTEE MEMBERS

Professor T. Kobayashi, Geological Institute, Faculty of Science, University of Tokyo, Tokyo.

Dr. T. Minakami, Head of Division of Volcanology, National Committee for Geophysics, Science Council of Japan, c/o Earthquake Research Institute, Tokyo University, Tokyo.

Professor Kobayashi has forwarded the following list of publications of importance since the 8th Pacific Science Congress.

Geological Survey of Japan, 1956, Geology and Mineral Resources of Japan.

Geological Survey of Japan, 1953, Geological Map of Japan, 1: 3,000.000.

Kimura, T., 1957, The Discovery of a low Angle Thrust along the Mikabu Line in East Kii Peninsula, Western Japan, etc. *Jour. Earth Sci. Nagoya Univ.* **2** : No. 2.

Kobayashi, T., 1953, Geology of Korea with Special Reference to the Limestone Plateau of Kogendo. *Jour. Fac. Sci. Univ. Tokyo Sect.* 2, **8** : Pt. 4.

——, 1954, On the Tectonic History of Taiwan (Formosa) *Ibid.* **9** : Pt. 2.

——, 1956, A Contribution to the Geotectonics of North Korea and South Manchuria. *Ibid.* **10** : Pt. 2.

——, 1956, The Triassic Akiyoshi Orogeny. *Geotektonisches Symposium zu Ehren Hans Stille.* Stuttgart.

——, 1956. The Shifting of the Chert-bearing Facies caused by the Migration of Geosyncline. *Gedenkb. H.A. Brouwer. Verhand. van het Koninkl. Nederl. Geol. Mijnb.* **14**.

Kojima, G., 1954, Geological Situation of the Cretaceous Hiroshima Granite. *Jour. Sci. Hiroshima Univ.* Ser. C, **1** : No. 4.

Makiyama, J., 1954, Syntectonic Construction of Geosynclinal Neptons. *Mem. Coll. Sci. Univ. Kyoto*, Ser. B, **21** : No. 2.

Minato, M. Yagi, K. and Hunabashi, M., 1956, Geotectonic Synthesis of the Green Tuff Regions in Japan. *Bull. Earthq. Research Inst. Tokyo Univ.* **34** : Pt. 3.

Tsuboi, C., Jitsukawa, A., Tajima, H., and Okada, A., Gravity Survey along the Lines of Precise Levels throughout Japan by Means of a Worden Gravimeter. Pts. 1-9. *Ibid. Suppl.* **4** : Pts. 1-8.

DISCUSSION

At the end of the Report the Chairman and Mr. Alcaraz asked for comments on it.

Mr. G.W. Grindley of New Zealand suggested an addition of Antarctic geologic reconnaissance work being done by two parties i.e. at the northern extremity of the New Hebrides and a site in the Ross Sea. Also he would like to mention the successful operation between France and New Zealand in exchanging geologists between New Caledonia and New Zealand, the two islands having quite a common geological set up.

Dr. Th. H.F. Klompé wished to point out that a Geologic Map of Indonesia on a scale of 1 : 2,000,000 has now been finished. It covers about 80 per cent of the total area of which only about four and a half per cent was systematically surveyed in detail.

Addendum

DATUM-PLANES IN THE GEOLOGICAL HISTORY OF THE PACIFIC REGION. SUPPLEMENTARY BIBLIOGRAPHY 1953-1957

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The list of references which follows, and in the compilation of which I have had help from a number of colleagues over-seas, is intended to supplement the bibliographies published in the "Report of the Standing Committee on Datum-planes in the Geological History of the Pacific Region" (*Proc. Eighth Pacific Sci. Congr.*, 1953, II, 1956, 325-423).

It is selective, does not aim at completeness, and refers only to the topics discussed in the earlier Report.

It has been prepared at the request of J. Healy, Chairman of the Standing Committee on Geology and Geophysics.

ACKNOWLEDGEMENTS

Dr. Dorothy Hill, University of Queensland, Brisbane, supplied a list of 18 papers containing data on the Palaeozoic corals in the Pacific region. The most significant paper published in the period under review is Dr. Hill's presidential address to Section C of the A.N.Z.A.A.S. Meeting in Dunedin in January, 1957 (Hill, 1957). She has also prepared for the Bangkok Congress a paper on "Circum- or Trans-Pacific Correlation of Palaeozoic Coral Faunas."

Miss Irene Crespin, Bureau of Mineral Resources, Canberra, has sent me a long list of papers on foraminiferal studies in Australia, on the Cambrian System in Australia, and on Australian stratigraphy which bear on Pacific problems. From this material I have included 17 items.

W. Storrs Cole, Cornell Univeristy, forwarded six titles on foraminifera.

Kiyoshi Asano, Tohoku University, Sendai, supplied a list of papers published by himself and his colleagues on foraminifera. Further Japanese references were provided by Teiichi Kobayashi, University of Tokyo.

J.A. Jeletzky, Geological Survey of Canada, has supplied information on current work on the Belemnites.

Edwin L. Hamilton, U.S. Navy Electronics Laboratory, San Diego, and M.F. Glaessner, The University of Adelaide, have also helped in this compilation. All these colleagues were invited by me to join a Standing Committee set up at the Seventh Pacific Science Congress in New Zealand in 1949, but the Committee never functioned as such and has since been discontinued. However I am deeply indebted to them for responding to an appeal to help in bringing the bibliographies of my earlier report (Allan, 1956) up-to-date.

BIBLIOGRAPHY, 1953-1957.

Allan, R.S., 1956, Report of the Standing Committee on Datum-planes in the Pacific Region. *Proc. Eighth Pacific Sci. Congr.*, 1953, **2**: 325-423.

Arkell, W.J., 1956, Jurassic Geology of the World. Oliver & Boyd, Edinburgh. XV + 806 pp., 46 pls.

Asano, K., 1953, Miocene Foraminifera from the Shintotsugawa Area, Kabato-gun, Hokkaido. *Trans. Proc. Pal. Soc. Japan*, N.S., **10** : 45-54, 1 pl.

———, 1953, Miocene Foraminifera from the Honya Shale, Joban Coal-field. *Trans. Proc. Pal. Soc. Japan*, N.S., **11** : 55-59, pl. 1.

———, 1953, Miocene Foraminifera from the Noto Peninsula, Ishikawa Prefecture. *Short Pap., Inst. Geol. Pal. Tohoku Univ.*, **5** : 1-21, pls. 3.

———, 1953, Oligocene Foraminifera from Utsunai, Tonbetsumura, North Hokkaido. *ibid.*, **5** : 22-24, pl. 1.

Banks, M.T., 1956, The Middle and Upper Cambrian Series (Dundas Group and its correlatives) in Tasmania. *Intern. Geol. Congr.* XXth sess. Mexico, Symp. Cambrian, **2** : 165-212.

Basse, E., 1953, L'Extension des *Kossmaticeras* dans les mers Antarctico-indo-pacifiques au néocrétacé. *Proc. 7th Pacific Sci. Congr.*, **2** : 130-5.

Browne, I.A., 1954, A Study of the Tasman geosyncline in the region of Yass, New South Wales. *Journ. & Proc. R.S.N.S. Wales*, **88** (1) : 3-11.

Campbell, J.D., 1955, The Oretian Stage of the New Zealand Triassic System. *Trans. R.S.N.Z.*, **82** (5) : 1033-1047.

——— and I.C. McKellar, 1956, The Otapirian Stage of the Triassic System of New Zealand—Part I. *Trans. R.S.N.Z.*, **83 (4)**: 695-704.

Cloud, P. E. J., 1956, Provisional Correlation of Selected Cenozoic Sequences in the Western and Central Pacific. *Proc. Eighth Pacific Sci. Congr.*, 1953, **2**: 555-573, pl. 1.

——— and Cole, W.S., 1953, Eocene Foraminifera from Guam, and their implications. *Science*, **117** : No. 3039, 323-24.

Cole, W.S., 1954, Larger Foraminifera and smaller diagnostic Foraminifera from Bikini drill holes. *U.S. Geol. Surv.*, Prof. Paper 260-0, 569-608, pls. 204-222.

——— and Bridge, J., 1953, Geology and Larger Foraminifera of Saipan Island. *U.S. Geol. Surv.* Prof. Paper 253, 45 pp., 15 pls.

Crespin, I., 1953, Lower Cretaceous Foraminifera from the Great Artesian Basin, Australia. *Contrib. Cushm. Fdn.*, **4** (1): 26-36.

———, 1954, The Nelson Bore, South-Western Victoria: Micropalaeontology and Stratigraphical Succession. *Bur. Min. Resources Austral. Rep.*, **11**.

———, 1954, Stratigraphy and Micropalaeontology of the Marine Tertiary Rocks between Adelaide and Aldinga, South Australia. *Bur. Min. Resources Austral. Rep.*, **12**.

Crespin, I., 1955, Bibliography of Australian Foraminifera. *Micropalaeontology*, **1** (2): 162-188.

———, 1956, Fossiliferous Rocks from the Nullarbor Plains. *Bur. Min. Resources Austral. Rep.*, **25** : 26-42.

———, 1956, Distribution of Lower Cretaceous Foraminifera in Bores in the Great Artesian Basin, Northern New South Wales. *J. Roy. Soc. N.S.W.*, **89** : 78-84.

———, 1956, Notes on a *Lepidocyclina* bearing Rock from Cebu, Philippines. *Bur. Min. Resources, Aust. Rep.*, **25**: 43-46.

———, 1956, Migration of Foraminifera in Tertiary Times in Australia. *Bur. Min. Resources, Aust. Rep.*, **25** : 1-15.

———, 1956, Changes in Ideas of Age of Certain Beds in the Australian Tertiaries. *Proc. Eighth Pacific Sci. Congr.*, 1953, **2** : 515-522.

Duncan, H., 1956, Ordovician and Silurian Coral Faunas of Western United States. *Bull. U.S. Geol. Surv.*, 1021-F.

Eames, F.E., 1953, The Miocene/Oligocene Boundary and the use of the term Aquitanian. *Geol. Mag.*, **90** (6) : 388-292.

Easton, W.H. and Gutschick, R.C., 1953, Corals from the Redwall limestone (Mississippian) of Arizona. *Bull. S. Calif. Acad. Sci.*, **52** : 1-27.

Fleming, C.A., 1957, The Genus Pecten in New Zealand. *N.Z. Geol. Surv. Pal. Bull.* **26** : 69 pp., 16 pls.

Fontaine, H., 1954, Étude et revision des Tabulés et Heliolitides du Devonien d'Indochine et du Yunnan. *Arch. Geol. Vietnam.* **2** : 1-86, pls. 1-8.

———, 1955, Les Tabulés du Carbonifère et du Permien de l'Indochine et du Yunnan. *Arch. Geol. Vietnam*, **3** : 65-81, pls. I-V.

Fujimoto, H., 1956, The Carboniferous-Permian Boundary in Japan. *Proc. Eighth Pacific Sci. Congr.*, 1953, **2** : 429-433.

Glaessner, M.F., 1953, Conditions of Tertiary Sedimentation in Southern Australia. *Trans. R.S.S. Austral.*, **76** : 141-146.

———, 1953, Some Problems of Tertiary Geology in South Australia. *J.R.S.N.S. Wales*, **87** : 31-45.

———, 1953, Time-stratigraphy and the Miocene Epoch. *Bull. G.S. Amer.*, **64**: 647-658. (Includes discussion of the "Letter Classification of Indonesia". pp. 654-656).

——— and Wade, M., 1956, The Foraminiferal Genus *Lepidocyclina* in South Australia. *Aust. J. Sci.*, **18** (6) : 220.

Gery, R.R., 1956, Eocene in the Philippines. *Proc. Eighth Pacific Sci. Congr.*, 1953. **2**: 503-573.

Hanai, T., 1953, Lower Cretaceous Belemnites from Miyako District, Japan. *Jap. Journ. Geol. & Geogr.*, **23**: 63-80, pls. v-vii.

Hanzawa, S., 1954, Notes on *Afghanella* and *Sumatrina* from Japan. *Jap. Journ. Geol. & Geogr.*, **24**: 1-14, pls. 1-3.

———, 1954, Stratigraphical Distribution of the Fusulinid Foraminifera in Japan. *Intern. Geol. Congr.*, Alger (1952), Sec. 13, Fasc. **15**: 129-137.

———, 1957, Cenozoic Foraminifera of Micronesia. *Geol. Soc. Amer. Mem.* 66, 163 pp., 41 pls.

Hill, D., 1954, Coral faunas from the Silurian of New South Wales and the Devonian of Western Australia. *Bull. Bur. Min. Res., Geol. & Geophys.*, **23**: 1-51, pls. 1-4.

———, 1954, Devonian corals from Waratah Bay, Victoria. *Proc. R.S. Vict.*, **66**: 105-118, pls. 6-9.

———, 1955, Ordovician Corals from Ida Bay, Queenstown and Zeehan, Tasmania. *Pap. Proc. R.S. Tas.*, **89**: 237-254, pls. i-iii.

———, 1955, Contributions to the Correlation and Fauna of the Permian in Australia and New Zealand. *Journ. Geol. Soc. Australia*, **2**: 83-107.

———, 1956, Paleozoic Corals from New Zealand. Part I. The Devonian Corals of Reefton, New Zealand. *N.Z. Geol. Surv. Pal. Bull.* **25**: 5-14, pls. 1-2.

———, 1957, The Sequence and Distribution of Upper Palaeozoic Coral Faunas. *Austral. J. Sci.*, **19** (3a): 42-61.

Hornibrook, N. de B., 1953, Faunal Immigrations to New Zealand; I, Immigration of Foraminifera to New Zealand in the Upper Cretaceous and Tertiary. *N.Z. Journ. Sci. & Techn., Sec. B*, **34** (6): 436-44.

Ichikawa, K., 1956, Triassic Biochronology of Japan. *Proc. Eighth Pacific Sci. Congr.*, 1953, **2**: 437-442.

Ikebe, N., 1956, Cenozoic Geohistory of Japan. *Proc. Eighth Pacific Sci. Congr.*, 1953, **2**: 446-452. figs.

Imlay, R.W., 1956, Stratigraphic and Geographic Range of the Early Cretaceous Ammonite Homolsomites. *Journ. Paleont.*, **30** (5): 1143-1146, pl. 120.

Jeffords, R.M., 1955, Septal arrangement and ontogeny in the Porpitid Corals. *Paleont. Contr. Univ. Kansas*, Coelenterata, **2**: 1-16, pls. 1-3.

———, 1955, Mississippian Corals from New Mexico and a related Pennsylvanian species. *Paleont. Contr. Univ. Kansas*, Coelenterata, **3**: 1-12, pls. 1-2.

Kanmera, K., 1954, Fusulinids from the Upper Permian Kuma formation, southern Kyushu, Japan, with special reference to the fusulinid zone in the upper Permian of Japan. *Mem. Fac. Sci. Kyushu Univ., Ser. D*, **4**: 1-38, 6 pls.

Kawada, S. and Morikawa, R., 1953, So-called *Parafusulina? japonica* and its stratigraphical significance. *Nat. Sci. & Mus.* (Tokyo, *Natl. Sci. Mus.)* **20** (1-2): 1-7. (Jap., Engl. summ.).

Kicinski, F.M., 1956, Note on the Occurrence of some Tertiary larger Foraminifera on Bouganville Island. *Bur. Min. Resources Austral. Rep.*, **25**: 76-77.

Kobayashi, T., 1955, The Ordovician Fossils from the McKay Group in British Columbia Western Canada: with a Note on the Early Ordovician Palaeogeography. *Journ. Fac. Sci. Univ. Tokyo, Sect.* 2, **9** (3).

Kummel, B. and Lloyd, R.M., 1955, Experiments on Relative Streamlining of Coiled Cephalopod Shells. *Journ. Paleont.*, **29** (1): 159-170.

Ladd, H.S. *et al.*, 1953, Drilling on Eniwetok Atoll. *Bull. Amer. Assoc. Petrol. Geol.*, **37** (10): 2257-2280, 2 pls. (A note on correlation by W.S. Cole on p. 2272.)

Leed, H., 1956, Paleozoic Corals from New Zealand, Part 2. Permian Reef-building Corals from North Auckland Peninsula, New Zealand. *N.Z. Geol. Surv. Pal. Bull.* **25**: 15-23, pls. 3-5.

Ludbrook, N.H., 1957, Permian Foraminifera from South Australia. *Austral. J. Sci.*, **19** (4): 161.

Marwick, J., 1953, Faunal Migrations in New Zealand Seas during the Triassic and Jurassic. *N.Z. Journ. Sci. & Techn., Sec. B*, **34** (5): 317-21.

Matsumoto, T., 1956, The Characteristic Features of the Cretaceous System in the Japanese Islands. *Proc. Eighth Pacific Sci. Congr.*, 1953, II, 457-462.

Miller, A.K. and Furnish, W.M., 1955, Aturias from Southern Chile. *Journ. Paleont.*, **29** (3): 467-468, pl. 51.

Minato, M., 1955, Japanese Carboniferous and Permian Corals. *J. Fac. Sci. Hokkaido Univ.*, **9** (4): No. 2, 1-202, pls. 1-43.

Opik, A.A., 1956, Cambrian Geology of Queensland. *Internat. Geol. Congr.* xxth Sess. Mexico, Symp. Cambrian, **2**: 1-24.

———, 1956, Cambrian Palaeogeography of Australia. *ibid.*, 239-284.

Petters, V., 1955, Development of Upper Cretaceous Foraminiferal Faunas in Colombia. *Joun. Paleont.*, **29** (2): 212-225.

Raggatt, H.G. and Crespin, I., 1955, Stratigraphy of Tertiary Rocks between Torquay and Eastern View, Victoria. *Proc. R.S. Vict.*, **67** (1) : 75-142.

Reynolds, M.R., 1953, The cainozoic Succession of Maslin and Aldinga Bays, South Australia. *Trans. R.S.S. Austral.*, **76** : 114-140.

Schouppé A v. and Stacul, P. 1955, Die genera *Verbeekiella* Penecke, *Timorphyllum* Gerth, *Wannerophyllum* n. gen., *Lophophyllidium* Grabau aus dem Perm von Timor. *Palaeontographica, Suppl.*, **4** (v): 95-196, pls. 7-8.

Silberling, N.J., 1956, "Trachyceras Zone" in the Upper Triassic of the Western United States. *Journ. Paleont.*, **30** (5): 1147-1153.

Spath, L.F., 1953, The Upper Cretaceous Cephalopod Fauna of Graham Land. *Sci. Rept. Falkland Is. Depend. Surv.*, No. 3, 60 pp.

Sutherland, P.K., 1954, New Genera of Carboniferous Tetracorals from Western Canada. *Geol. Mag.*, **91** : 361-371, pls. 9-10.

Teichert, C., 1953, Some Trans-Pacific Paleozoic Correlations. (Abs.) *Bull. Geol. Soc. Amer.*, **64** (12) : 1516-7.

———, 1953, A New Ammonoid from the Eastern Australian Permian Province. *Journ. & Proc. R.S.N.S. Wales*, **87** (2) : 46-50.

and Glenister, B.F., 1952, Fossil Nautiloid Faunas of Australia. *Journ. Paleont.*, **26** (5) : 730-752.

Thomas, D.E. and Singleton, O.P., 1956, The Cambrian Stratigraphy of Victoria. *Intern. Geol. Congr.* XXth Sess. Mexico, Symp. Cambrian, **2** : 149-164.

Tischler, H., 1956, A New Mississippian Tetra coral from Death Valley, California. *J. Paleont.*, **30** : 110-112.

Thompson, M.L., 1954, American Wolfcampian fusulinids. *Univ. Kansas Paleont. Contr.*, Protozoa, **5** : 1-226, pls. 1-52.

Todd, R. and Post, R., 1954, Smaller Foraminifera from Bikini drill holes. *U.S. Geol. Surv., Prof.* Paper 260-N, 547-568.

Toomey, D.F., 1954, A Bibliography of the family Fusulinidae. *Journ. Paleont.*, **28** : 465-484.

———, 1956, Addendum to a Bibliography of the Family Fusulinidae. *Journ. Paleont.*, **30** (6) : 1360-6.

Vella, P., 1957, Studies in New Zealand Foraminifera. Part II: Upper Miocene to Recent Species of the Genus *Notorotalia. N.Z. Geol. Surv. Pal. Bull.* **28** : 42-58, pls. 1-3.

Weiss, L., 1955, Foraminifera from the Paleocene Pale Greda Formation of Peru. *Journ. Paleont.*, **29** (1) : 1-21, pls. 1-6.

Yale, H. and Suzuki, A., 1955, Second Occurrence of Colonial Corals of Devonian Type in Tyosen (Korea). *Proc. imp. Acad. Japan*, **31** : 355-359.

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A GENETIC CLASSIFICATION OF CONTINENTAL SHELVES

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INTRODUCTION

The margins of all continents are bordered by a continuous submerged terrace whose width varies from less than one to over 700 miles (average 40 miles), whose outer margin has depths varying from zero to greater than 250 fathoms (average 70 fathoms), and whose surface varies in relief from completely smooth to greater than 300 fathoms. In spite of these wide variations over the earth as a whole, shelves within given areas possess well-defined similarities that permit them to be conveniently catalogued according to types. The distinctive topography of each type reflects in turn the primary phenomenon that has shaped it.

The classification presented herein is an outgrowth of the shelf types described by Shepard (1948). It was devised for the purpose of presenting to students a genetically consistent and useful framework, based on current data and concepts, to which all shelves could be fitted and compared in a systematic way. Much of the information on shelf dimensions and sediments that is presented in the classification has been drawn from Shepard.

SOME BASIC CONSIDERATIONS REGARDING SHELF ORIGIN

Before introducing the classification, some recent developments and some thoughts that bear on the origin of shelves will be presented. The discussion will be restricted to shelves in middle latitudes, which are best known and which provide the best preserved clues to the history of the continent margins. These comparatively uniform shelves have been under the dominating influence of waves and currents, and have been free of the complications of glaciation and attendent crustal warping under ice loading in polar latitudes, and of coral reef growth in the tropics.

WAVE EROSION OF THE SEA FLOOR

Recent observations (Dietz and Menard, 1951, and others), supported by wave theory, have shown that wave action can effectively erode hard rock bottoms only in shallow water in and near the breaker zone. The depth of erosion is dependent upon the magnitude of the wave action, and on exposed coasts of the great oceans storm waves abrade the bottom only to an average depth of about five fathoms. Currents on the other hand do not erode hard rock bottoms except in narrow channels where strong tidal currents occur and locally on open shelves off points where unusually strong coastal currents sweep the bottom. Currents do, however, maintain non-depositional environments on many outer shelves by preventing the permanent settling of fine suspended sediment.

The conclusion can be drawn that nearly everywhere rock is exposed on the open shelf, sea level with its attendant wave action has stood within a few fathoms of that elevation. The fairly common occurrence of rock on the outer margins of shelves, which seems to be distinctive of mountainous coasts, indicates accordingly that these shelves are essentially wave-beveled surfaces, last planed off in the surf zone by a glacial sea level.

WAVE-CUT SHELVES

The probable wave-cut structure of most shelves off mountainous coasts has been confirmed for the Southern California shelves. There the thickness of superficial sediment and the shape of the underlying hard rock surface has been mapped by the writer (in preparation) nearly across the shelf near Santa Barbara using core-hole data, and by the oil industry (personal communication) in several areas between San Diego and Santa Barbara using a newly developed bottom-penetrating sonic sounder (the Marine

Sonoprobe). These studies show the shelf to be essentially a hard rock surface on which unconsolidated marine sediments lie as a thin veneer, generally having a maximum thickness of a few tens of feet on the inner half of the shelf seaward of the surf zone, and thinning out completely or to only a few feet at the shelf margin. The occurrence of rock exposed on the outer margins of many other shelves off mountainous coasts implies a similar shelf structure.

In addition to the bedrock nature of these shelves, the common occurrence of marine terraces at high elevations on the adjacent coast, and indeed the presence of mountains fronting the coast, all signify that a net emergence of these continent margins is occurring. It seems probable that as each successive glacial sea level has oscillated across these shelves, a thin layer of rock and superficial sediments has been chewed off so that a net loss of rock mass has resulted during the Quaternary Period.

Control of Sedimentation by Waves

The depth to which waves control the deposition of sediment is also restricted to within a few fathoms of the sea surface. Detailed studies of changes in the bottom profile accompanying varying wave conditions off an open sand beach in Southern California showed that nearly all bottom changes occurred in depths less than 5 to 6 fathoms, but minor variations were recorded as deep as 12 fathoms (Inman and Rusnak, 1956).

In many areas where rivers deliver large volumes of fine sediment to the coast a shoal terrace extends seaward from the river mouth. The control by wave action of the development of such a terrace was clearly demonstrated in the case of the modern marine delta of the Atchafalaya River in the northern Gulf of Mexico, where a terrace about two fathoms deep has been built five miles across the shelf since 1890 (Thompson, 1955). The occurrence of similar terraces off many large rivers, such as the four-fathom terrace off the Amazon having a width of 25 miles, was first noted by Shepard (1948), who has since termed them delta-front platforms (Shepard, 1956). The depths of the shoal platforms off large rivers range from about 2 to 6 fathoms, and are proportional to the magnitude of wave action in the water bodies into which they are built. There is little doubt that all are adjusted to present sea level.

Sediment-Constructed Shelves

Off broad alluvial coastal plains for which seismic and well-log data are available, the shelf is shown to form the surface of a mass of conformable Cenozoic and Mesozoic shallow-water sediments many thousands of feet thick. The sediment-constructed origin of these continent margins through long continued subsidence is evident. Their Quaternary history, on the other hand, is largely unknown, except in the northern Gulf of Mexico where the search for oil has spurred intensive study. There, except in the vicinity of the Mississippi River mouth, Quaternary sediments do not appear to exceed a few hundred feet in thickness according to data presented by Toulmin (1952) and Fisk (1944). A similar thickness is suggested for the American Atlantic Coast by data from Cooke (1936) and Swain (1947).

The area around the Mississippi River mouth presents a striking exception, however. The Quaternary sediments there exceed 3000 feet in thickness, 600 feet alone having been deposited since the last interglacial period on the Prairie shelf margin according to Fisk and McFarlan (1955). These writers also show that the shelf margin in that area has been built seaward a maximum distance of 40 miles since the last interglacial, but that away from the delta the modern and interglacial shelf margins coincide. Shepard has pointed out that the Mississippi River, like the Nile and Niger Rivers, is unusual in that it has managed to build its modern delta completely across pre-existing shelves.

Postglacial marine deposition on the outer shelf has been negligible in the northeastern Gulf of Mexico as evidenced by the occurrence of Pleistocene relict sediments there (Gould and Stewart, 1955), and in the northwestern Gulf Recent sediments appear to be generally on the order of ten feet thick (Greenman and LeBlanc, 1956; McClelland, 1952). It is thus apparent that the shelf margin in the northern Gulf, except in the vicinity of the Mississippi Delta, was last molded by a near-glacial sea level. Its relatively shallow depth, which is typical of the shelf edge off large rivers, can be attributed to control of deposition by that sea level.

The American Gulf and Atlantic Coasts have clearly received a net accumulation of sediments during the Quaternary Period, deposition having centered about the fluctuating shoreline of the past. Upbuilding of the inner shelf in the Gulf appears to have been accomplished largely by the construction of deltaic plains during the longer interglacial sea level stands when rivers had sufficient time to alluviate their courses completely. On much of the Atlantic Coast upbuilding of the inner shelf occurred by the deposition of strand and bay facies, indicating that stream filling generally was not completed there before sea level fell with the approach of each glacial period. Upbuilding of the outer shelf on both coasts has probably been accomplished mainly by the deposition of marine deltaic sediments off rivers and strand sediments in the interfluvial areas. Upbuilding did not occur without some wave planation accompanying transgressing sea levels.

It is probable that other shelves off broad alluvial coastal plains have a similar Quaternary structure and history. It also seems likely, judging from the Mississippi Delta, that those areas where the shelf is being downwarped rapidly off river mouths are quite localized and occur only off rivers that transport unusually large volumes of sediment to the shelf in regions where it is not being conducted continually to oceanic depths via flow down submarine canyons. The latter situation may be occurring off the Congo River, incidentally.

SEA LEVEL CONTROL AND STABILITY OF THE SHELF MARGIN

Many lines of evidence point to the conclusion that the break-in-slope at the shelf margin was controlled by one or more glacial sea levels that remained stationary for a significant period of time at or near the elevation of the shelf break. The fairly common occurrence of rock and of relict sediments on the outer shelf have been mentioned. The typically well-defined appearance of the break nearly everywhere and the continuity it displays also favor strand-line control. Further, the relatively uniform depth of the break agrees reasonably with the generally accepted estimates of the elevation of the Wisconsin sea level based on the probable volume of continental ice (Flint, 1947). Finally, the projection seaward across the shelf of the late Quaternary pre-alluvial profiles of some large rivers has shown that sea level, probably in late Wisconsin time, was at or near the shelf margin.

Because shelf margins off mountainous coasts appear to be rock surfaces that have been little masked by marine sediment since planation by a glacial sea level, variations in the depth of the margin can be used to estimate maximum vertical displacement that has been experienced due to tectonic or isostatic activity since that time. These shelves range in depth from about 50 to 100 fathoms, with a mean depth given by Shepard of about 80 fathoms. Consequently, the maximum vertical displacement has nowhere exceeded about 30 fathoms from the mean elevation; whereas, sea level has risen about 80 fathoms from that elevation (assuming no significant uplift or depression of these shelves as a whole to have occurred). Assuming that sea level was near the shelf edge in late Wisconsin time some 12,000 to 20,000 years ago, the maximum rate of vertical shelf movement has amounted to 10 to 15 feet per 1000 years.

Estimates of shelf movement off deltaic coastal plains must be based on coring data from the outer shelf in order to unravel recent sedimentary history, consequently these are available only for the northern Gulf of Mexico. According to Fisk and McFarlan, the late Wisconsin shelf margin in the vicinity of the Mississippi Delta has been downwarped more than 500 feet, giving an average rate of 25 to 40 feet per 1000 years. However, elsewhere in the northern Gulf it is evident from the depth of the shelf margin and the thickness of Recent marine sediments that the shelf has experienced much slower vertical movements. Other evidence relating to the stability of shelves in middle latitudes and in the tropics have been reviewed briefly by Kuenen (1955).

Because glacial sea level fluctuations have exceeded considerably the rates of vertical movement of nearly all shelves during much of the Quaternary period, the oceans can be visualized as having periodically encroached upon and receded from the comparatively stationary continent margins nearly everywhere, swinging through a full range generally estimated at 450 to 650 feet.

SUBMARINE CANYONS IN RELATION TO SHELF HISTORY

Because of the intimate association of submarine canyons and continental shelves, some pertinent concepts and observations regarding canyon origin will be discussed. For a general review of arguments on canyon origin, the reader is referred to the works of Kuenen (1950) and Shepard (1948).

There is impelling evidence that nearly all submarine canyons owe their origin entirely to marine processes, having been carved into the continental slopes and shelves by the flow of turbidity currents down their axes. The heads of some canyons may have been modified by subaerial erosion during exposure on the shelf accompanying glacial sea levels, however Shepard, 1949). There appears to be at least three conditions that must be met for canyon initiation and cutting: (1) a permanent sediment supply to the coast, (2) continual reservoiring of the sediment in the same location, where it repeatedly accumulates until unstable, then slides away, and (3) a steep slope down along which the sliding may take place. In addition, it is probable the sediment should have a considerable fraction that of sand-sized material. It is apparent that these conditions have occurred only during periods when sea level lay at or near the shelf margin.

It seems incongruous that submarine canyons, which are clearly erosional features, should cut sediment-constructed continent margins. However, Fisk and McFarlan give a consistent explanation of how this may come about in the case of the now dormant Mississippi Canyon. There, cutting appears to have occurred only during the period when coarser sediments, such as were transported by all rivers as a consequence of increased gradients during glacial sea levels, were carried directly to the shelf edge. During low sea levels, but prior to and following canyon cutting when sediments were not being carried directly to the shelf edge, hundreds of feet generally finer sediment blanketed the slope and shelf.

The canyons on the broad shelf off the American Atlantic Coast also are clearly related to rivers on land. They were likewise eroded only during glacial sea levels, and have been left stranded on the outer shelf to remain dormant until the time when sea level may fall again.

In contrast, the canyons along the California Coast have cut almost completely across the narrow shelf and head near shore where they trap beach sand being transported along the coast by longshore currents (Crowell, 1952). Some show no relationship to land drainages, modern or ancient, and were initiated during a glacial sea level probably by the accumulation of longshore drift behind major points which acted to reservoir sand at the brink of the continental slope. Headward erosion has kept pace with rising sea level so that many of these canyons are active today.

Submarine canyons have a variety of ages. Most appear to be products of the Pleistocene Epoch, but some that are related to large-scale physiography of the coast, like the Monterey Canyon, may have originated in Tertiary time. Others have been excavated only as recently as the Late Wisconsin, as in the case of the Mississippi Canyon (Fisk and McFarlan, 1955). There is no doubt, however, that erosion of all canyons proceeded extremely rapidly during the Pleistocene glacial maxima.

TOPOGRAPHY OF CONTINENTAL SHELVES

AGE OF SHELF TOPOGRAPHY

It is evident from the foregoing discussion that the topography of modern shelves reflects the history of many events that have occurred over a wide spectrum of time extending from the present back into the past. In general, the smallest features that can be observed are youngest and the largest oldest.

Minor features, such as individual rocks and depressions, submerged terraces, tidal-scour channels, beach deposits, etc., and a few larger features, such as barrier reefs and coral banks, were formed only during the most recent major glacial oscillation of sea level. These will be partially or completely eliminated by erosion or burial if sea level will again experience a fluctuation of amplitude similar to the last.

Most large-scale topographic features on the shelves took longer to form, and existed prior to the most recent glacial cycle. Some large river valleys show evidence of having been cut and filled through several major sea level oscillations (Zeuner, 1950). Large glacial troughs on the shelves undoubtedly were scoured by ice repeatedly in the Pleistocene. And some submarine canyons have been active periodically during glacial sea levels, although others have been enlarged by submarine erosion continuously since their inception. It is apparent, then, that nearly all topographic features on modern shelves are products of the Ice Ages, all having been either formed or last modified during the most recent major sea level cycle.

Shepard has pointed out, in reference to shelves in middle latitudes, that the general width of shelves depends upon whether they lie adjacent to young mountain ranges, off which the continental slope is notably steep, or adjacent to coasts with large rivers, and their more gentle continental slope. It may also be observed that shelf widths off glaciated coasts in general bear a similar relationship to the relief of the coast. Thus the overall width of modern shelves reflects the general relief of the continent margins, which in many areas is clearly related to the gross geologic structure. The gross shape, then, has been acquired through an even longer period of time — of mountain-building duration or longer.

In fact, contemplation of the nature of wave and current action in and near the surf zone leads one to the conclusion that shelves must have been maintained continuously off most coasts of the earth as long as there have existed well-defined ocean basins and continents.

GEOLOGY OF THE CONTINENT MARGINS

The continent margins can be considered to consist of two general types— the relatively stable areas that include pre-Cambrian shields and continent platforms, and the unstable areas where thick accumulations of Mesozoic and Cenozoic sediments are experiencing active tectonic evolution, as manifested by the presence of mountain ranges, or are undergoing extensive active subsidence, as is occurring off broad coastal plains.

Most stable areas of the continents lie within a few hundred feet of sea level and form lowland coasts off which the shelf tends to be broad, such as off the Arctic coasts of Europe and Asia. However, some shield areas stand a few thousand feet above sea level and effectively form mountainous coasts, and there the shelves are typically narrower, as off Labrador and South Africa. Unfortunately the gross geology of the continental shelves over most of the earth is unknown, particularly off stable coasts, so that it is impossible as yet to classify them on the basis of their geology. However, because shelf widths do bear a close relationship to the physical relief of the coast they are treated accordingly in the classification that follows.

SUPERFICIAL SHELF-SHAPING AGENCIES

Four distinctly different agencies have helped shape shelves during the Quaternary Period as sea level has oscillated back and forth across the continent margins: (1) land ice, (2) ice at sea, (3) waves and currents, and (4) coral reef growth. The magnitude of the relief and the nature of the sediments present on a given shelf have been determined largely by the character of the dominant agency that has been operating.

Thus, the highly erratic character of erosion and deposition by glacial ice in polar latitudes has produced a grossly irregular topography that in some areas has a relief exceeding 300 fathoms. This irregular surface undoubtedly did not exist on present shelves prior to the onset of the great Pleistocene glaciations, except possibly in certain restricted regions.

In marked contrast, shelves in high latitudes that have not been glaciated commonly display an irregular bottom having a relief of only a few fathoms, which appears to be caused by the grounding of sea ice in depths at least as great as several tens of fathoms. The topography and sediments of these shelves are also modified by the freezing of bottom materials into the sea ice near shore, and by their eventual rain over the bottom upon melting.

Shelves which have been shaped dominantly by waves and currents associated with the swinging Pleistocene sea levels also display a relatively subdued topography, particularly off deltaic coastal plains. Their relief appears to be generally less than 10 fathoms, and depends upon the resistance of rocks to wave erosion, variations in sediment deposition, and recent tectonic activity.

In regions where coral growth has been the dominant agency in shaping the shelf, differential reef growth over a late Wisconsin glacial platform since sea level has risen to its present elevation can account for the major relief of less than 50 fathoms (from reef flat to lagoon floor) that has been observed in the case of nearly all coral shelves. In addition, because of the rapidity of coral growth, coral reef shelves have distinctively shoal margins that are adjusted essentially to modern sea level, in contrast to other shelves. For recent comprehensive discussions of these shelves, the reader is referred to Kuenen (1950) and Fairbridge (1950).

The shelf-shaping agencies have been roughly latitudinally distributed in their effect upon the continent margins; consequently, it is convenient to refer to the associated shelves as polar, middle-latitude, and tropical shelves.

GENETIC CLASSIFICATION OF SHELVES

THE CLASSIFICATION

A brief description of the history, topography, and sediments of each of the three basic shelf types is presented in the following outline. Because the appearance of modern shelves is primarily a product of the events of the last glacial cycle, the history will be reviewed only back through the late Wisconsin cycle. In addition, the effects of small-scale sea-level fluctuations associated with minor climatic variations, such as the Climatic Optimum, which probably have occurred throughout the existence of the oceans, will not be considered.

The outline provides only a mean description of the continental shelves; wide variations from the mean occur within each type. Shelves around oceanic islands and in isolated ocean-connected seas, as well as coral banks and atolls, may also be classified in the same way; however, their average dimensions are generally smaller than those stated below.

I. Polar Shelves — High latitude shelves that have been modified by glacial ice or sea ice.

A. Glaciated shelves—Includes all shelves that have been covered by glacial ice in the Quaternary Period.

1. History — Following the last interglacial period, most shelves exposed during falling sea level were probably modified somewhat by river erosion and deposition. Glaciers and ice sheets then moved down river valleys and former glacial troughs to the glacial sea level, cutting deepest where the ice was thickest and the valley gradients steepest. Regional downwarpings occurred under ice load. With rising sea level ice disappeared on nearly all but Antarctic and Greenland coasts, leaving fjords and gulfs along the coast, deepened troughs and basins extending across the shelf, and banks on many outer shelves.

2. Topography — Extremely irregular, with glacial troughs, basins, and banks of large and small size. Some troughs extend more than 300 f. below the open shelf surface, and some fjords exceed a depth of 800 f. Width averages 100 mi., but varies from less than 10 to over 700 mi. Depth of the margin averages 112 f., but is highly variable. There is no typical profile.

3. Sediments—Probably largely glacial till irregularly distributed in highly variable thicknesses on a rock surface, and veneered with glacial marine sediments in many areas. Mud is common in basins and off large rivers, and wave — and current — winnowed sand occurs on shoal banks. Shorelines are commonly rocky and irregular and beaches are meager and of varied texture.

4. Sub-types

a. Shelves off mountainous (rising) coasts — Topographic relief is the most extreme of all shelves, and is the product of erosion by valley glaciers. The outer margin is typically interrupted by glacial troughs, and the coastline is the classical fjord type. Shelves are narrower than the average glaciated shelf. An example is the British Columbia shelf.

b. Shelves off lowland (subsiding) coasts — Gross topography was produced by an overriding ice sheet. Relief is more subdued and the shelf is broader. Gulfs and bays are common but classical fjords are absent. An example is the Maine-Nova Scotia shelf.

B. Non-glaciated shelves — Includes all shelves that have not been overridden by glacial ice, but which were and are being influenced by fast ice (both frozen to and grounded on the bottom or shore). Examples occur off the Bering Sea coast of Alaska and much of the Arctic coast of Siberia.

1. History — These shelves have been very little studied. They occur in regions where snow accumulation has been insufficient to produce glacial ice, and are restricted to the Northern Hemisphere. They are further restricted mainly to lowland coasts because most mountainous coasts in high latitudes have been glaciated. Large rivers commonly drain the coasts. The gross history and structure of these shelves appears to be similar to that of the shelves off lowland coasts in middle latitudes.

2. Topography — The shelf profile is relatively smooth, in marked contrast to the glaciated shelf. However, large areas of the sea floor display small-scale irregular mounds and depressions having a relief of a few fathoms, which appear to be caused by sea ice grounding on the bottom in depths at least as great as several tens of fathoms relative to the contemporary sea level. Although large icebergs can ground in all depths across a shelf, they are very uncommon in the Arctic Ocean.

3. Sediments — Typically poorly sorted mud and sand of ice-rafted and river origin.

II. Middle-latitude shelves — Shelves that have been influenced dominantly by waves and currents.

A. Shelves off mountainous (rising) coasts—The following description is restricted to mountainous coasts in young orogenic belts such as ring much of the Pacific Basin; however, the presence of mountains along older coasts such as the southwest African coast suggests a similar history and character.

1. History — Falling sea level following the last interglacial period left behind a wave-planed rock terrace generally covered with a few feet of beach and littoral sediments. Variable thicknesses of alluvium accumulated on the upper parts of the terrace, and rivers universally embedded themselves in steep-sided valleys cutting across the terrace. During the glacial maximum all submarine canyons were actively enlarging and some new ones were formed near coastal points and off large rivers. With rising sea level, waves associated with the landward advancing shoreline beveled off the former shelf, commonly producing sea cliffs and leaving an elevated terrace. Rivers and streams alluviated their courses. Some submarine canyons became dormant as the sediment supply to the heads was cut off, but others remain active. Except off large rivers, only a thin blanket of Recent marine sediment has accumulated on the bedrock surface, the layer being thickest on the inner and central shelf.

2. Topography — Width averages 10 mi. and depth of margin averages 80 f. Typical profile is sharply concave near the shoreline, nearly flat in mid-shelf, gently convex on the outer shelf, and sharply convex at the shelf margin. Shelf surface is fairly smooth, with the relief of rocks, depressions, and terraces commonly not exceeding 10 f. General trend of the shelf margin and coastline is fairly smooth in contrast to glaciated shelves. Some bays occur where stream courses have not been completely alluviated. Beaches are typically meager and discontinuous, and range in size from pocket beaches on up. Seacliffs typically form the coastline.

3. Sediments—The outer shelf is commonly a non-depositional environment and rock exposures and relict sand and coarse sediments are common there. Rock is also common in the surf zone and along the shore. Mud is common on the inner and central shelf. Most beaches are sandy but cobble and boulder beaches also occur.

B. Shelves off lowland (subsiding) coasts—This description applies only to shelves off broad coastal plains that are known to form the surface of a thick subsiding sediment mass. These coasts are typically the loci of large rivers. The structure, hence the history, of shelves off other lowland coasts, such as that off French West Africa, is essentially unknown.

1. History—The Quaternary history of most coastal plain shelves differs from that of mountainous coasts in that these shelves appear generally to have experienced a net accumulation of material rather than a net loss. During the last interglacial period when the oceans stood at a high level for a period of time, former entrenched valleys on some coasts (e.g., the northern Gulf of Mexico) were generally alluviated completely and broad deltaic plains were subsequently constructed across the inner shelf. Off other coasts (e.g., the eastern United States) alluviation was incomplete, and littoral and brackish bay sediments were deposited. With falling sea level, rivers entrenched themselves and transported larger sediment loads and coarser textures. Marine deltaic deposits accumulated off river mouths and strand deposits formed between to build up the shelf, across which sea level subsequently progressed. The exposed terrace experienced mild erosion. When rivers debouched directly at or near the continent margin old submarine canyons were reactivated and new ones were formed. With rising sea level, submarine canyons became dormant and river courses were alluviated, although incompletely in most cases so that estuaries and bays formed. Superficial wave planation by the advancing shoreline commonly occurred, leaving behind a veneer of littoral marine sediments. Some rivers completely filled their channels and are currently building deltaic plains across the shelf. Apparently unique conditions have prevailed off some large rivers like the Mississippi that carry unusually large sediment loads. There, great thicknesses of sediment have accumulated locally, accompanied by rapid local downwarping of the shelf.

2. Topography—Width averages perhaps 75 mi., except where large rivers have built deltas across the shelf (e.g., Nile, Niger, Mississippi), and where cuspate forelands have formed (e.g., Cape Hatteras on Atlantic Coast of United States). Depth of shelf margin averages 60 f. Profile is similar to that off mountainous coasts but is more subdued. Relief typically

does not exceed a few fathoms. Trend of shelf margin and of open coastline between major points is very smooth. Long barrier-island chains commonly form the open coast, inside of which occur large bays and estuaries.

3. Sediments—Hard rock outcrops are notably absent. Sand is common on the shelf, but mud predominates in the vicinity of rivers. Beaches are typically sandy, although extensive mud beaches occur adjacent to some large rivers.

III. Tropical shelves—Shelves in low latitudes that have been modified by coral reef growth (coral shelves composed in part of calcareous oölite, like that off western Florida, are included).

A. History—During the last interglacial period reefs were probably built to a high sea level much as they are today. Falling sea level exposed reefs, including the Pacific oceanic atolls and the Bahamian platforms, to the destructive processes of solution, denudation, and wave erosion, which eventually lowered them approximately to the elevation of the late Wisconsin sea level. At the same time, peripheral reef growth widened the coral platform. With the subsequent rise of the oceans the reef margins grew upward rapidly to form barrier reefs enclosing lagoons. Lagoon floors have since been built upward somewhat by coral growth and by the accumulation of calcareous debris and detritus. In many areas reefs have grown upward on non-coralline shelf surfaces of late Wisconsin age.

B. Topography—Width is typically highly variable and often difficult to define, the widest shelf being 125 mi. across in eastern Australia. Depth of the margin is less than 20 f. nearly everywhere, and generally only a few fathoms. Major topography, typically consisting of a barrier and fringing reef separated by a

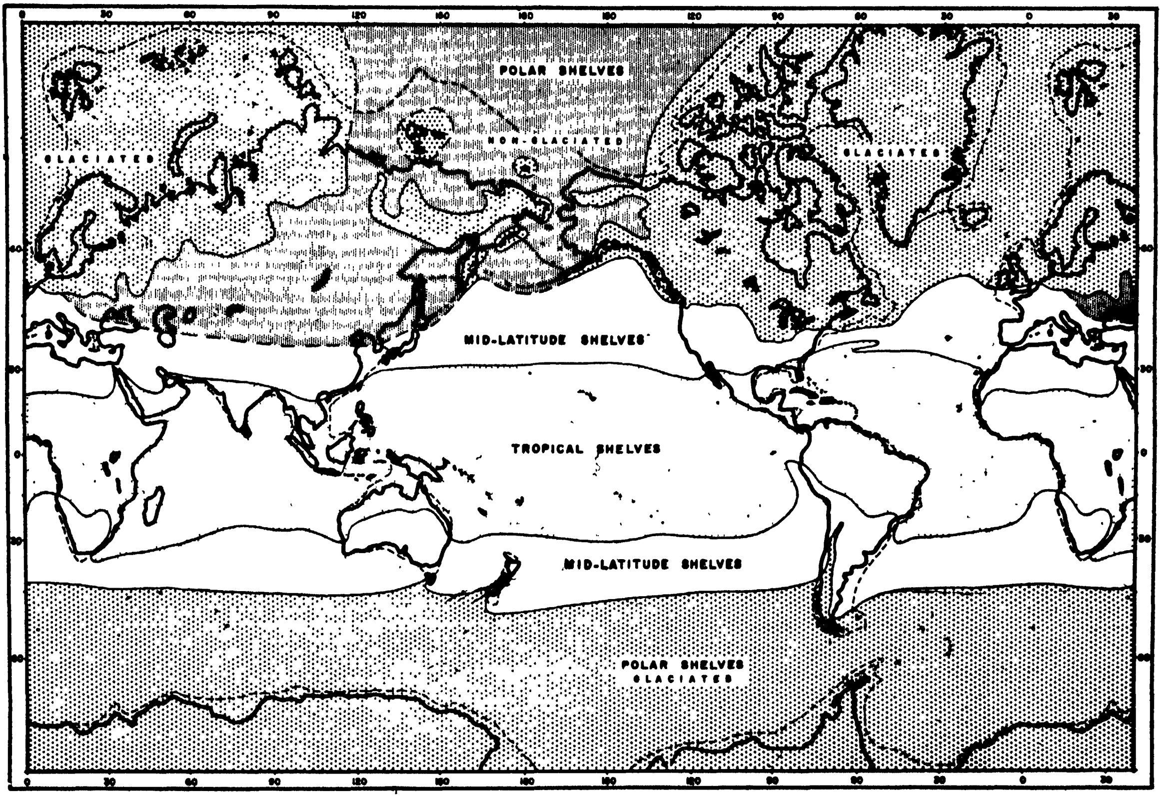

Fig. 1.—Distribution of continental shelf types. The long dashed boundaries are uncertain. The short dashed line represents the shelf margin.

lagoon, is irregular with a relief averaging about 25 f. and generally not exceeding 50 f. Minor topography is typically very irregular and includes such features as coral heads, negro heads, reef-edge notches, and boat channels. The shelf margin is commonly marked by a precipitous drop-off or a steep talus slope. Beaches are typically meager.

C. Sediments — Reefs are largely coral rock masses, but some reefs are sand-covered and some are bordered with boulder ramparts along the seaward margin. The floors of lagoons and depressions are of calcareous sand or mud. Beaches are typically coral sand but shingle beaches also occur. Where reefs have been built on non-coralline shelves, inorganic clastic sediments are also present.

Distribution of Shelf Types

The distribution of shelf types is shown in the attached figure. The boundaries of the glaciated shelves in the Northern Hemisphere follow essentially the limits of maximum Pleistocene glaciation presented by Flint (1947). The boundaries of the non-glaciated polar shelves were derived from data on the present distribution of sea ice (Hydrographic Office, 1946) and the present trend of winter isotherms (minimum monthly) over ocean and land areas (Sverdrup, 1943; Haurwitz and Austin, 1944). The boundary of the polar shelves in the Southern Hemisphere follows the general trend of modern winter isotherms. The boundaries of the tropical shelves follow the sea surface isotherm of 18°C in the coldest winter month, which determines the approximate geographical limit of modern coral reef growth. The shelf boundaries shown in the figure have been extended across the deep oceans and across land areas mainly for the sake of continuity, although they do serve to classify the shelves around islands and in inland seas.

It should be pointed out that the boundaries between shelf types shown in the figure are not everywhere clearcut. Thus, the boundary between middle-latitude and tropical shelves is typically gradational, which reflects the variability of the distribution of favorable living environments for reef-building corals near the geographical limits of reef growth. The boundaries of glaciated shelves on the other hand are generally well-defined, and can be distinguished readily on bathymetric charts in most regions.

Shelf types likewise are not pure forms within the areas shown in the figure. For example, middle-latitude mountainous coasts are commonly interrupted by large valleys or locally fronted by narrow plains off which the shelf characteristics tend toward those of the middle-latitude lowland coast. An example is the Oxnard Plain in California which is drained by the Santa Clara River. Shelves off middle-latitude coastal plains, on the other hand, are typically pure examples of the lowland shelf type along the entire length of the coastal plain.

Coral reef shelves are particularly heterogeneous, reefs in many areas commonly occurring as a patchwork in an otherwise non-coralline environment. Also, great stretches of coast in the tropics do not support reefs, particularly in the vicinity of large rivers. Thus the shelves along much of the west and north sides of the Indian Ocean and adjacent to the Amazon Delta are actually middle-latitude types. Because of the very irregular and incompletely known distribution of coral reefs, no attempt has been made in the figure to distinguish between those tropical shelves that do and do not support them. For details of the world-wide distribution of reefs the reader is referred to Joubin (1912).

The polar Siberian shelf that is classified as non-glaciated in the figure may also be a composite shelf. According to the world map issued by the National Geographic Society in March 1957, the shelf margin is interrupted by a number of indentations strongly suggestive of a glacial origin. Also, the sparsely mapped shelves of the Berents and Kara Seas may be non-glaciated in part. Flint believes that shelf ice extended into these seas from the surrounding land areas during Wisconsin time, but that the deeper central parts were not overridden by ice.

Classification of Coasts and Shorelines

Coasts and shorelines are products of the same agencies that have shaped the shelves, and consequently they can be classified genetically on a worldwide basis in the same manner as the shelves. The classification clearly differs from earlier ones (Johnson, 1919; Shepard, 1948), but its discussion is beyond the scope of this paper.

REFERENCES

Cooke, C.W., 1936, Geology of the Coastal Plain of South Carolina. *U.S. Geol. Surv., Bull.* 867, 196 pp.

Crowell, J.C., 1952, Submarine Canyons Bordering Central and Southern California. *Jour. Geol.*, **60**: 58-83.

Dietz, R.S. and H.W. Menard, 1951, Origin of Abrupt Change in Slope at Continental Shelf Margin. *Amer. Assoc. Petrol. Geol., Bull.* **35**: 1994-2016.

Fairbridge, R.W., 1950, Recent and Pleistocene Coral Reefs of Australia. *Jour. Geol.*, **58**: 330-401.

Fisk, H.N., 1944, Geological Investigation of the Alluvial Valley of the Lower Mississippi River. Miss. River Comm., Vicksburg, Miss., 78 pp.

Fisk, H.N. and E. McFarlan Jr., 1955, Late Quaternary Deltaic Deposits of the Mississippi River. *Geol. Soc. Amer., Spec. Paper* **62**: 279-302.

Flint, R.F., 1947, Glacial Geology and the Pleistocene Epoch. John Wiley & Sons, New York, 589 pp.

Gould, H.R. and R.H. Stewart, 1955, Continental Terrace Sediments in the Northeastern Gulf of Mexico. Soc. Econ. Paleon. and Mineral., Spec. Pub. **3**: 2-20.

Greenman, N.N. and R.J. LeBlanc, 1956, Recent Marine Sediments and Environments of Northwest Gulf of Mexico. *Amer. Assoc. Petrol. Geol., Bull.*, **40**: 813-847.

Haurwitz, B. and J.M. Austin, 1944, Climatology. McGraw-Hill, New York, 410 pp.

Hydrographic Office, 1946, Ice Atlas of the Northern Hemisphere. Navy Department, Wash., D.C., H.O. **550**: 105 pp.

Inman, D.L. and G.A. Rusnak, 1956, Changes in Sand Level on the Beach and Shelf at La Jolla, California. Beach Erosion Board, U.S. Corps of Engrs., Tech. Memo. **82**: 30 pp.

Johnson, D.W., 1919, Shore Processes and Shoreline Development. John Wiley & Sons, New York, 584 pp.

Joubin, L., 1912, Bancs et Récifs de Coraux (Madrépores). *Annales Inst. Oceanogr.*, **4**.

Kuenen, Ph. H., 1950, Marine Geology. John Wiley & Sons, New York, 568 pp.

Kuenen, Ph. H., 1955, Sea Level and Crustal Warping. *Geol. Soc. Amer., Spec. Paper* **62**: 193-204.

McClelland, B., 1952, Foundation Investigations for Offshore Drilling Structures in the Gulf of Mexico. Amer. Soc. Civil Engr., Convention Preprint Paper No. 16, New Orleans Convention, March 5-7, 1952, 18 pp.

Shepard, F.P., 1948, Submarine Geology. Harper & Bros., New York, 348 pp.

Shepard, F.P., 1949, Terrestrial Topography of Submarine Canyons Revealed by Diving. *Geol. Soc. Amer., Bull.*, **60**: 1597-1612.

Shepard, F.P., 1956, Marginal Sediments of Mississippi Delta. *Amer. Assoc. Petrol. Geol.*, **40**: 2537-2623.

Sverdrup, H.U., 1943, Oceanography for Meteorologists. Prentice-Hall, New York, 235 pp.

Swain, F.M., 1947, Two Recent Wells in the Coastal Plain of North Carolina. *Amer. Assoc. Petrol. Geol., Bull.*, **31**: 2054-2060.

Thompson, W.C., 1955, Sandless Coastal Terrain of the Atchafalaya Bay Area, Louisiana. Soc. Econ. Paleon. and Mineral., Spec. Pub. **3**: 52-77.

Toulmin, L.D., 1952, Volume of Cenozoic Sediments in Florida and Georgia. *Geol. Soc. Amer., Bull.*, **63**: 1165-1176.

Zeuner, F.E., 1950, Dating the Past. Methuen & Co., London, 2nd edit., 474 pp.

SEDIMENTS OF SHALLOW PORTIONS OF EAST CHINA SEA AND SOUTH CHINA SEA

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(Abstract)

Nearly 1000 bottom samples from the shallow portions of the East and South China Seas were studied and compared with sources and oceanographic conditions. Sediments of the Gulf of Pohai and Central Yellow Sea are fine grained, low in calcium carbonate, and contain many unstable minerals and a moderately high percentage of organic matter. They are contributed by the Hwangho, Yangtze, and many smaller rivers. In the absence of strong currents they have formed a thick blanketing deposit that constitutes a modern zeugogeosyncline. The sediments on the west consist largely of reworked loess.

Sediments of the inner half of the continental shelf between Shanghai and Hainan and in the Gulf of Tonkin are similar to those of the Central Yellow Sea and represent modern detrital materials contributed to the continental shelf by many rivers, but so far in amounts insufficient to completely cover the shelf. Seaward of these sediments, on the outer half of the continental shelf between Korea and Hainan is a broad belt of coarse sandy sediment from which finer sediments are winnowed away or prevented from being deposited by the strong Kuroshio Current. The sediment contains glauconite and much calcium carbonate in the form of foraminiferal tests and broken mollusk shells but very little organic matter. Because the detrital portion is much coarser than that nearer shore, it is believed to constitute a littoral deposit left from a Pleistocene time of glacially lowered sea level. Locally on the shelf are small areas of residual sediment near rock outcrops and usually containing reworked fossils. Occasional pieces of pumice and many small shards of volcanic glass are present in the sediments but nowhere are they abundant enough to form a true volcanic sediment. The shelf sediments are similar in most respects to those on the shelves of California and they clearly indicate temporary conditions below present base levels of equilibrium—not epicontinental sea deposits.

Seaward of the shelf edge, in deep water of the continental slope, the sediments become finer grained and contain more calcium carbonate, mostly from foraminiferal tests. These sediments consist of the finergrained terrigenous material that by-passes the shelf and is deposited so slowly in the quiet deep water that Foraminifera make up a large percentage of the total sediment.

SUBMARINE VALLEYS OF THE PACIFIC MARGIN

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The paper was presented with illustrations at the meeting, but was not handed to the Publication Committee, and no instruction has been received up to the time of going to press.

— Editor

PRESENT-DAY VERTICAL MOVEMENTS OF FAR EASTERN SEACOASTS OF THE USSR

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PRESENT-DAY VERTICAL MOVEMENTS OF FAR EASTERN SEACOASTS OF THE USSR.

Paleogeographical constructions, including the reconstructions of the ancient coastlines, the correlation of the quarternary marine deposits as well as some problems of modern dynamics of the sea coasts can only be solved correctly if the direction and speed of the vertical movements of the coasts in the past and also at the present time is found out.

The literature dealing with the Pacific coasts contains a good many indications of the character of present-day and modern relative displacements of the coastline (Knappen, 1929; Moffit, 1954; Valentin, 1954). These works contain—not infrequently—quite opposite views and opinions on the speed and direction of such displacements for the same regions of the coast (Okayama, 1931; Valentin, 1954). Such contradictory estimations can be apparently accounted for as follows: a) different explanation of the mechanism of formation of some parts of the coastal relief; b) imperfect method of research; c) slipshod demarcation of the signs of the modern and present-day vertical movements of the land.

By present-day vertical movements the authors imply such movements which had occurred at the period of the formation of the present-day coastal relief, i.e. the relief of the underwater coastal slope to the depth of active action of the waves, of present-day coastal accumulative forms and the cliff. This period covers a few millenaries and in general coincides with the historical time. Thus the present-day vertical movements of the coast zones are taking place as if it were "before the very eyes of the people". A good example of the present-day vertical coastal movements is furnished by the negative and positive movements of the earth crust in the region where the well-known ancient temple of Jupiter-Serapis (Italy) is situated. The present-day vertical movements strikingly manifest themselves in Japan, where a number of fishing villages and ports found themselves removed from the sea, as a result of a rise of the land (Okayama, 1931).

The raised or subsided marine terraces which are beyond the present coastal zone cannot be considered an indication of the present-day vertical movements of the coasts. They testify to earlier, modern displacements of the coastline.

Repeated levelling is considered a most reliable and precise method of exploring the vertical movements of the land. But this method necessitates specially organized work requiring much effort and long intervals between the periods of observation, which is often impossible to do on account of the remoteness and inaccessibility of the regions being explored. Therefore, the Soviet explorers most widely apply geomorphological methods, of which the main one consists in an analysis of the structure of the marine accumulative forms. They originate from a continuous accumulation of clastic material and quickly react on the relative changes of the sea level. With a constant sea-level and a sufficient amount of clastic material the absolute heights of the beach ridges complicating the surface of the accumulative forms are approximately the same. If the sea-level was changing while the accumulative forms appeared (on condition of the homogeneousness of the clastic material and the constancy of the wave regime) the absolute heights of the beach ridges were changing accordingly, from new to older ones (Johnson, 1919; Zenkovitch, 1948). Therefore an analysis of the profiles of the instrumental levellings of the surfaces of the marine accumulative forms is the most reliable qualitative method of determining the present-day relative movements of the seacoasts (Budanov, 1951a).

The following data should be compared with those of the levellings: a) observation of the morphology and dynamics of the sea coasts, obtained as a result of direct exploration and of analysis of the material of aerial photography; b) the profiles of the underwater coastal slopes and other material of the morphology of the coastal zone of the bottom (depth gauge, diving observations etc.); c) literary information, in particular, archaeological data.

This method of determining the present-day vertical movements of the coasts was worked out at the Laboratory of the dynamics and morphology of the seacoasts,—Institute of Oceanology, Academy of Sciences of the USSR, under the guidance of Professor V.P. Zenkovitch. This method has been applied by the authors during the explorations on the seacoasts of the Soviet Union, including those of Chukotka, the Bering Sea, the Sea of Okhotsk and the Sea of Japan (Budanov, 1951b; Budanov and Ionin, 1956; Zenkovitch and Vladimirov, 1950; Ionin, 1955).

The material collected made it possible to obtain comparable results and to lay down the general character of present-day relative differentiated movements of the Far Eastern seacoasts. As to the direction of the present-day vertical displacements, the Far Eastern sea coasts are divided into a number of regions. Some of them are, according to available data, subsiding, others—rising, and, finally, there are relatively stable regions without clearly expressed signs of any vertical movements. On the diagram-map (fig. 1) subsiding, rising and stable regions as well as the points of levelling of the surfaces, of the marine accumulative forms are indicated by conventional signs.

The coasts of Southern Sakhalin, of the Southern part of Primorye, of some regions of Eastern Kamchatka and the Koryak upland and also of the Western part of the Anadyr bay (fig. 1) may be called rising coasts. According to G.S. Ganeshin's data, the coasts of the Shantar Isles are rising, while the materials of V.I. Lymarev's (1955) and V.F. Kanayev's (1958) research testify to a rise of the Great Kuriles.

A lessening of the absolute height of the beach ridges on the accumulative forms towards the shore-line, which has been ascertained by instrumental levelling (fig. 2, a, b) is the most reliable sign of the present rise of the above-mentioned region of the sea coast. The beach ridges on the mid-bay bars and spits are well preserved. This is because in most cases the accumulative forms are made up of pebbles, rarer—of sand-pebble

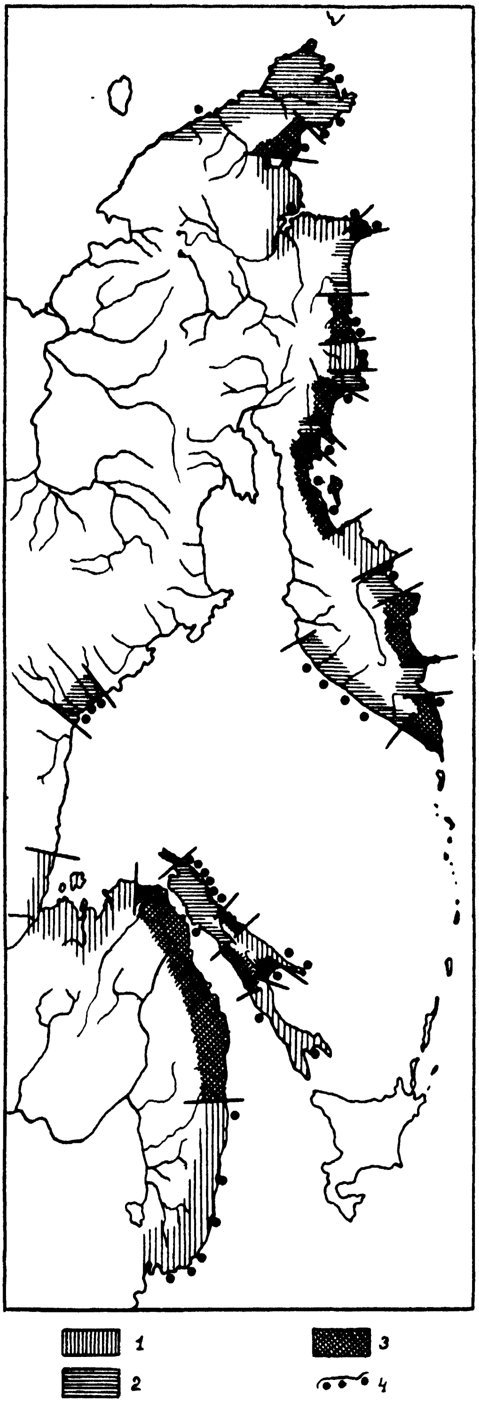

Fig.—1. Sketch Map of Present-Day vertical movement of Far Eastern Seacoasts of the USSR.
1. Legend: Parts of insignificant relative rise,
2. Parts of insignificant relative subsidence,
3. Relatively stable parts of coasts,
4. Places of instrumental levellings of the surfaces of the marine accumulative forms.

and boulder material. In the Southern regions the beach ridges situated far from shore-line are not infrequently grown with turf. All this precludes errors in determining the real heights of these forms, created by the sea, for they are practically not liable to changes worked by subaerial processes.

The older beach ridges are relatively higher than the later ones on the rising coasts,—this difference in heights varies widely. An instrumental levelling of the surfaces of the marine accumulative forms has shown that this difference in height amounts to 1-2 m in the bays of Southern Primorye deeply cut in the dry land, to 2-2.5 m on the coasts of the Anadyr firth, to 3-3.5-4 m on the coasts of the Koryak upland and Sakhalin and even to 6.5 m in Kamchatka. Such a difference in the heights of the beach ridges is not only a convincing proof of a rise of the land in these regions but it obviously shows its unequal speed in every region.

Abrasion terraces well expressed in the relief of the bottom (fig. 3, a, b) are a characteristic feature of the morphology of the underwater coastal slope of the rising coast zones. As is known when the coast rises, new and old regions of the bottom which become open to the action of the waves are subject to abrasion. Therefore an abrasion platform with small slopes whose outer margin protrudes farther and farther into the sea is formed on the underwater coastal slope. However these underwater terraces on the rising coasts are not wide. Their rear parts are coming out from under the sea level, as a result of the rise, changing into above water terraces. These terraces, or, as they are often called "uplifted benches" (rock sections of the sea bottom with no debris) are bordering many abrasion sections of the coast within Sakhalin and the Kuriles.

Owing to an extension of the underwater abrasion terraces and uplifted benches, abrasion on the rising coasts is usually retarded. Cliffs no longer touched by the waves are often to be found. Wave-cut niches raised to a considerable height and bearing clear traces of wave action (the Patience Peninsula on the Sakhalin, the Kuriles)—if the coast is made up of durable rock—may be observed on their surface.

The appearance of peculiar relict accumulative forms on rock bases is caused by a rise of the coasts. Being formed on a higher sea-level they were fed mainly, thanks to a drifting of the debris, from the neighbouring abrasion regions. With the rise of the land and a dying away of the

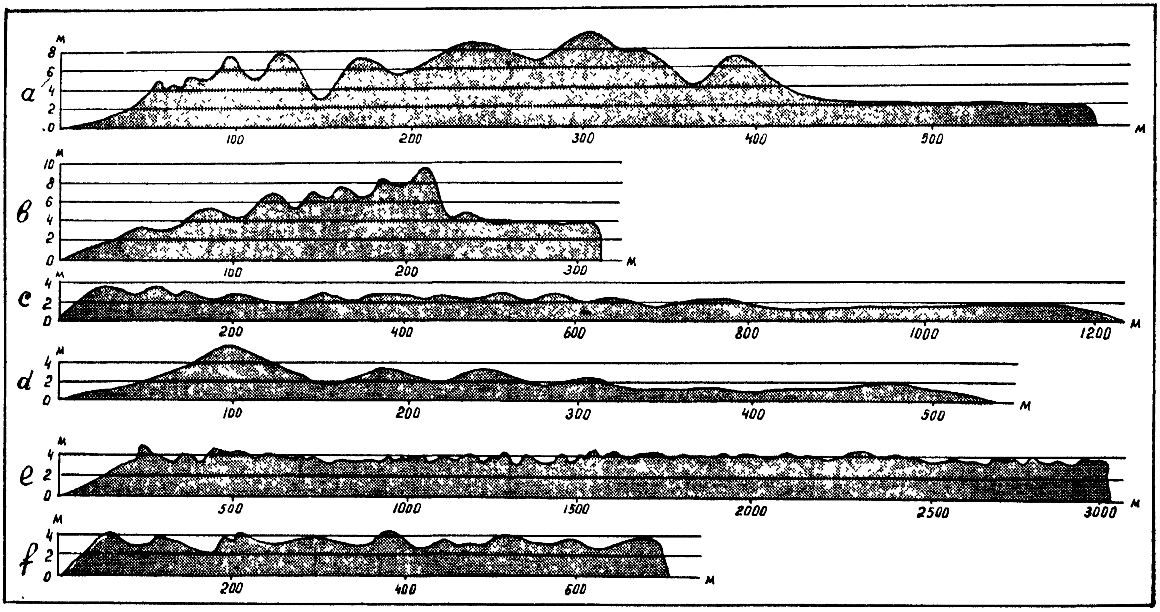

Fig.—2. Typical profiles of instrumental levellings of the surfaces of present marine accumulative forms.
a, b — Relatively raised coast profiles,
c, d — Relatively subsided coast profiles,
e, f — Relatively stable coast profiles.

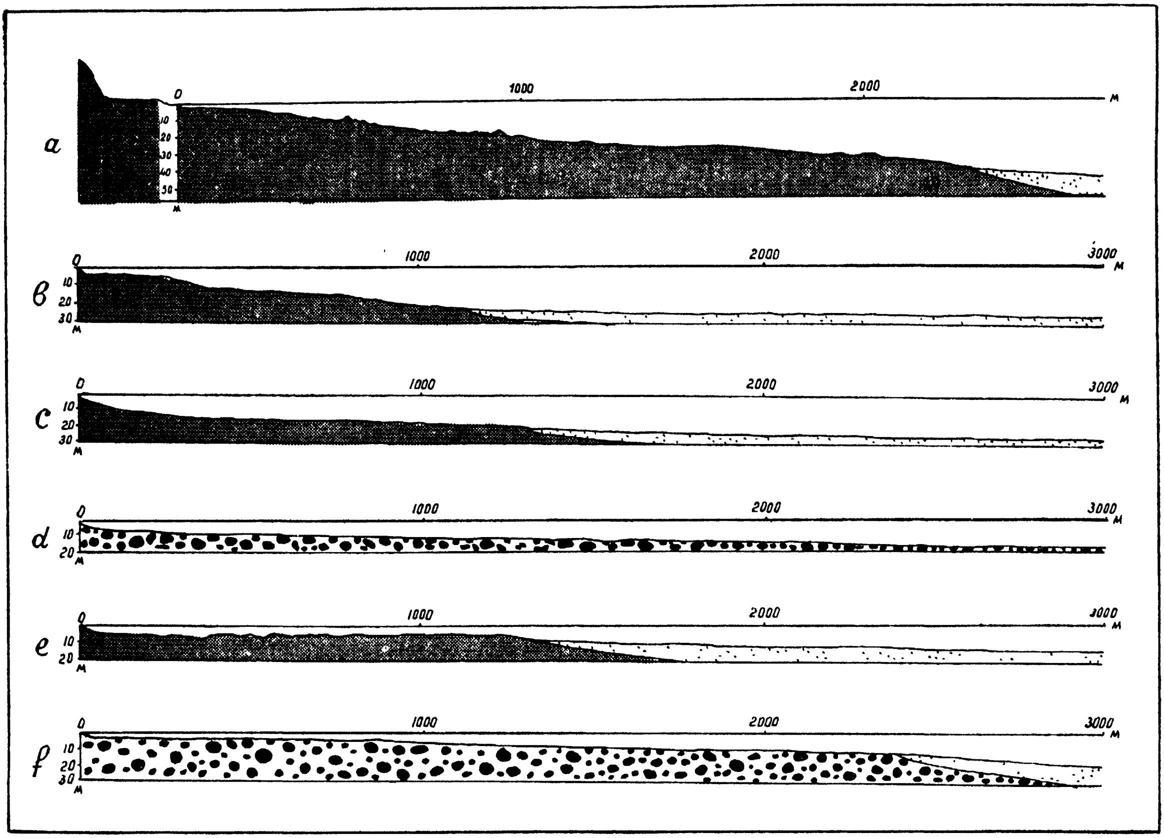

Fig.—3. Typical profiles of underwater˜coastal slopes.
a, b — Relatively raised coast profiles,
c, d — Relatively subsiding coast profiles,
e, f — Relatively stable coast profiles.

abrasion processes the amount of the clastic material in the coastal zone is decreasing, which causes erosion and a reconstruction of the accumulative forms. Some of them are eroded completely, others — owing to a rapid relative fall of the sea level — are raised and isolated from the waves on the rock bases.

The existence on some coasts of dried out lagoons may be noted among other signs of a rise of the above-mentioned regions. Such lagoons are most frequently to be found in the Anadyr Bay. The dried out parts of the lagoon bottoms usually border upon midbay-bars and are raised 0.5 m higher than the shore line. They are made up of modern marine deposits, the upper part of which is covered with a layer of lagoon slime, which makes it possible to judge for a rise of the coast.

In natural conditions it is only a complex of signs which helps arriving at the conclusion of a rise of a certain region of the coast. Any of these signs taken separately can lead to an incorrect inference. So, for instance, the speed of abrasion does not in itself allow to judge of a sign of the vertical movements, for an active destruction of the cliff by the waves may take place not only on subsiding coasts but in a number of cases in the places of a rise, provided there is a lack of debris in the coastal zone. One should also determine with discretion the sign of vertical movements by hanging junctions to be met with on rising as well as subsiding coasts. The character of the profile of the present-day accumulative form surfaces is to be considered the most reliable sign of a movement of the earth crust or sea-level.

We observed the most pronounced traces of the present-day relative subsidence of the land in the Eastern and the Western parts of the Chukotka Peninsula, the North-Eastern part of the Koryak coast, some regions of the Eastern and Western coasts of Kamchatka and North-Eastern Sakhalin.

A lessening of the absolute height of the beach ridges on the accumulative forms toward the land from newer to older ones, is the main indication of the present-day relative subsidence of the above-mentioned regions of the coasts.

According to the data of instrumental levelling the heights of the old beach ridges differ from the newer ones by 1-2, 3-4 and, sometimes, even 6-7 m (the latter figure refers to Western Kamchatka). (fig. 2, c, d). Homogeneousness of the material, of which the accumulative forms are made up, proves that a lowering of the beach ridges with the removal from the shore-line, in the conditions of an open coast, cannot be caused by any change in the character of the clastic material supplied in the process of development to the beach ridges. This is the output of the relative subsidence of the land, which not infrequently results in the older beach ridges of the rear parts of the accumulative forms being found lower than the present sea-level (Kamchatka, Sakhalin, etc.).

The underwater coastal slope of the subsiding regions has no abrasion terraces expressed in the relief. (fig. 3, c, d). Such coasts are sometimes sunk to a considerable depth and buried under cover of the latest deposits. In the coastal part of the bottom there is usually a sloping concave abrasion surface with no debris. In the regions where moraine strata occur, their surfaces are covered with close set boulders and clods washed by the waves from the stratum of argillaceous grounds. At the present time these boulders and clods are overgrown with seaweeds, which proves their immobility even during strong storms. On the Western coast of Kamchatka and East of the Chukotka Peninsula the lower border of this so-called "boulder-clod bench" may be traced to a depth of 10-12 m. The presence of large clods and boulders, reaching 2 m in diameter can only be explained, at such a depth and so far removed from the coast, as a result of recession of the cliff and relative sinking of the coast. In another case, the heap of boulders and clods, as it is forming itself in front of the coasts, receding due to abrasion, protects the cliff from the action of the waves (Zenkovitch, 1949).

An intense abrasion of very long rock regions of the coast as a result of which high (up to 200 m), sometimes overhanging, cliffs are appearing, is an indirect sign of the present-day relative subsidence of a number of regions of the Far Eastern seacoasts. The peat bogs found during drilling in a number of areas of the Chukotka and Kamchatka Peninsulas, situated lower than the present sealevel, is a still more striking sign of the subsidence.

Lagoons are widespread on the subsiding coasts in the Far East (the Northern coast of the Chukotka Peninsula, Western Kamchatka, North-Eastern Sakhalin). Many of them are formed during the moving up of the storm-worked ridge upon the sloping surface of the plains at the foot of the mountains in the process of a slow subsidence of the land. A strip of the lowland, adjoining the rear of the beach ridge, often sinks lower than the sea-level and is flooded by the waters of the sea filtering through the ridge. The dimensions of the aquatoria of such lagoons are gradually increasing with the progressive subsidence of the coastal land. The described process of formation of the lagoons is also taking place at the present time and can be most clearly traced on the subsiding coasts of the Chukotka Peninsula (Zenkovitch, 1950; Kaplin, 1957).

As is the case with the rising coasts, it is impossible to determine the sign of the vertical subsiding movement according to one of the above-mentioned signs. Therefore, all the regions of subsidence marked on the diagram-map are indicated on the basis of a whole complex of geomorphological signs.

At the present stage of geological history, some regions of the Far Eastern sea-coasts are in a relatively stable state (fig. 1). It seems that in such regions (Eastern coast of the Bay of the Cross, central part of the Eastern coast of the Koryak upland, a number of regions on the coasts of Eastern Kamchatka and Western Sakhalin) the eustatic rise of the level of the World Ocean is compensated by an equal tectonic rise of the land.

The signs of a relatively constant position of the sea-level in these regions of the coast are in many respects similar to those of a rise of the coasts, described above. With the help of instrumental levelling of the surfaces of accumulative forms it becomes possible to establish the fact that all the beach ridges are approximately at the same height above sea-level. This makes it possible to arrive at a reliable enough conclusion on the stability of a certain region of the coast (fig. 2, e, f).

Rather wide shallow abrasion terraces worked out by the waves in hard rock (fig. 3 c) and friable quarternary strata (fig. 3 f) are a distinguishing feature of the morphology of the underwater slope of the abrasion regions of the coast. These abrasion terraces possess the smallest surface slopes and their most intense working out is taking place until the very surface reaches the utmost width, so that the waves rolling over shallow water are broken, lose their energy and no longer reach the coastal cliffs. In such a case the latter crumble, and wide beaches or accumulative terraces are formed in their place. They are made up of material thrown up by the waves from the sea-bottom during the further destruction and levelling up of the surface of the underwater abrasion terrace.

The width of the underwater abrasion terraces in the stable regions of the coast varies widely, depending considerably on the stability of the rock, the abrasion and strength of the waves in certain regions of the coast. The underwater abrasion terraces in regions along the coast, made up of deposited strata of rock, are very wide. For instance, at the North-Eastern end of the Koryak upland, on the coasts of the Olyutor bay and Western Sakhalin the width of the underwater abrasion terraces frequently reaches 1-1.5 km. Particularly wide underwater abrasion terraces can be found on the coasts made up of friable boulder bearing argillaceous grounds. Such terraces on the Eastern coast of the Bay of the Cross and North-Eastern Kamchatka are about 2-2.5 km wide.

A lack of some indirect signs characteristic of the rising coast, namely: "drying lagoons", "uplifted benches", "accumulative forms with rock basis",—form additional evidence for the stability of the above-mentioned coastal regions, taking also into account the data on the levellings.

On the Far Eastern seacoasts, the whole complex of signs testifying to the definite direction of the present-day vertical displacement of the coast line is not often met with. On the contrary, symptoms may sometimes be found in one and the same region testifying to opposite signs of the present-day vertical movements. Such cases prove either the fluctuating character of the present-day vertical movements or a recent change of the sign into an opposite one. For example, the underwater coastal slope on the Western coast of Sakhalin has a profile in its lower part that is usually characteristic of subsiding coasts, while the levelling of the surfaces of accumulative forms and the presence of a bench near the shoreline (fig. 3 a) point to a rise of the land in this region. It appears that not long ago the vertical movement of one sign gave place to its opposite in this part.

In connection with the late glacial transgression of the sea, an ingressive outlook is common to all the Far Eastern sea coasts. However, this can not be considered an indication of present-day subsidence of the coast, for on the rising coasts an eustatic rise of the level was not compensated by tectonic movements. Thus for those regions of the coast where we noted a rise, the latter is not relative but absolute as to its sign.

A negligible subsidence or stability of individual regions of the coast should be estimated as relative displacements, for they are the algebraic sum of an eustatic rise of the level of the World Ocean at the late glacial time and of the tectonic movements of the earth's crust.

It is clear that the speed of movements of the coast regions going through the same displacements may be different.

On the Far Eastern coasts in general, no region with considerable speeds of vertical movements can be found like those registered in Fennoscandia, Nova Zembla and the Caspian Sea. Therefore the differences in the speeds of movements of individual regions of the coast may only be estimated conventionally according to the difference between the heights of old beach ridges and newer ones or vice versa. As an example, the difference in the height of the old beach ridges of accumulative forms in the open regions of the coast of Western Kamchatka in regard to the modern ridges amounts to 6-7 m and on the Chukotka Peninsula to 1.5-2 m. This fact shows that the extent and apparently, the speed of the relative subsidence of the Western coast of Kamchatka during the historical time exceeds 3-4 times those of the Eastern part of Chukotka.

Determination of the speed of vertical movements as well as their duration is impossible because we do not know the average interval of time during which definite types of accumulative forms and individual beach ridges are created. The uncertainty as to determining these values is still more aggravated by the fact that the accumulative forms can be repeatedly abraded and reconstructed during the process of their development. At the same time, the difference in the relative uplift of the ridges can, in many cases, be determined by the peculiarities of the wave regime in the given region of the coast and by the character of the material of which the accumulative form is made up.

Application of precise methods for determining the age of the accumulative forms using C14 isotope may give an answer to the question about the speeds of the vertical movements of the coasts, also of the duration of these movements and of the moment of change of their signs. In the Southern regions the method of determining the age of the beach ridges of different generations by the annual rings of trees growing on these ridges (Galazy, 1955) could be applied for these purposes. More detailed archaeological exploration of primitive human settlements sometimes found on the accumulative forms, will undoubtedly furnish a lot of interesting material comparable to long periods of observation of various levels in different points of the Far Eastern seacoasts.

More detailed exploration of the coasts of the Chukotka, Bering, Okhotsk and Japan Seas will undoubtedly show a more complex picture of differentiated present-day vertical movements of the coasts and the choice of the more indicative evidences will make it possible to establish connections between individual tectonic structures and the vertical displacement of certain sections of the earth's crust.

REFERENCES

Budanov V.I., 1951, Concerning the Method of Study of Seashores. *Scientific Publications of the Oceanology Institute, USSR Academy of Sciences*, **5**.

________, 1951, On Raising of Seashores of Maritime Territory. *Scientific Publications of the Oceanology Institute, USSR Academy of Sciences*, **6**.

________ and Ionin A.S., Present Vertical Movements of Western shores of the Bering Sea. *Scientific Publications of the Oceanography Committee, Presidium of the USSR Academy of Sciences*, **1**.

Galazy G.I., 1955, Botanical Method of Determination of Dates of High Historical Water-Levels and of Some Other Phenomena of the Lake Baikal. *The Far Eastern Academy of the USSR*, **103**, (5).

Johnson D.W., 1919, Shore processes and shoreline development. New York.

Ionin A.S., 1955, New Data on Vertical Movements of Seashores. *Scientific Publications of Oceanology Institute, USSR Academy of Sciences*, **13**.

Kanayev V.P., 1958, New Geomorphological Observations on the Kuril Islands. *Scientific Publications of the Oceanology Institute, USSR Academy of Sciences*, **32**.

Kaplin P.A., 1957, On some peculiarities of the North-Eastern shores of the USSR. *Scientific Publications of the Oceanography Committee, Presidium of the USSR Academy of Sciences*, **2**.

Knappen R.S., 1929, Geology and mineral resources of the Aniakchak District. *U.S. Surv. Bull.* **797**.

Lymarev V.I., 1955, Basic regularities of shore formation of some volcanic islands of the Kuril ridge. *Scientific Publications of the Alma-Ata State Pedagogical Institute named after Abai, natural geography series*, **7**.

Moffit F.H., 1954, Geology of the Prince William sound region, Alaska, Washington.

Okayama T., 1931, Relation between topography and resylts of Precise Levelling. *Journal of Geology*, **8**: (4).

Valentin H., 1952, Die Küsten der Erde. *Ergänzungsheft zu Petermans Geogr. Mitt.* **246**, Gotha.

Zenkovitch V.P., 1948, Methods of determining vertical movements according to shore morphology. *Scientific Publications of the Council on methods of studying movements and deformation of the earth-crust.* Geodesy Publishing House.

________, 1949, Block bench as indication of sinking of shores. *Scientific Publications of the Oceanology Institute, USSR Academy of Sciences.* **4**.

________, 1950, On methods of lagoon formation. *Reports of Acad. of Sci. of the USSR.* **75**: (4).

________ and Vladimirov A.T., 1950, Latest sinking of shores in Western Kamchatka. *Reports of Acad. of Sci. of the USSR.* **72** :(4).

SUBMARINE MOUNTAINS IN THE KURILE RANGE AREA

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(Abstract)

1. In 1949-1956 the Institute of Oceanology of the Academy of Sciences of the USSR carried out investigations of bottom relief in the area of the Kurile Islands. Detailed studies have made it possible to discover some new important features of submarine relief and to mark some regularities of its structure.

The Kurile range consisting of two ridges (the inner one-the Kurile Islands uplift and the outer a submarine ridge of the Vitjaz) is a part of the present-day geosynclinal area. High tectonic activity and intensive surface and submarine volcanism are responsible for the main features of composite bottom relief of the region.

2. Before the investigations made by the Institute there was no authentic information about submarine mountains of the Kurile range. Now there are known 49 submarine mountains (among them no less than 26 submarine volcanoes), 41 of which are situated along the Okhotskoye Sea border of the inner ridge, five-along its axis and only three mountains are within the outer ridge. The majority of submarine mountains are located near the deepest gulfs, those of: Freeze, Bussol, Krusenshtern and Chetverty Kurilsky.

3. Submarine volcanoes are, as a rule, conical. Their relative height varies from some hundred meters up to 2,500 m. The summits of the volcanoes are at depths from 60 to 2,260 m. The diameter at the base of the greatest volcanoes is up to 20 km. The slope gradient is 17° which corresponds to the gradient of the middle part of the slopes of surface Kurile volcanoes. Some submarine volcanoes are active.

4. Both submarine and surface volcanoes of the range are characteristically situated in linear direction both along and across the range. The transverse rows consisting of 3-5 volcanoes are located mainly near deep gulfs as well as the latter are connected with deep fractures.

5. Some submarine volcanoes and mountains have flat tops covered with boulders, pebbles and sand. As a rule tops are at the depths of 100 to 150 m, but in several cases at much greater depths up to 950 m. The formation of flat tops at the depths up to 150 m. may be attributed to abrasion which took place when the sea surface was lower during the quarternary glaciation. Volcanoes, the tops of which are at greater depths, have undoubtedly suffered tectonic subsidence.

6. The above mentioned distribution of submarine volcanoes and mountains can be seen on the geomorphological map of the Kurile Islands area, compiled in the Institute of Oceanology.

PROCEEDINGS OF THE NINTH PACIFIC SCIENCE CONGRESS

PACIFIC FLOODINGS OF THE CANADIAN ROCKY MOUNTAIN AREA

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INTRODUCTION

The study of paleogeography in North America has been synonymous with the name of Charles Schuchert for half a century. Through insertions in text-books, his maps became the background for the study of ocean floodings onto the North American continent. Of necessity, speculation largely determined his paleogeographic pattern for north-west Canada. The results of the past decade of oil exploration in western Canada permits a modification of Charles Schuchert's posthumous legacy (1955) concerning the distribution of lands and seas in North America. Seas with a Pacific connection extending eastward into northwest Canada are the particular concern of this contribution.

The earliest detritus deposited on the Pacific margin was derived (Warren 1951) from the igneous-metamorphic complex of the Canadian shield. This craton is flanked on the north and west by sedimentary belts. One belt, passing through the Canadian Arctic archipelago, strikes north-east; the other, including the British Columbia Cordillera, strikes north-west. It is customary to think of the Arctic archipelago sediments as "Boreal" and the British Columbia sediments as "Pacific". It is doubtful if such discrimination is valid until after mid-Lower Cretaceous time.

PRECAMBRIAN

In Beltian (late Precambrian) time the Pacific Ocean lapped over most of the Canadian Rockies area from the southern boundary of Canada into the Yukon Territory. The sediments were derived from the craton to the east (Warren 1951). There is no evidence that at this time there was any land mass (Cascadia) lying to the west. The western half of British Columbia was covered by deep water, too far from shore-line to receive significant clastic sediment. The Belt sediments appear only in eastern British Columbia and Central Yukon. The near-shore shallow-water facies may be traced by calcareous algae in the southern portion of the Rockies and by actual hiatus in the northern Rockies and eastern-most Yukon. In Canada, the Rocky Mountain trench probably marks the approximate western boundary of the pre-Beltian craton. The positive and negative elements of the radial segmentation of the craton, indicated by Burwash (1957), created a sinuous shoreline of headlands and embayments. The most critical headland was in the latitude of Peace River; the most obvious embayment was in the area of the southern Canadian Rockies. The southern boundary of this embayment was "Montania". The Yukon positive area marks an arbitrary division between the "Boreal" sedimentary margin and the Pacific margin in the same way that Alaska at the present day separates the Arctic and Pacific oceans.

PALAEOZOIC

At the start of the Palaeozoic, the Pacific Sea transgressed the continental shelf and flooded, in part, the basement portion of the craton. The deepest penetration was made in the embayments which probably represented drainage basins of major Precambrian river systems. The Lipalian interval within the embayments was undoubtedly of short duration.

The Lower Cambrian quartzites probably represent a continuation of Precambrian conditions as differentiation is made only on the presence or absence of trilobites. Calcareous algae in the Lower Cambrian indicate shoreline depths along the line of the west side of the Rockies, west of Fernie, in British Columbia. Banff and Jasper in Alberta, farther north, appear to be in the heart of the embayment from the Pacific with very thick Lower Cambrian sections. The increased flooding into the embayments in Middle Cambrian time brought the seas into the area east of the Rockies in southern Alberta. By Upper Cambrian time the seas extended as far east as Saskatchewan reducing the size of the Montana headland and flooding the Williston basin. North of the Peace River "high" the waters of the Pacific coalesced with those of the Arctic in Lower and Middle Cambrian time and salt-pans developed on the depressed northwestern margin of the craton.

Graptolitic shaly deposits of Lower Ordovician to Middle Silurian age along the west side of the southern Rockies, in the western Mackenzie Mountains and in the Richardson Mountains, are in marked contrast with the predominently limey shelf-facies of the eastern Rockies and the craton. The extensive flooding of the craton in Ordovician time probably left only the headlands of Montana and the Peace River high as islands, marking the Western margin of the drowned continent.

In Silurian time the intra-cratonic basins and Pacific embayments were re-defined by continental uplift and the headlands were once again connected with the inner craton. No rocks of Silurian age have been found between the Williston basin and Great Slave Lake. (Rutherford 1951). The Pacific embayment in the southern Rockies area was restricted to the edge of the craton whereas the Liard embayment was continuous with the Arctic sea before the Caledonian disturbance. Uplift in Late Silurian and Early Devonian time expelled the seas from the craton leaving evidence of deposits of this age only in northern-most Yukon. Elsewhere, earlier Palaeozoic deposits suffered erosion, and angular unconformities representing the Caledonian interval are present in northwest Canada.

At the beginning of Middle Devonian time the northwest margin of the craton was depressed, and flooding extended from the Arctic to the Peace River protaxis. South of this, the sea did not reach east of the Rocky Mountain trench. The faunas attending this flooding were cosmopolitan in aspect and later Middle Devonian faunas contain many Chinese types. The *Stringocephalus* sea flooded through the Liard embayment from the Pacific, spreading behind the high land that marked the western margin of the hedreocraton to inundate the low areas toward the Williston Basin. This landlocked arm developed salt basins fringed by reefs. There is no evidence that boreal connections were broken at this time but an eastern margin to the flooding is traced by *Stringocephalus*-bearing reefs aligned with the the present margin of the shield as exposed today. Regression of this sea left an erosional hiatus, marked by plant remains, over most of western Canada. Re-expansion of the Pacific flooding through the Liard embayment took place in Upper Devonian time with progressive transgression until western Canada, including the headlands, was inundated. Late Caledonian (Acadian) disturbances raised the Arctic area, provided coarse, clastic plant-bearing beds and destroyed the epicratonic coalescence of Pacific and Arctic waters for the remainder of geologic time. The uplift in the boreal area was complemented by the depression of the entire western Canada Pacific margin, and the Montana and Peace River headlands were encompassed and flooded by the sea. The faunas of the late Devonian (Palliser) time show strong Asiatic affinities.

After a minor withdrawal of the Pacific Ocean the Liard embayment acted as an exogeosynclinal downwarp and thick black shale was deposited with detritus from the Yukon high. The Pacific transgressed over the Peace River and Montana highs to flood Alberta and the Williston basin with shallow epi-continental seas. A late Mississippian sandstone facies developed along the northern margin of the Liard embayment. South of the Liard area the Pacific transgression deposited shallow-water shale and limestone with chert in the Rocky Mountain area. The chert reflects the incipient volcanism of the Fraser belt farther west. It was the development of the volcanic archipelago of the Fraser belt that first provided a source for sediments from west of the craton. Sympathetic uplift of the craton during world-wide Late Palaeozoic disturbances expelled the Pacific ocean by mid-Pennsylvanian time to a position west of the present Rockies. Accentuation of the volcanic island chains of western British Columbia created the "Cordilleran" geosyncline west of the craton. Thick fusulinid-bearing Permian sediments, interbedded with volcanics, are found throughout western British Columbia but only thin shore-line clastic sediments are found in the Rocky Mountain area. The clastic sediments extend farther to the east in the Liard and Peace River areas to lie unconformably on Mississippian rocks. The Cordilleran geosyncline was restricted in the north by the promontory of the Yukon high, and Permian clastics found in Northern Yukon are not part of the geosynclinal fusulinid facies.

MESOZOIC

The beginning of the Mesozoic was marked by a general subsidence of both the Pacific margin of the craton and the volcanic archipelago. This subsidence provided an epi-continental shelf receiving Lower Triassic clastics. In southern Alberta, east of the mountains, pre-Jurassic erosion has removed the shoreline facies but in the Peace River-Liard basin farther north this facies is preserved in subsurface, the Rocky Mountains carrying only the off-shore facies in outcrop. Uplift, accompanying re-activation of vulcanism in western British Columbia, left shallow limey sediments and evaporites in the Peace River area, by Middle Triassic time. The Upper Triassic sea transgressed east of the

Rockies only in the Peace River-Liard basin. The base of the chains of volcanic islands in British Columbia provided a lip to a partially euxinic basin, and corals and volcanics in the Upper Triassic were confined to the western side of the lip. In late Triassic—early Jurassic time the western plains area suffered severe erosion removing Triassic beds and much of the late Palaeoczoic sediment. This uplift marked the end of the calcareous phase (Millard) of deposition along the Pacific margin of the Alberta area which had pertained since Lower Cambrian time.

At the beginning of Jurassic time the seas were in much the same position as in the late Triassic. The Pacific advance into the Rocky Mountain area was earliest in the Peace River—Liard basin where Hettangian faunas are known. For the remainder of Lower Jurassic time the shore-line of the Pacific lay to the east of the present Rockies and Foothills. In Middle Jurassic time the sea reached eastward to the Williston basin where limey phases are found. Along the Canadian Rocky Mountain foothills a black shale phase was persistent. Farther west, in western British Columbia, the island chain provided volcanics and greywacke.

Mid-Upper Jurassic (Kimmeridge) time (post-Swift) marked the draining of the Sundance sea of the Williston Basin and north central United States through a narrow passage-way to the north-east of the Montana high. At the same time the Yukon high was accentuated. Between these highs, in the Canadian Rockies and foothills, marine arenaceous clastics mark the shallow neritic margin to the Pacific flooding. The two main river systems, one draining the old Sundance basin (Morrison) and the other draining northeastern British Columbia, debouched into the Pacific. Estuarian facies developed in both northeastern and southeastern British Columbia bringing marine ammonites of both Portlandian and Tithonian ages as far east as the Rockies. There appears to be no important break to indicate the Jurassic-Cretaceous boundary. Coal swamps developed in south-eastern British Columbia. At the beginning of Cretaceous time the Selkirk mountains commenced to rise. This restricted the sea in south-eastern British Columbia. Farther north along the Rockies *Aucella*-bearing Neocomian sandstone marks, at this time, the greatest penetration of the Pacific on to the continent. The presence of ammonites and pelecypods of Lower Neocomian age in the foothills of the Peace River area, similar to those found in British Columbia on both sides of the Coast Range batholith today, is sufficient evidence that the latter had not as yet appeared as an effective barrier. Further uplift of the Yukon high and northern British Columbia combined with further uplift in southern British Columbia left but an estuarian remnant of the old Pacific embayment. This estuary marked the main drainage exit for most of western Canada. Reflooding of the lower reaches of this river system in late Neocomian time marked the last transgression of the Pacific into the Rocky Mountain area. The regressive phase of the Pacific was marked by the development of coal swamps in the Rockies and Central British Columbia. The emplacement of the Coast Range batholith 105 million years ago, (Folinsbee, et al., 1957) as well as the Nelson and Cassiar-Omineca batholiths effectively prohibited further Pacific marine floodings (other than marginal) into the Cordilleran region. From Aptian time onward the marine sediments of the Rocky Mountains and central plains areas were deposited in waters connected with the Arctic, Atlantic or Gulf of Mexico seas and not with the Pacific.

REFERENCES

Armstrong, J.E., 1949, Fort St. James Map Area, Cassiar and Coast districts, British Columbia. *Geol. Surv. Can.*, Mem. **252**.

Baillie, A.D., 1953, Devonian system of the Williston basin. *Mines Branch, Prov. of Manitoba*, Pub. **52** (5).

Bostock, H.S., 1948, Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel *Geol. Surv. Can.*, Mem. **247**.

Burwash, R.A., 1957, Reconnaissance of subsurface Precambrian of Alberta. *Bull. Amer. Assoc. Petrol. Geol.*, **41** (1): 70-103.

Crickmay, C.H., 1931, Jurassic history of North America; its bearing on the development of continental structure. *Proc. Amer. Phil. Soc.*, **70** (1): 1-102.

Daly, R.A., 1950, Communication: *Amer. Jour. Sci.*, **248**: 741-43.

Folinsbee, R.E., Ritchie, W.D. and Stansberry, G.F., 1957, The Crowsnest Volcanics and Cretaceous Geochronology. *Alberta Soc. Petrol. Geol.* Guide Book, (in press).

Frebold, H., 1953, Correlation of the Jurassic of Canada. *Bull. Geol. Soc. Amer.*, **64** (10): 1229-1246.

Hume, G.S., 1953, Lower Mackenzie River area, Northwest Territories and Yukon. *Geol. Surv. Can.*, Mem. **273**.

Kay, Marshall, 1951, North American geosynclines. *Geol. Soc. Amer.*, Mem. **48**.

McLearn, F.H., 1953, Correlation of the Triassic formations of Canada. *Bull. Geol. Soc. Amer.*, **64** (10): 1205-1228.

Peterson, James A., 1957, Marine Jurassic of Northern Rocky Mountains and Williston basin. *Bull. Amer. Assoc. Petrol. Geol.*, **41** (3): 399-440.

Rutherford, R.L., 1951, Structural interpretation of loci of petroliferous parts of Devonian reefs in Edmonton area, Alberta, Canada. *Bull. Amer. Assoc. Petrol. Geol.*, **35** (4): 844-853.

Schuchert, Charles, 1955, (Posthumous edited by Dunber C.O.). Atlas of Paleogeographic maps of North America. John Wiley & Sons, New York.

Walcott, C.D., 1928, Pre-Devonian Palaeozoic formations of the cordilleran provinces of Canada. *Smithsonian Misc. Coll.*, **75**: (5).

Warren, P.S., 1951, Rocky Mountain Geosyncline in Canada. *Trans. Roy. Soc. Can.*, **45** (4): 1-10.

Warren, P.S. and Stelck, C.R., 1954, Stratigraphic significance of the Devonian coral reefs of Western Canada. *Bull. Amer. Assoc. Petrol. Geol.* Symposium, Western Canada Sedimentary basin, Tulsa, Oklahoma, pp. 214-218.

Warren, P.S. and Stelck, C.R., 1956, Significance of the Cretaceous fossil succession of Western Canada. *XX International Geological Congress*, Mexico City. (in press).

Webb, JB., 1954, Geological history of Plains of Western Canada. *Amer. Assoc. Petrol. Geol.* Symposium, Western Canada Sedimentary basin, Tulsa, Oklahoma, pp. 3-28.

EXPLANATION OF PLATES

PLATE I

Map 1. Paleogeographic map showing extent of Late Beltian and Late Lower Cambrian seas.

Map 2. Paleogeographic map showing extent of Early Upper Cambrian and Late Upper Ordovician (Richmond) seas.

PLATE II

Map 3. Paleogeographic map showing extent of Early Middle Silurian (Clinton) and Late Middle Devonian (*Stringocephalus* zone) seas.

Map 4. Paleogeographic map showing extent of Mid-Upper Devonian (D2) (*T. cyrtiniformis* zone) and Lower Mississippian (Middle Kinder-hook) seas.

PLATE III

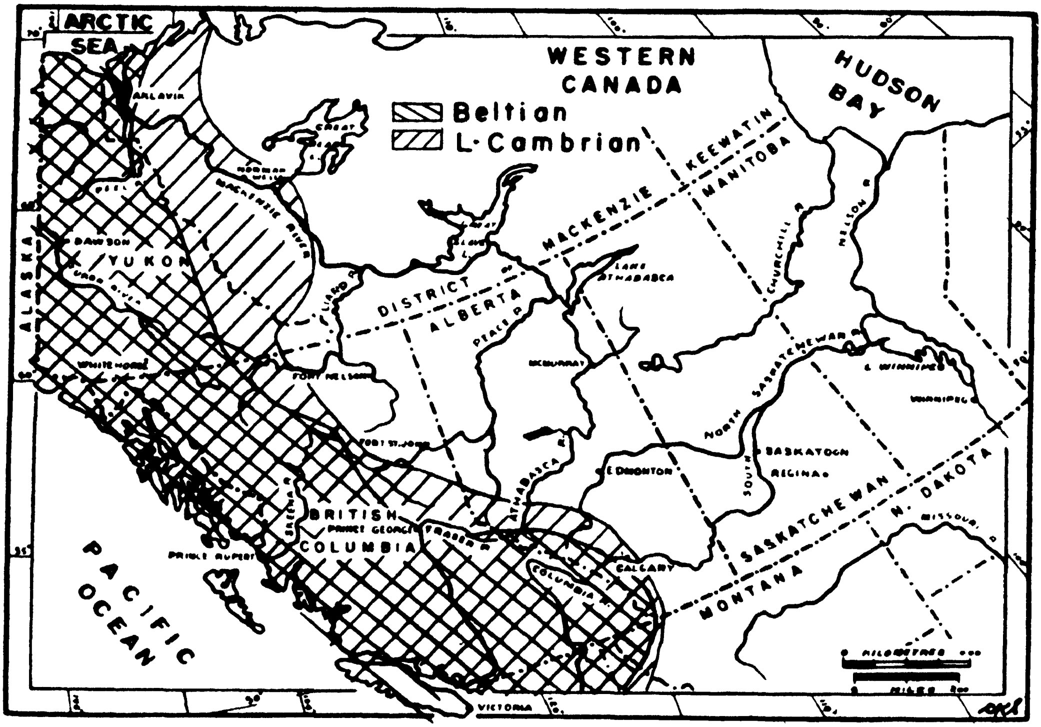
Map 5. Paleogeographic map showing extent of Early Middle Permian and Lower Triassic (*Flemingites* zone) seas.

Map 6. Paleogeographic map showing extent of Middle Triassic (Late Ladinic) and Early Lower Jurassic (Hettangian) seas.

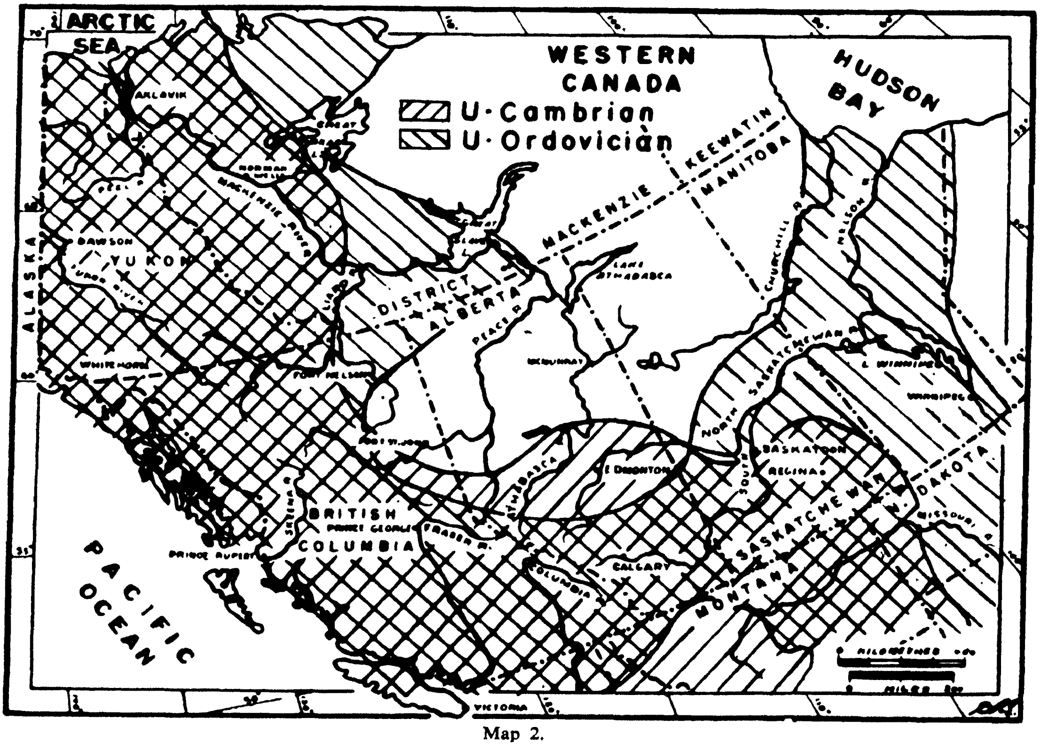
PLATE IV

Map 7. Paleogeographic map showing extent of Early Upper Jurassic (Oxfordian) and Earliest Lower Cretaceous (Infra valanginian) seas.

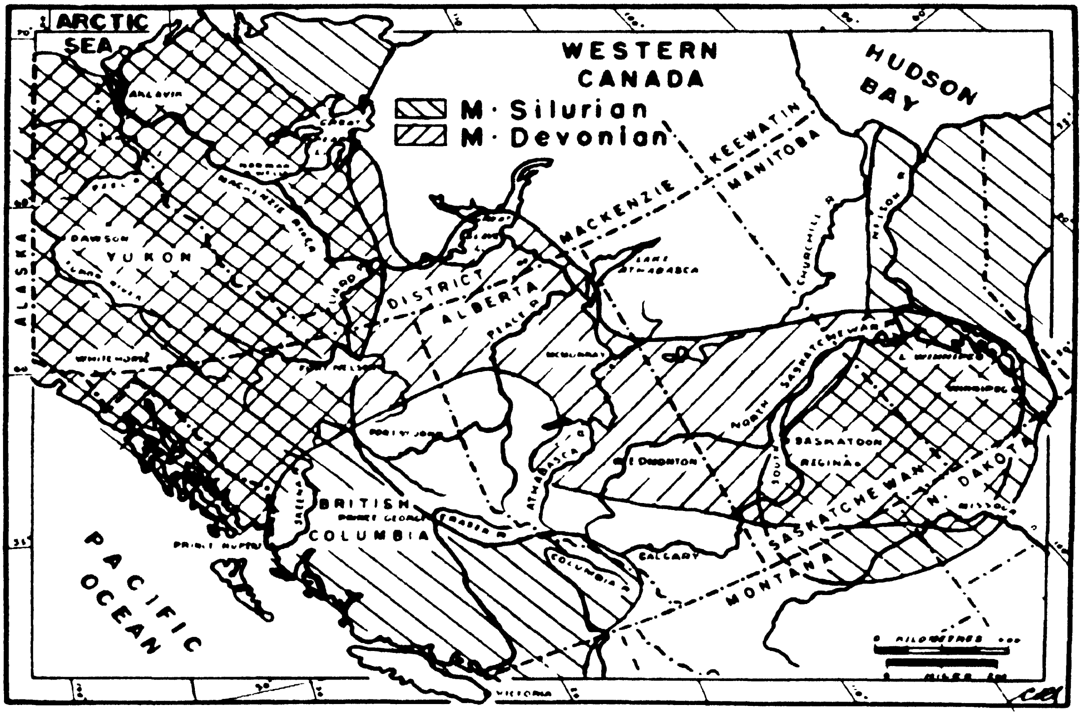
Map 8. Paleogeographic map showing extent of Early Lower Cretaceous (Valanginian) and Mid-Lower Cretaceous (Upper Neocomian).


ARCTIC SEA
WESTERN CANADA
HUDSON BAY
Beltian
L-Cambrian
ALASKA
AKLAVIK
DAWSON
YUKON
WHITE HORSE
MACKENZIE RIVER
DISTRICT MACKENZIE
KEEWATIN
MANITOBA
ALBERTA
LAKE ATHABASCA
PEACE R.
FORT NELSON
FORT ST. JOHN
CHURCHILL R.
NELSON R.
SASKATCHEWAN R.
L. WINNIPEG
WINNIPEG
NORTH SASKATCHEWAN
SOUTH SASKATCHEWAN
SASKATOON
REGINA
EDMONTON
CALGARY
SASKATCHEWAN
N. DAKOTA
MONTANA
MISSOURI R.
BRITISH COLUMBIA
PRINCE GEORGE
FRASER R.
COLUMBIA R.
PRINCE RUPERT
SKEENA R.
PACIFIC OCEAN
VICTORIA
KILOMETRES
MILES

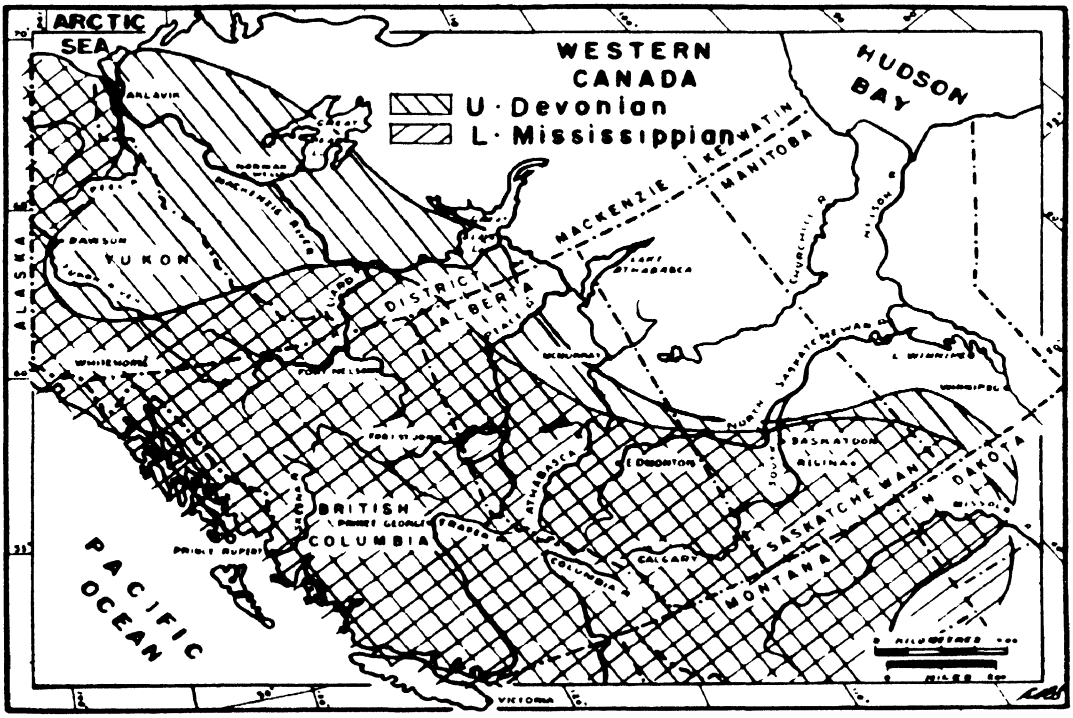
Map 1.


ARCTIC SEA
WESTERN CANADA
HUDSON BAY
U-Cambrian
U-Ordovician
ALASKA
AKLAVIK
DAWSON
YUKON
WHITE HORSE
MACKENZIE RIVER
DISTRICT MACKENZIE
KEEWATIN
MANITOBA
ALBERTA
LAKE ATHABASCA
PEACE R.
FORT NELSON
FORT ST. JOHN
CHURCHILL R.
NELSON R.
SASKATCHEWAN R.
L. WINNIPEG
WINNIPEG
NORTH SASKATCHEWAN
SOUTH SASKATCHEWAN
SASKATOON
REGINA
EDMONTON
CALGARY
SASKATCHEWAN
N. DAKOTA
MONTANA
MISSOURI R.
BRITISH COLUMBIA
PRINCE GEORGE
FRASER R.
COLUMBIA R.
PRINCE RUPERT
SKEENA R.
PACIFIC OCEAN
VICTORIA
KILOMETRES
MILES

Map 2.


ARCTIC SEA
WESTERN CANADA
▧ M · Silurian
▨ M · Devonian
HUDSON BAY
KEEWATIN
MANITOBA
MACKENZIE
DISTRICT
ALBERTA
YUKON
DAWSON
AKLAVIK
ALASKA
WHITEHORSE
FORT NELSON
FORT ST JOHN
LAKE ATHABASCA
McMURRAY
EDMONTON
CALGARY
SASKATOON
REGINA
L. WINNIPEG
WINNIPEG
NORTH SASKATCHEWAN
SASKATCHEWAN
N. DAKOTA
MONTANA
BRITISH COLUMBIA
PRINCE GEORGE
PRINCE RUPERT
VICTORIA
PACIFIC OCEAN
MACKENZIE RIVER
LIARD
PEACE R
ATHABASCA
FRASER R
COLUMBIA R
SOURIS
CHURCHILL R
NELSON R
KILOMETRES
MILES

Map 3.


ARCTIC SEA
WESTERN CANADA
▧ U · Devonian
▨ L · Mississippian
HUDSON BAY
KEEWATIN
MANITOBA
MACKENZIE
DISTRICT
ALBERTA
YUKON
DAWSON
AKLAVIK
ALASKA
WHITEHORSE
FORT NELSON
FORT ST JOHN
LAKE ATHABASCA
McMURRAY
EDMONTON
CALGARY
SASKATOON
REGINA
L. WINNIPEG
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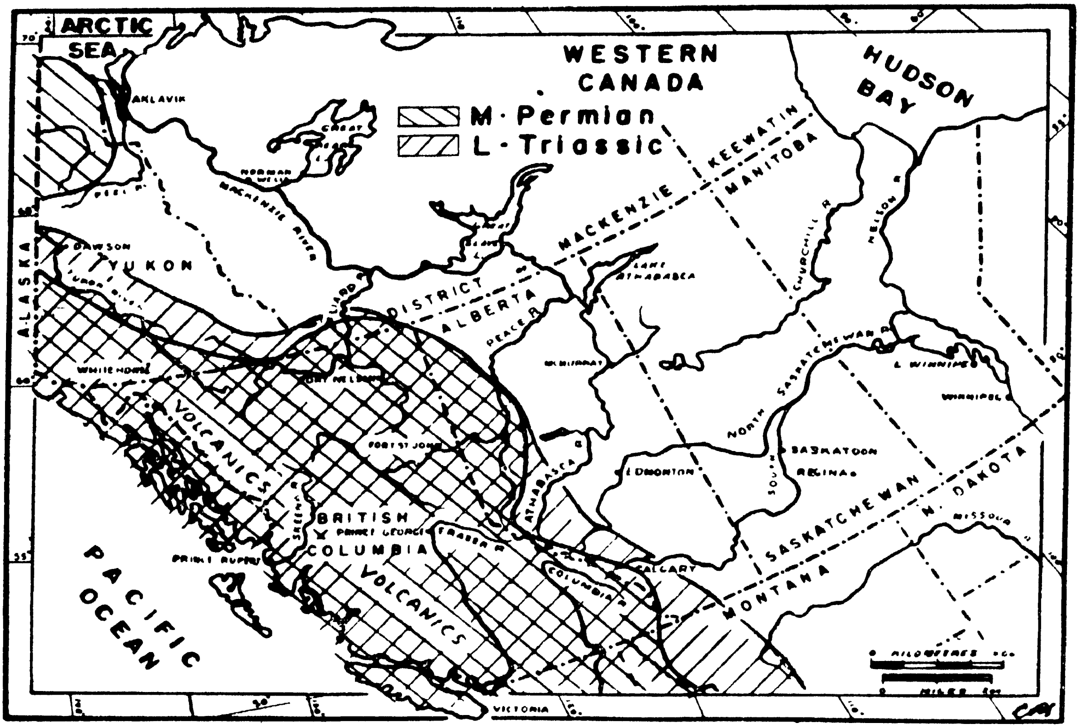
NORTH SASKATCHEWAN
SASKATCHEWAN
N. DAKOTA
MONTANA
BRITISH COLUMBIA
PRINCE GEORGE
PRINCE RUPERT
VICTORIA
PACIFIC OCEAN
MACKENZIE RIVER
LIARD
PEACE
ATHABASCA
FRASER
COLUMBIA R
SOURIS
CHURCHILL R
NELSON R
KILOMETRES
MILES

Map 4.


ARCTIC
SEA
WESTERN
CANADA
HUDSON
BAY
▧ M · Permian
▨ L · Triassic
AKLAVIK
GREAT BEAR L
NORMAN WELLS
MACKENZIE RIVER
PEEL R
DAWSON
YUKON
YUKON RIVER
ALASKA
KEEWATIN
MANITOBA
MACKENZIE
DISTRICT
ALBERTA
LIARD R
GREAT SLAVE L
PEACE R
L ATHABASCA
McMURRAY
CHURCHILL R
NELSON R
SASKATCHEWAN R
L WINNIPEG
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SASKATOON
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MISSOURI
MONTANA
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COLUMBIA R
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VOLCANICS
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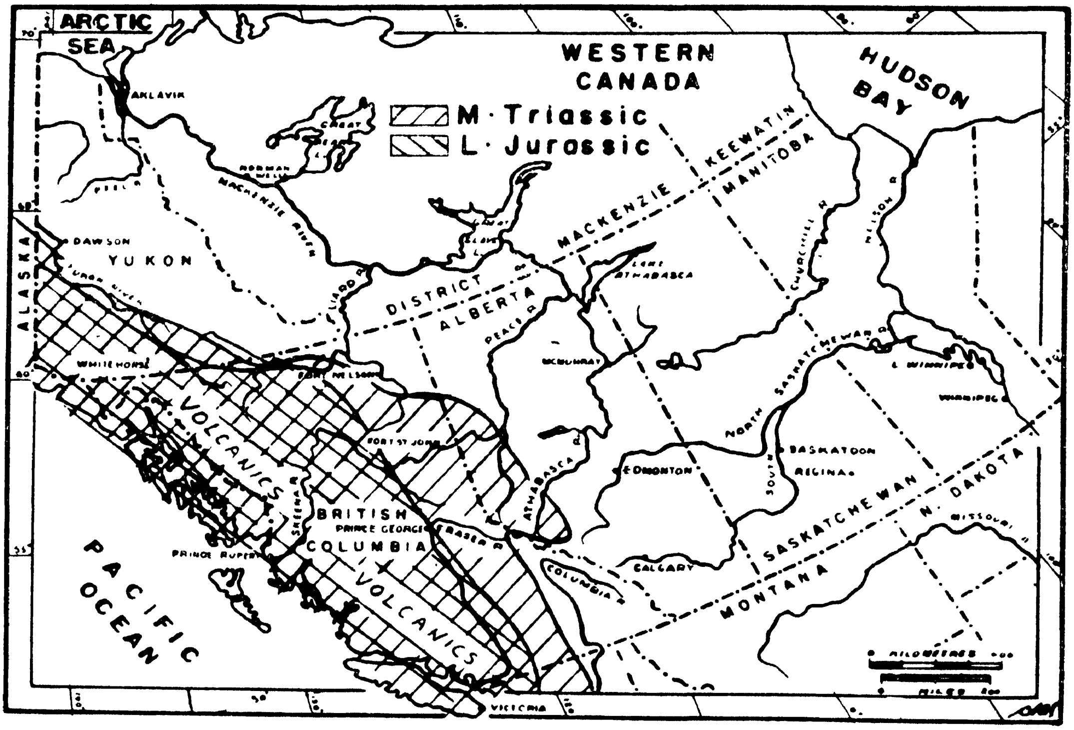
PRINCE GEORGE
COLUMBIA
SKEENA R
PRINCE RUPERT
VOLCANICS
PACIFIC
OCEAN
VICTORIA
KILOMETRES
MILES
70°
60°
55°

Map 5


ARCTIC
SEA
WESTERN
CANADA
HUDSON
BAY
▨ M · Triassic
▧ L · Jurassic
AKLAVIK
GREAT BEAR L
NORMAN WELLS
MACKENZIE RIVER
PEEL R
DAWSON
YUKON
YUKON RIVER
ALASKA
KEEWATIN
MANITOBA
MACKENZIE
DISTRICT
ALBERTA
LIARD R
GREAT SLAVE L
PEACE R
L ATHABASCA
McMURRAY
CHURCHILL R
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CALGARY
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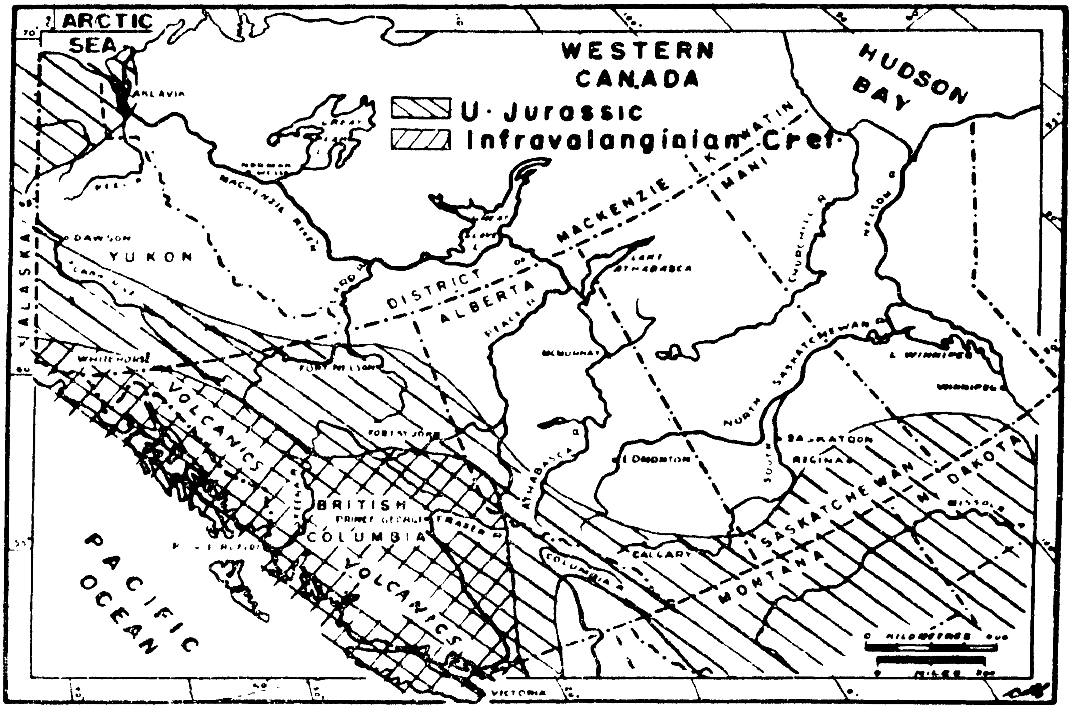
WHITEHORSE
FORT NELSON
FORT ST JOHN
VOLCANICS
BRITISH
PRINCE GEORGE
COLUMBIA
SKEENA R
PRINCE RUPERT
VOLCANICS
PACIFIC
OCEAN
VICTORIA
KILOMETRES
MILES
70°
60°
55°

Map 6.


ARCTIC
SEA
WESTERN
CANADA
HUDSON
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U·Jurassic
Infravalanginian Cret.
ALASKA
YUKON
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WHITEHORSE
DISTRICT OF MACKENZIE
KEEWATIN
MANITOBA
ALBERTA
BRITISH
COLUMBIA
PRINCE GEORGE
VOLCANICS
PACIFIC
OCEAN
FORT NELSON
FORT ST JOHN
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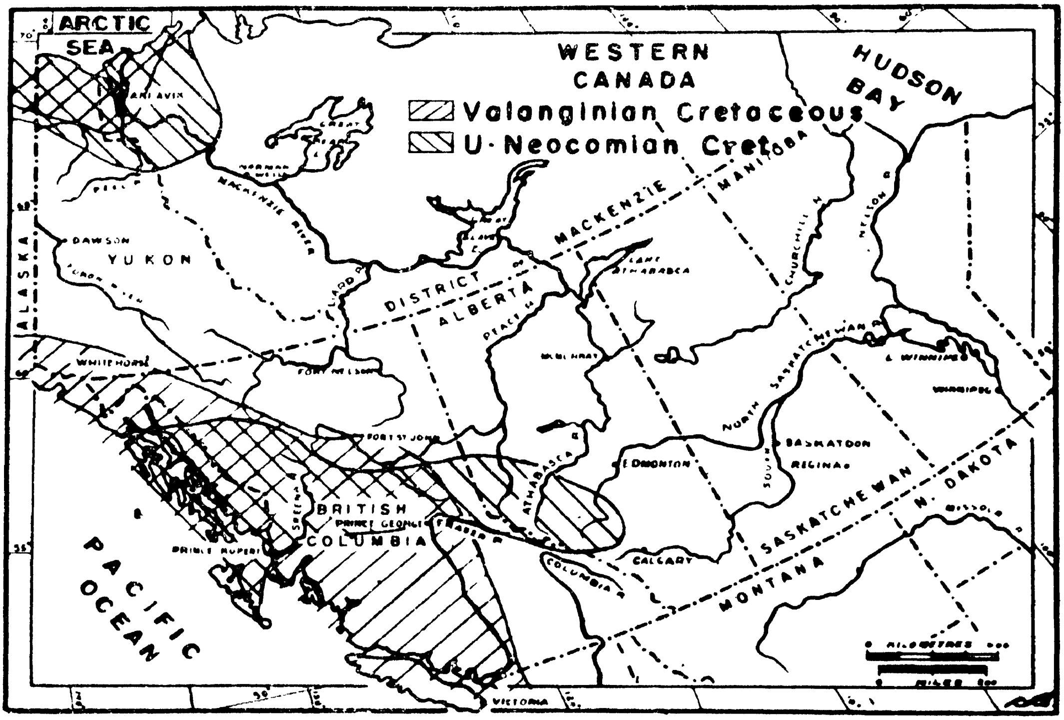
VICTORIA
WINNIPEG
L. WINNIPEG
LAKE ATHABASCA
MACKENZIE RIVER
ATHABASCA
FRASER R
COLUMBIA R
KILOMETRES
MILES

Map 7


ARCTIC
SEA
WESTERN
CANADA
HUDSON
BAY
Valanginian Cretaceous
U·Neocomian Cret.
ALASKA
YUKON
DAWSON
WHITEHORSE
DISTRICT OF MACKENZIE
MANITOBA
ALBERTA
BRITISH
COLUMBIA
PRINCE GEORGE
PRINCE RUPERT
PACIFIC
OCEAN
FORT NELSON
FORT ST JOHN
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CALGARY
SASKATOON
REGINA
SASKATCHEWAN
MONTANA
N. DAKOTA
VICTORIA
WINNIPEG
L. WINNIPEG
LAKE ATHABASCA
MACKENZIE RIVER
ATHABASCA
FRASER R
COLUMBIA R
KILOMETRES
MILES

Map 8.

PACIFIC TYPE OF STRUCTURE OF THE EARTH'S CRUST AND PROBLEMS PERTAINING TO THE ORIGIN AND GROWTH OF CONTINENTAL MASSES†

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(Abstract)

1. The report outlines the main principles of researches on the structure and development of the Earth's crust, published by the authors during the period of 1948-1957. The scheme suggested has quite a lot in common with the hypotheses of V.A. Magnitzky (USSR, 1953) and J.T. Wilson (Canada, 1948-1957).

2. The gravimetric map of the World (1 : 22,000, 000) and gravimetric maps of Eurasia, Africa and North America (1:6,000,000), compiled by the authors in Bouguer reduction according to materials available in world literature, display clearly the difference between the Pacific and continental types of structure of the crust. Gravity anomalies in this reduction reflect with a precision up to 50-100 milligals the depth of the Mohorovicic discontinuity, separating the crust (sial) from the heavy ultrabasic substratum (sima). This correlation has been established by a comparison of gravity anomalies with the data on the thickness of the crust in Middle Asia and in other points obtained by the seismic refraction method and other methods.

3. Considering geophysical data the systematics of large structural units of the crust can be presented as follows:

A. Oceanic platforms — platform regions, which occupy 40 per cent of the surface of the globe in those parts of the Pacific, Atlantic, Indian and Northern Arctic oceans where the depth of the sea exceeds 4000 m. They are characterized by a small thickness of the crust (4-13 km.), high positive gravity anomalies in Bouguer reduction (from + 200 to + 450 mgl.) and are, probably, closest to that original uniform structure of the external parts of the solid mantle, which preceded the formation of continental masses.

B. Modern geosyncline regions subdivided in their turn into: a) regions of Cainozoic (Alpine) folding and volcanism in the Pacific and Alpine-Himalayan belts, consisting of geoanticlines and geosynclinal and internal troughs. Geoanticlines are usually characterized by gravity minima and a greater thickness of the crust (up to 75 km. in Hindu Kush range and on Pamir, where gravity anomalies come to -400 up to -500 mgl.); b) median masses with a continental structure of the crust (sections of Paleozoic and Pre-Cambrian folding-Iranian, Hungarian and other masses); c) foredeeps, originating mainly on Pre-Cambrian and Paleozoic platforms—Subalpino, Subcarpathian, Subhimalayan, etc.; they are characterized mostly by negative (up to -50 mgl.) anomalies in Bouguer reduction and a considerable thickness of the crust; d) foredeeps formed on the margins of oceanic platforms—abyssal hollows of Kurile-Kamchatka, the Philippines, Puerto-Rico, etc. Many of these troughs are characterized by positive anomalies in Bouguer reduction which indicate a small thickness of the crust, however, they have big negative anomalies in isostatic reduction and are highly seismic; e) median masses of deep internal basins, possessing a crust structure similar to the structure of the ocean floor, but with a greater thickness of the sedimentary veneer; their anomalies in Bouguer reduction come to + 150 mgl. to + 400 mgl. These are masses of deep depressions of the Mexican gulf, Caribean sea, Mediterranean sea, Banda sea in Indonesia, sea of Okhotsk, sea of Japan and the Bering sea. Paleogeography provides proofs of a lengthy association of the sea basins to these depressions, which have been centres of sea transgressions, invading from time to time the adjoining land.

C. Platform regions. They are characterized by a continental structure of the crust and Bouguer anomalies from + 50 mgl. up to + 500 mgl. Within the present platforms it is possible to distinguish regions of Mesozoic (Pacific), Upper Paleozoic

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† Presented by Dr. E.V. Karus, U.S.S.R.

(Hercynian), Lower Paleozoic (Caledonian) and Pre-Cambrian (subdivided into several cycles) folding. All these platform regions correspond to former geosyncline belts which originated as early as Pre-Cambrian and which experienced a closure during different geological periods. Pre-Cambrian platforms (shields, plates) are cores of continental masses of the sial, which were growing at the expense of later zonal annexations owing to folding and injection of a great number of granitic intrusions.

4. The material of the crust (igneous rocks as well as sedimentary, formed by their destruction) is being built up gradually during the entire geological history of the development of the Earth, owing to the ascent of magma from the depths of the solid peridotite mantle. Magmatic acid (granitic, close to the eutectic quartz-alkaline feldspar, etc.), alkaline (close to the eutectic nepheline-feldspar, etc.), medium (of andesitic composition) and basic (basaltic, close to the eutectic plagioclase-pyroxene) melts have a temperature of melting much lower than peridotite and are segregated in the ultrabasic substratum by smelting of eutectoid mixtures. The source of energy leading to the local smelting of eutectics lies in radioactive heat and the energy of mechanical processes displayed in earthquakes at a depth of 60-800 km. The ascent of magma to the surface of the Earth proceeds along deep fractures both under the influence of tectonic stresses and owing to a lesser density of these melts as compared to the density of the simatic shell.

5. Several stages can be traced in the development of geosynclinal regions. The earliest stage corresponds to the origin of fractures on the oceanic platforms (for instance the Murray fracture in the Eastern part of the Pacific ocean) and the formation of nearly straight submarine mountain ranges and island chains owing to the accumulation of volcanic material arriving from a great depth. Such are the Hawaii islands, the zone of Kermadec and Tonga islands on the continuation of New Zealand structure, etc. The next stage of development is illustrated by island arcs and archipelagoes like Indonesia. In the intervals between wide belts of the sial, formed along geoanticlines, there still have been at this stage less reworked relics of the original crust—median masses of deep internal basins of "B" type. The further process of rework in the structure of the crust, its crumpling, disintegration and injection of magma brings about a closure of geosyncline systems and the formation of a mature continental platform or shields.

CONTINENTAL DRIFT AND THE PRESENT VELOCITY OF SHIFT OF THE CONTINENTAL MARGIN OF EASTERN ASIA†

TING YING H. MA

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(Abstract)

From coral data it can be traced that an ancient continental mass of Laurasiafrica was separated into the present major continents which have reached their present relative positions through widening of the Arctic, Atlantic and Indian Oceans. Meanwhile the continent of Australia shifted toward Southeast Asia with counter-clockwise rotation. The motion of the Americas toward the Pacific caused the orogenic belts of the marginal tectonic complex on their west coast. The motion of two Americas against each other caused the orogenic belts of the West Indies intercontinental tectonic complex. The clockwise rotation of Africa from India against Europe caused the orogenic belts of the Mediterranean intercontinental tectonic complex. The motion of Asia into the Pacific resulted in (1) the orogenic belts of the East Indies intercontinental tectonic complex against the northwestward motion of Australia, (2) the orogenic belts of the Himalaya-Assam intercontinental tectonic complex against the held stable Deccan Massif and (3) the orogenic belts of the marginal tectonic complexes represented by the island chains and geanticlinal ridges in the Western Pacific. The shear planes represented by present earthquake foci on the margin of a continent or between two crustal masses are the yet weak zones over which crustal masses were overthrusted during the last sudden total displacement of the solid earth shell that shook up the the crustal masses. There is a slow motion of crustal masses over these shear planes due to the rotation of the earth and the amount of lateral shift can be determined from the amount of uplift because the angle of the shear plane is permanent. From the gradual rise of the continental margin of Eastern Asia it can be calculated that there is a 30 cm. shift toward the Pacific per century at present.

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† Published in the First Series of private research publications by Ting Ying H. Ma, *Research on the Past Climate and Continental Drift*, **12** : October, 1957.

GEOTECTONICS OF THE PACIFIC: DIVISION OF THE NORTHERN PACIFIC INTO TWO OCEANIC PARTS, AND THE TECTONIC COMPARISON OF BOTH THE CONTINENTS, WESTERN AND EASTERN

SHINGO EHARA

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INTRODUCTION

The Northern Pacific may be divided into two oceanic parts, a western and an eastern, by tectonic lines, represented by the Emperor Sea Mounts and the Hawaiian Chain. The former runs approximately NNW. along the Emperor Sea Mounts while the latter trends WNW.-ESE. carrying large volcanoes at its eastern end. They join together west of Midway Island.

The most remarkable tectonic differences between the western and eastern continents are: In California, where shallow earthquakes predominate, both, trenches as well as deep-earthquake zones are missing. In eastern Asia, however, there are the Nippon and Mariana trenches associated with deep-earthquake zones; and furthermore the Ryukiu and Philippine trenches accompanying deep-earthquake zones which occupy the inner side of the former. The tectonic difference between the two continents may be mostly due to the strength of the orogenic force from the southern Pacific which may be verified by the tectonic structure of the Pacific.

In the Japanese Is. we have experienced that the geotectonics of the Is. was subjected to lateral thrusts coming as well from the Pacific as from the Continent. Going further south along the Nippon and the Mariana trenches we reach the Caroline Sea, where is found not only the direction of the Pacific movement which has brought about the Yap-Palau echelon and the Halmahera orogene, but in the Polynesian chain we also encounter Dana's axis of the Pacific, manifesting the tectonic trend of the western Pacific.

WESTERN PACIFIC

THE JAPANESE TRANSVERSE RIFT AND THE SHICHITO DEEP-EARTHQUAKE ZONE

In Eastern Asia there are two parallel zones of deep-earthquakes associated with the trenches lying on the inner and the outer side. The outer zone lies along the boundary between the sima crust exposed on the Pacific floor and the border land of the Asiatic continent, represented by the Nippon, Mariana and Chishima trenches. The inner zone lies between the borderland and the Asiatic continent represented by the Philippine and the Ryukiu trenches. Probably these two zones might have been formed at the same time but their relation has not been confirmed yet in detail, therefore one of the outer trenches may here be discussed in detail.

Shichito deep-earthquake zone: The Shichito trench, running north-south, delineates an arc with the convex side toward the west, between Ogasawara Is. and Cape Inubo. It comes into contact with the Shichito batholith underlying the Shichito submarine ridge. The fact suggests that the Shichito trench, whose depth reaches over 9,000 m, was subjected to the orogenic force coming from the Pacific floor, which presses upon the Shichito batholith.

The Shichito batholith which is subjected to this orogenic force over a distance of 500 km., between Ôshima I. and the Sôfu rock, might have produced the shearing plane running NNW.-SSE. through which the Fuji volcanic zone erupts. At that time, on the one hand, the tapering apex of the Shichito batholith pushed into the outer zone of central Honshu and bended the Median line forming the Toyohashi-Suwa arc; on the other-hand, the transverse rift (Itoigawa-Nirazaki-Sunto line) was made between the Kwanto range and the Mino-Hida plateau, along which the Kwanto range was horizontally moved over about 60 km. northward by the orogenic force of the Pacific and formed on the latter the echelon of the Nippon Alpine range Hida, Kiso, and Akaishi.

The transverse rift trends parallel to the Shichito deep-earthquake zone extending north-north-west and by transversing the Japan Sea may reach the continent.

The closest connection may be suspected between the transverse rift and the Shichito deep-earthquake zone. The transverse rift may form a fault plane dipping west, extending into the earth interior; first after advancing some distances to the west it may diverge to a fault plane at a depth of 250 km. which corresponds to one of the intermediate earthquake zones, then it may descend steeply toward the west and reach a depth of over 400 km. in the deep-earthquake zone.

The transverse rift and the deep-earthquake zone suggest, that in the beginning of the Miocene the Pacific orogenesis was powerful and profound; on the one hand it built up an echelon of Nippon Alpine ranges at the surface of the earth, on the otherhand, the fault plane which declines away from the Pacific and reaches till 400 km. and more in the depth where deep-earthquakes originated.

EASTERN PACIFIC

From Alaska via British Columbia to California there are no marked oceanic deeps or troughs. The present structure of California is largely determined by block faulting, although older folded structures exist, and folding appears to be still in progress in the Coast Range. In the Coast Range the most conspicuous and most active faults are strike slip features associated with a characteristic rift topography. The main fault of these is the San Andreas Fault, with several branches and parallel structures.

SAN ANDREAS RIFT

The San Andreas Rift whose trend is northwest to southeast, starts from the Cape of Pt. Arena running southeast through the San Francisco Peninsula, and passing through the neighbourhood of Stanford extends further south and reaches Salton Lake. The entire length is appr. 500 miles, including an extension into the sea, which is out of sight, and the depth of the fault plane may be said to reach 100 km.

With regard to the origin of the rift, B. Willis gives the following explanation: "Since the strike of the San Andreas is about northwest-southeast, the effective stress should impinge upon the fault plane from south or north approximately." In this determination he may be a little too careful, but the effective stress must have come from the Pacific floor which lies to the south of the rift. According to Gutenberg and Richter, the San Andreas is accompanied by a zone of shallow earthquakes but not of deep or intermediate ones.

The San Andreas whose depth does not exceed 100 km., is unable to accompany a deep or intermediate earthquake zone and trench; however, in Eastern Asia, the transverse rift which depth reaches approximately to 500 km., might have caused the formation of the deep or intermediate earthquake zone and trench. The shallower depth may be due to the weakness of the stress coming from the Pacific, but the deeper to the strong one coming from the Pacific floor.

SUBMERGENCE OF THE SOUTHERN CONTINENT

According to Gutenberg and Richter, in the southern Pacific shallow earthquakes predominate around the Easter Is., which on the one hand extends toward the west occupying the south of the Polynesian chain, while on the other side it approaches the east of New Zealand. If the zone of shallow earthquakes is the scope of the old continent it might have occupied 1/3 of the southern Pacific. In the submergence, compression might have been caused around the southern Pacific, especially in the 3 directions, east, west and north-west; to the east the Andes are pushed toward the Brazilian shield, and the trenches at the foot of the Andes might have increased the depth in great magnitude, probably extending the fault plane dipping east into the earth interior which is associated with the deep and intermediate-earthquake zones; to the west, however, the borderland of Australasia is pushed toward Australia; wherein the compression of New Caledonia, New Hebrides, Solomon and Fiji Is. Pressure from the Pacific, as Andrews once mentioned, might have arisen; and the trenches of Tonga-Kermadec might have increased the depth in great magnitude, probably extending the fault plane dipping west into the interior of the earth, which is associated with as well the deep as the intermediate earthquake zones.

In the north-west the sima crust, exposed on the Pacific floor, is subjected to compression, and produced many fissure eruptions which are represented by the Polynesian and the Caroline chains. Beyond the tropics, the compression extended itself to the north-west Pacific toward Japan and Chishima, where orogenesis, the deepening of trenches accompanied by deep-earthquake zones, is strikingly developed.

REFERENCES

Andrews, E.C., 1921, The Framework of the Pacific. *Proc. First Pan-Pacific Sc. Cong.* Hawaii, **3**: 875-881.

Benson, W.N., 1924, The Structural Features of the Margin of Australasia. *Trans. New Zealand Inst.* **55**: 99-137.

Dana, J.D., 1845, Manual of Geology. p. 37.

Daly, R.A., 1916, Problems of the Pacific Islands. *Amer. Jour. Sc.* (4th series) **41**.

Dietz, R.S., 1954, Marine geology of Northwestern Pacific: Description of Japanese Bathymetric chart 6901. *Bull. Geol. Soc. Amer.* **65**: (12) Part 1, 1199-1224.

———, and Menard, H.W., 1953, Hawaiian Swell, deep and arch, and Subsidence of the Hawaiian Islands. *Jour. Geol.* **61**: 99-113.

Ehara, S., 1953-54, Geotectonics of the Pacific concerning the Japanese Is., I-IV. *Jap. Jour. Geol. Soc.*, **59-60**.

———, 1955-56, Geotectonics of the Pacific with reference to South-Western Japan. I-III. *Ibid.* **61-62**.

, 1957, Geotectonics of Northwestern Honshu, Hokkaido & Chishima Islands. *Ibid.* **63**, No. 737.

Ehara, S., 1957, Geotectonics of the Yap-Palau echelon brought about by the Pacific movement. *Ibid.* **63**.

Gutenberg, B. & Richter, C.F., 1949, Seismicity of the Earth. Princeton Univ. Press.

Marshall, P., 1923, General statement on the structure of the Pacific Region. *Proc. Pan-Pacific Sc. Cong.* Australia, p. 730.

Suess, E., 1909, The Face of the Earth. **4**.

Willis, B., 1926, Geotectonics of the Pacific. *Proc. Third Pan-Pacific Sc. Cong.* Tokio, **1**: 258-369.

——— and Willis, R., 1929, Geologic structures. Second Edition, McGraw-Hill Book Company.

PACIFIC INFLUENCES IN THE TECTONICS OF EASTERN AUSTRALIA

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(Abstract)

The word "Pacific" is used herein for geological attributes related to the present major features of the Pacific Ocean and its margin.

In Upper Proterozoic time tillites and rudaceous-arenaceous sediments were widespread. The tillites were in part deposited in geosynclinal troughs and the implication of both facies is that at that time parts of Australia were cratonic, while other belts were geosynclinal.

This distinction is reflected in the present continental structure, which therefore bears a certain resemblance to that of the Upper Proterozoic. In Lower Cambrian times submarine basic lavas and tuffs in Victoria represent a volcanic pile in a geosyncline flanked by land on the south (Tasmanian craton), on the north-east, and probably on the north-west beneath the Murray Basin. These are typical of the thick ophiolitic facies, such as is seen in northern Syria (described by Dubertret). The existence of flanking pre-Cambrian blocks is seen in the wide distribution in Victoria of arenaceous-argillaceous beds containing much detrital tourmaline, felspar and quartz, derived from the north-east, also the Upper Ordovician is neritic in New South Wales.

The existence of Cambrian trilobitic limestones in Victoria and in the South Island of New Zealand demonstrates neritic facies and shows a structural high where New Zealand now exists, with sea between (Lower Ordovician graptolites are similar in Victoria and New Zealand). The broad pattern already bears a resemblance to the present.

Vulcanicity and igneous intrusions in Eastern Australia from Cambrian to Cenozoic show widely ranging magma types, but the distribution is always within the mobile eastern zone, suggesting a constant tectonic relationship with the main Pacific margin. It is suggested that the Devonian lamprophyric and the hypersthene dacitic magmas of Victoria were injected as a magmatic wedge from the direction of the Pacific.

Cenozoic volcanic trends and belts are clearly related with parallel features in the Tasman Sea, the Coral Sea and the Pacific margin.

The former extension of Australia towards the East is unquestioned. The present boundaries and the elevation of the Eastern Highlands tectonic, not due to isostatic uplift, so that the geological resemblances are a reflection over common tectonic origin geometrically related to the Pacific. The geological evidence indicates a thick stable shield lying to the west; a broad zone of thinner basement rock beneath the Great Artesian and Murray Basins; a complex geosynclinal zone on the east; and a subsided, probably thin sialic area beneath the Coral and Tasman Seas.

Thus the overall picture is in accord with the major tectonic elements of the Australasian region, and, with variations, this has been so since the Upper Proterozoic.

THE ROLE OF LATERAL FAULTING IN CIRCUM-PACIFIC OROGENY—IS THE PACIFIC BASIN ROTATING?

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(Abstract)

The geologic structure of the eastern shore of the Pacific Ocean from Baja, California, to a point off the Washington-Oregon coast is dominated by the San Andreas Fault and sub-parallel strike slip faults, right lateral in nature. The faulting in southeastern Alaska is also right lateral. The Denali fault in the Alaska Range appears to be right lateral as does the Nixon Fork-Iditarod fault. Right lateral faulting has been described from the Alaska Peninsula. Seismic evidence shows that much of the Aleutian Island faulting is right lateral. First motion studies by Hodgson show the Kamchatka-Kurile Arc to be largely right lateral in displacement. Benioff has demonstrated on the basis of distribution of aftershocks that the major faulting there is right lateral in sense and parallel to the Arc.

Gorshkov describes a tectonic pattern in this area that indicates that it is being deformed in shear by a dextral couple parallel to the arc.

Faulting in Japan is thought to contain a right lateral component parallel to the arc. The Alpine fault in New Zealand is right lateral and of a compatible direction.

It is therefore concluded that the Pacific Basin is rotating counter-clockwise with respect to the continents.

The cause of the movement is suggested as being a Coriolis force resulting from a convergent convection cell under the Pacific.

The present zone of orogeny extends inland in the United States and Alaska for 100 miles or more.

Old lines of faulting such as the Rocky Mountain Trench suggest that the orogenic zone was larger or extended further to the east than it now does. It is thought that this motion is very old and has been going on since before the end of Mesozoic time. The orogeny in a given place decreases as the continental crust forms and stiffens or as the orogenic cell decreases in size or drifts from place to place. It appears that the continents are growing at the expense of the Pacific Ocean basin.

The peripheral velocity of the rotation is in excess of 20 feet per century on the eastern side of the Pacific.

The primary structural geologic forms are lateral faults, with conjugate shears producing normal "tensional" faults or reverse faults, thrust faults and folds as compressional features. Volcanoes develop in the areas between "en-echelon" lateral faults or at the intersection of these with the tensional conjugate shears.

The structural picture is complicated by the intersection of submarine topographical alignements such as the Mendocine and Murray escarpments with the peripheral orogenic zone. The regions of intersection being the transverse ranges.

SEISMIC RESULTS IN RELATION TO THE ANDESITE LINE

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During the past ten years a considerable number of seismic measurements have been made in the Pacific Ocean. This work is continuing, and although much more measurement is needed to determine the geological structure in all parts of the ocean, it is possible to make some generalisation which fit with the results already published. These generalisations are of use in indicating where future work will be of most interest.

The seismic refraction method has produced the greater part of the information that exists about deep ocean sea-bed structure; reflections have assisted sometimes in interpreting the refraction results, but alone they are a weak tool because no bore-holes or outcrops are available to allow a determination of the vertical velocity profile. One of the important numbers that the refraction method provides is the velocity of compressional waves in the various rock layers, and much of generalisation that is possible with the sea seismic results depends on correlating similar velocities found at different places. It is unfortunate that each rock type does not possess a unique value for its compressional wave velocity. Limestones for example extend from about 2 Km/sec to 6 Km/sec, a range of values which overlaps severely those for volcanic rocks, for which 4.5 Km/sec has been found for Hawaiian lava flows, and values ranging up to over 8 Km/sec for basic rocks such as dunite. Since the seismic method can only measure travel times and velocities it can never postulate for certain what is the geological structure. What it does do is show the most probable structure and also restrict the field of geological speculation.

There appears to be a comparatively simple geological structure in the sea-bed beneath the deep Pacific ocean. This structure is represented by a layer within 1 or 2 Km of the sea-bed, in which the compressional wave velocity is 6.7 Km/sec (Raitt 1956, Gaskell and Swallow 1952, Eiby 1957, Officer 1955). The overlying material is partly low-velocity sediment which is from 0.1 to 1.5 Km thick, with a mean (obtained without regard to the distribution of observations, so that it tends to be weighted to the areas where there are most measurements) of 0.3 Km. There is evidence that a Layer 2 exists between this soft sediment and the 6.7 Km/Sec layer. The Layer 2 has been recorded with velocities ranging from 4.5-6.3 Km/Sec and its normal thickness averages about 1 Km. The seismic results do not indicate whether the Layer 2 extends down to the 6.7 Km/Sec layer, or whether it is a band of hard rock separating an upper and a lower layer of soft sediment. In some parts of the ocean basin refracted waves from a second layer are not observed because they are masked by the waves from the 6.7 Km/Sec layer, but evidence of a second layer is provided by a study of shear waves and of reflections (Gaskell and Swallow 1954).

When measurements are made near volcanic islands the 6.7 Km/Sec layer is deeper than normal and clear indications of Layer 2 are provided by first arrival refracted waves. For example, near the Hawaiian islands more than 2 Km of 4.5 Km/Sec material was observed, and laboratory measurements made on samples from Hawaiian lava flows suggest that in this case the Layer 2 is part of the root of the volcano. This view is supported by the fact that the Layer 2 decreases in thickness away from the volcanic island. If Raitts (1956) results on Layer 2 are divided into two groups those with velocity above 4.9 Km/Sec have an average thickness of 1.05 Km while those in the lower velocity group have an average thickness of 2.06 Km. The report does not state which stations are near islands, but it seems possible that the two groups correspond to the Gaskell and Swallow (1952) classification. It is possible that all Layer 2 is volcanic material, but although there are many sea-mounts which could be sources of supply it seems unlikely that volcanic material covers the whole ocean floor. It is much more likely that the layer 2 remote from features such as sea-mounts and islands is some form of cemented sediment. The velocities observed for layer 2 are not incompatible with limestone. If layer 2 is a band of hard rock about 0.1 Km in thickness underlain by 3.0 Km/Sec soft sediment, there will be a reduction in the depth of the 6.7 Km/Sec layer below the sea bed from an average 1.3 to one of 0.8 Km; the two extreme profiles are:—

Soft sediment	2.0 Km/Sec	0.3	0.3 Km
Layer 2	5.5 Km/Sec	1.0	0.1 Km
Soft sediment	3.0 Km/Sec	0.0	0.4 Km
		1.3	0.8

The value of 6.7 Km/Sec for the compressional velocity in the first well marked layer below the sea-bed is found in the Atlantic and Indian ocean as well as in the Pacific (Ewingctal 1954, Raitt 1956, Gaskell and Swallow 1951, 1952, 1953). The widespread occurrence of a material showing the same seismic properties lead to the belief that the 6.7 Km/sec layer is some crystalline rock which is a fundamental part of the earth's crust. There are physical reasons for believing that the material is crystalline rock rather than limestone. The strength of the refracted waves observed from the 6.7 km/sec layer are large compared with those observed in land refraction measurements or limestone. Limestone generally is layered, which tends to make it a poor carrier of seismic energy, and it often has shale breaks and faults which attenuate seismic waves by back scattering. Furthermore, laboratory experiments show that limestone has a greater attenuation factor than do crystalline rocks, and there is a tendency for the velocity in limestone to decrease with depth, so that refracted waved are made weaker by bending of energy downwards. It is probable that the 6.7 Km/sec is a layer of basic rock. The granites that are known do not possess velocities much in excess of 6 Km/sec.

The characteristic ocean bed structure has an 8.2 Km/sec velocity layer about 10-13 Km below the sea surface. This is quite different from the structure found beneath continents, where the Mohorovici discontinuity (the top of the 8.2 Km/sec layer) is at 30-40 Km below sea-level. Seismic measurements on continents show much greater variation in the velocity of the layer immediately above the 8.2 Km/sec layer and they also have much less regular depth of overburden.

The Challenger expedition made seismic measurements at two stations near the coast of the United States, to landward of the andesite line. These stations were in about 1500 m of water and there was no 6.7 Km/sec layer such as was recorded under similar conditions on the ocean side of the andesite line. Similar results were obtained at stations in the Southwest Pacific, north of New Zealand, where instead of 6.7 km/sec, velocities 5.8-6.0 km/sec were observed. The Challenger measurements were not carried too long enough distances to show the depth of the Moho, but Officer (1955) and Eiby (1957) have found that an 8.2 Km/sec layer exists about 18 Km below sea surface in this region. These observers also found a 6.0 Km/sec layer below 5.0-5.7 Km/sec material.

Only two measurements have been made in the Philippine sea, which is an interesting area because the water is as deep as the main Pacific ocean, and yet the area is to landward of the andesite line. The seismic measurements showed a layer with velocity 5.7 Km/sec to be within a few Kms of the sea-bed. The Moho was not reached, but the results suggest that the area is not typical oceanic, and that it may well be similar to the Southwest Pacific area to the north of New Zealand.

In the Indian ocean Challenger found results similar to those in the Pacific for Stations to the East of meridian through Ceylon. A station on a sea-mount showed that the bulk of the seamount was made of material in which the compressional wave velocity was 4.3 Km/sec, which is what would be found for one example near the Hawaiian Islands. At the Seychelles, which are made of granite, seismic results showed that the rock at the surface had a compressional wave velocity of 6-Km/sec, and that a considerable thickness of this rock existed.

It does appear then, that oceans and continents are different in their vertical rock profiles, and that the andesite line is a marker of seismic as well as of chemical significance. The andesite line, in fact marks the limit of the permanent ocean basins. There is, however, good reason to believe in extensive areas of an intermediate type of structure, in which the Moho is about 15-18 Km below sea surface and where probably considerable thicknesses of granitic rock are present.

REFERENCES

Raitt, R.W., 1956, *Bull. Geol. Soc. Amer.* **67**: 1623-1639.

Eiby, G.A., 1957, New Zealand D.S.I.R. *Geophysical Memoirs.*

Officer, C.B., 1955, *Trans. Amer. Geophys. Un.* **36**: 449-59.

Gaskell, T.F. and Swallow, J.C., 1954, paper presented at I.U.G.G. Rome Meeting.

Ewing, M., Sutton, G.H. Officer, C.B., 1954, *Bull. Seismol Soc. Amer.* **44** :21.

Gaskell T.F. and Swallow J.G., 1951, *Nature* **167** : 723.

Gaskell T.F. and Swallow J.C., 1952, *Nature* **170** : 1010.

Gaskell T.F. and Swallow J.C., 1953, *Nature* **172**: 535.

CONTINENTAL MARGIN OF THE SOUTHWEST PACIFIC: ADVANCING OR RETREATING?

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(Abstract)

Progressively younger fold-belts have been welded on to the eastern margin of Australia, apparently increasing the E-W width of the continent 2400 miles in 600 million years, which represents a mean rate of 0.25 inch or 6 mm. per year. In the terminology of Stille, these units (Eo-, Paleo-, Meso-, and Neo-Australia) represent successive belts of orthogeosynclinal character: the youngest is the present zone of deep sea trenches coinciding with the "Andesite Line" that marks the present limit of "continental" andesites against the true, thalassocratonic Pacific.

The problem arises in explaining the nature of the fairly deep marine basins that lie in the region between eastern Australia and the Andesite Line—the "Melanesian Subcontinent." There is ever-increasing evidence of paleogeographic nature, that these basins (at least, in part) represent former semi-continental areas that have been more or less recently fragmented and have suffered differential subsidence. Highly complex and varied submarine topography points to an involved history. Some observers therefore visualize a current break-down of the Melanesian region, rather than a progressive build-up.

However, paleontological evidence fails to identify any rocks older than younger Paleozoic in the central (New Caledonian) belt of islands; and nothing older than the Tertiary in the easternmost islands (Fiji, Tonga). The petrology of the older sediments in each belt gives no hint of earlier rocks of continental or granitic nature. Search by the writer and others has failed to uncover any secondary evidence of a long-lost Paleozoic or Precambrian basement here.

Seismic work at sea by Russell Raitt on Expedition CAPRICORN of the Scripps Institution of Oceanography in 1952-53 has shown that the typical subocean crustal thickness in the Fiji region is 10-20 km of basaltic characteristics, overlain by 1-2 km of sediment (demonstrated by coring, to consist essentially of reworked volcanic-type muds). Earthquake seismology over this area points to the same conclusion, viz. an absence of a thick acid rock continental-type basement. Gravity observations by submarine made by Columbia University in cooperation with the Royal Navy and Royal Australian Navy demonstrated a profile across the area which is entirely compatible with this data.

In conclusion, the Melanesian region shows evidence of progressive expansion to the east, at the expense of the true Pacific, but that repeated oscillations over the intervening area indicate "regeneration" of imperfectly differentiated and consolidated crust of intermediate thickness.

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† Presented by Dr. Roger Revelle.

SHALLOW SUBMERGED MARINE TERRACES OF SOUTHERN CALIFORNIA

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(Abstract)

Sounding profiles across the mainland shelf, island shelves, and bank tops of southern California show the presence of five separate flattenings that are interpreted as erosional marine terraces cut during times of low sea level of the Pleistocene Epoch. Similar terraces have been discovered recently in widely separated parts of the world, such as Japan, Guam, and the Persian Gulf, supporting the interpretation of their relationship to eustatic changes of sea level. A correlation diagram of the terraces of southern California shows that each one is deeper around offshore islands and banks than off the mainland; this is attributed to regional warping that from other evidence is believed to have begun in Late Miocene time. The warping indicated by the deepest terrace, at the shelf edge, amounts to about 140 feet per 100 miles.

Symposium: *Mesozoic Orogeny in the Pacific*

Convener: G. W. GRINDLEY (New Zealand)

MESOZOIC OROGENIES IN NEW ZEALAND

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(Abstract)

The New Zealand geosyncline, a subsiding trough that probably extended east of southern New Zealand to Chatham Island and north-west of Auckland peninsula to New Caledonia and New Guinea, was a major tectonic feature of the late Paleozoic and early Mesozoic in the south-west Pacific. In the Permian, the geanticlinal ridge west and south of this geosyncline was capped by active volcanoes, that supplied fresh volcanic detritus to the Permian sediments and built up thick volcanic accumulations on the subsiding flanks of the geanticline, Volcanism, at first mainly andesitic and basaltic, changed to andesite-dacite-rhyolite in the Triassic, and became practically extinct at the end of the Triassic. The geanticlinal ridge rose rapidly through the Triassic and a wedge of coarse sediment (Hokonui facies) built out toward the geosyncline. In the late Triassic, a granitised core was exposed on the geanticline and supplied granitic and dioritic material to the geosyncline. From sequences observed in southern New Zealand, it is known that both shelf and geosynclinal sediments to a total thickness of many miles (estimates range from 10 to 50) accumulated in the Permian-Triassic geosyncline. It is currently considered by many New Zealand geologists that the Chlorite and Biotite schists in Otago province, along the Southern Alps and in Marlborough province, were formed by deep burial of this thick accumulation of geosynclinal sediments. The schists now form an anticlinal arch and grade into Permian greywackes on the south-west (geanticline) side and into Triassic greywackes on the north-east (Pacific Ocean side). This suggests migration of the geosyncline axis away from the geanticline towards the Pacific in the Triassic.

The New Zealand geosyncline was folded and elevated in the early Jurassic, as indicated by middle and upper Jurassic sandy, carbonaceous, conglomeratic and fresh water sediments in two flanking belts on either side of the axis of elevation (schist anticline). The western belt became part of the geanticline in the late Jurassic; the eastern belt continued to subside as a narrow geosyncline along the east coast from north Canterbury to East Cape until the upper Cretaceous. The greywacke sediments deposited in this geosyncline are a rewash of the older greywackes of the New Zealand geosyncline. The metamorphic core (schist axis) of this geosyncline was exposed in the lower Cretaceous in Otago, where fresh-water beds contain schist boulders. Studies of sedimentary facies and thickness show that the axis of this East Coast geosyncline also migrated eastward towards the Pacific Ocean. In the late Cretaceous only a small area in the extreme north-east of New Zealand was truly geosynclinal. A variety of relatively thin, sandy, muddy, calcareous and bentonitic sediments accumulated on broad shelves flanking the mature geanticline which occupied most of New Zealand. The sea gradually whittled away the geanticline in the late Cretaceous and early Tertiary until the Oligocene, when only a few islands survived.

Volcanism in the late Mesozoic included spilitic pillow lavas, dolerites and minor ultramafics in the small geosynclines in Northland and the East Coast; probably a line of andesite volcanoes on the Pacific side of the East Coast geosyncline; and rhyolite, quartz porphyry, andesite and dacite flows interbedded with fresh-water sediments on the geanticline.

Compilation of the paleogeographic maps is complicated by the large (300 mile) most-Triassic clockwise transcurrent displacement postulated for the Alpine Fault. This fault displaces lower Mesozoic paleogeographic boundaries but is confined in the upper Mesozoic to the geanticline and so does not affect the later geosynclinal boundaries.

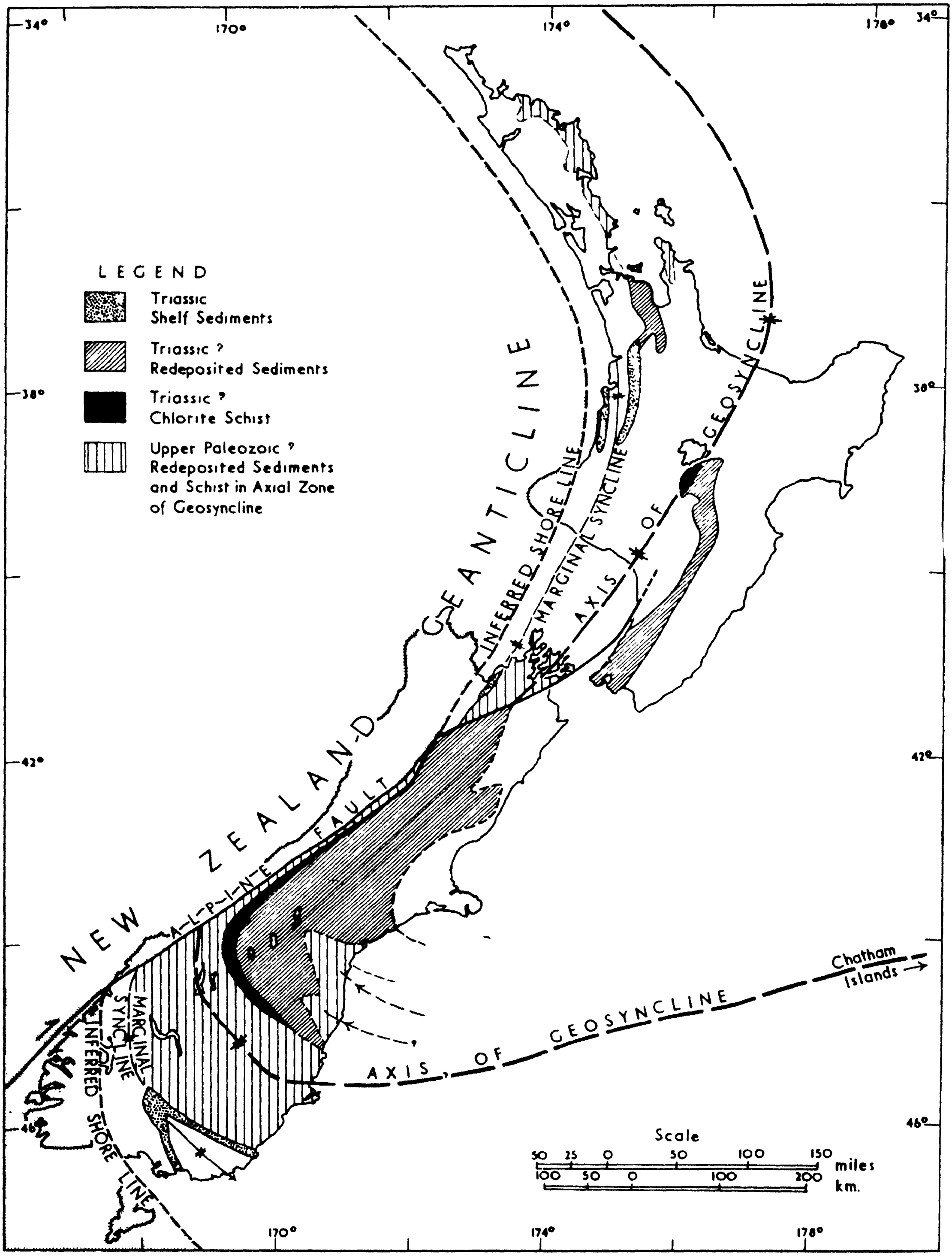

Fig. 1.—Triassic Paleogeography.

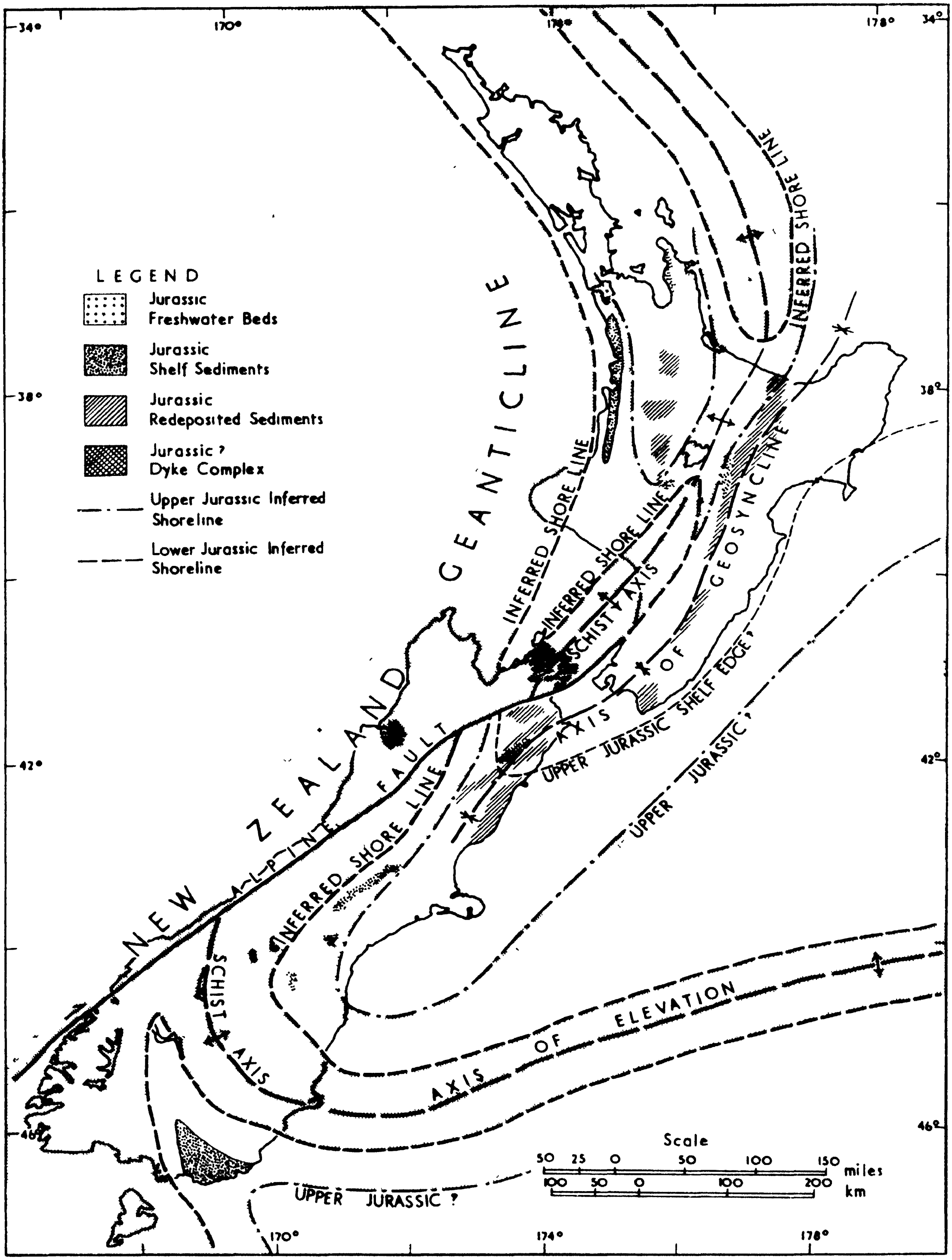

Fig. 2.—Jurassic Paleogeography.

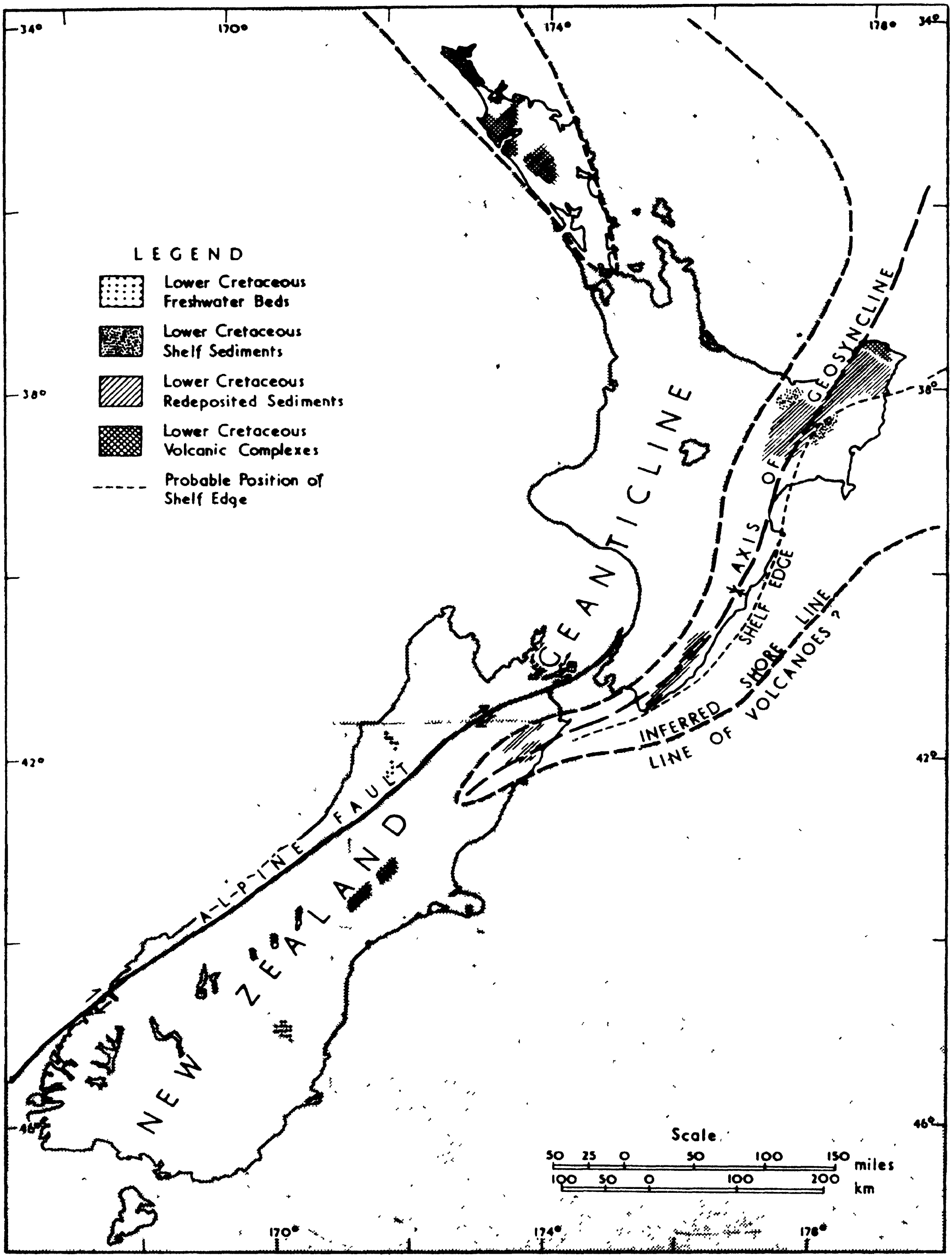

Fig. 3. — Lower Cretaceous Paleogeography.

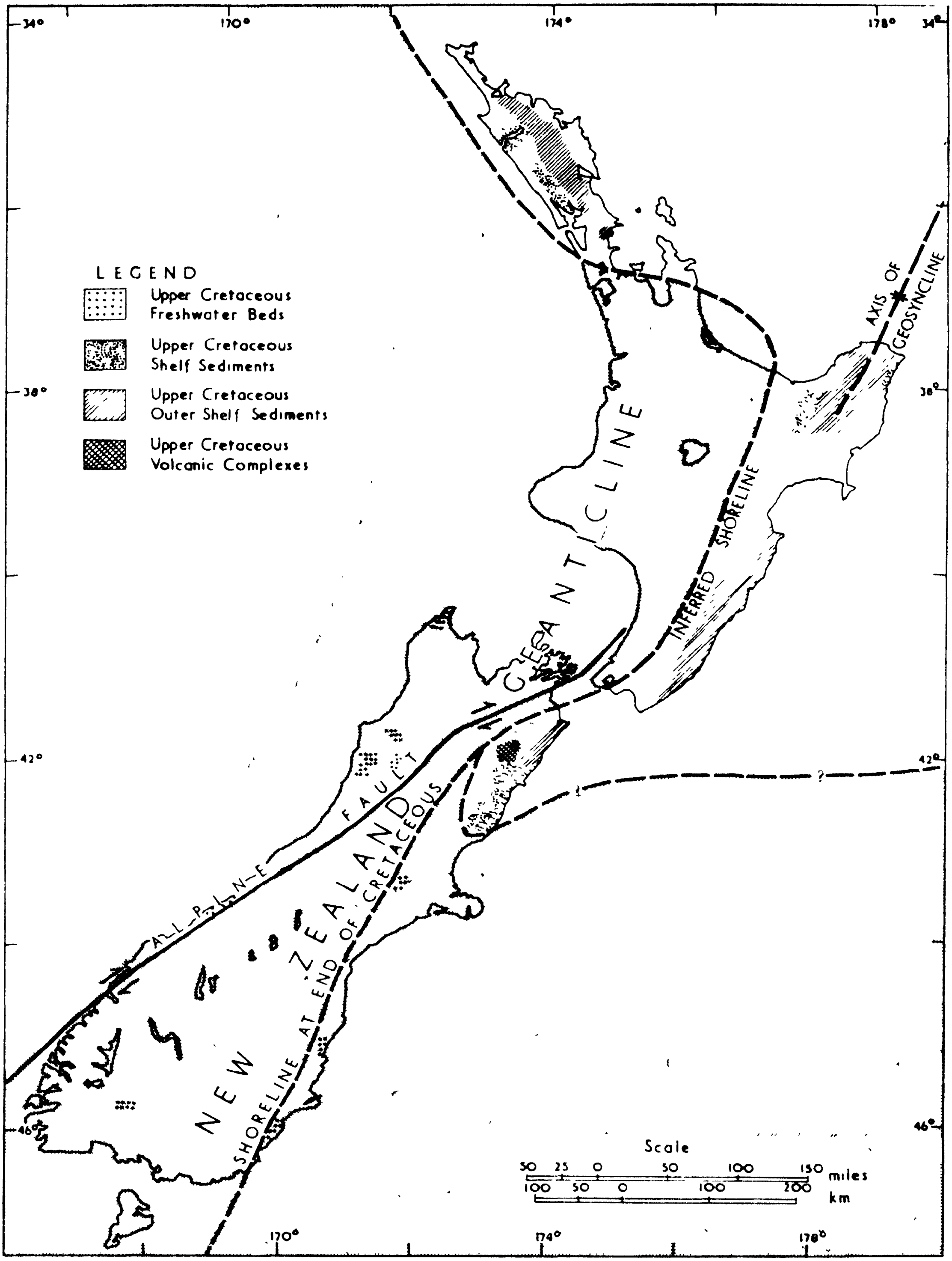

Fig. 4. — Upper Cretaceous Paleogeography.

PACIFIC AND VARISCIAN OROGENY IN INDONESIA. A STRUCTURAL SYNTHESIS

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The development of the pacific orogeny in Southeast Asia clearly shows the great importance of this orogeny for the gradual consolidation of the borderlands of this part of Asia. The diastrophism of the Malayan Orogen should be considered as the continuation of an orogenic zone known from the Asiatic mainland in Malaya, East Burma, Thailand, Yunnan and China. The Pegu Yoma of Burma forms a representative on the mainland of the Sumatra orogen. The Sunda and Moluccas orogens have their equivalents in the Arakan Yoma, the Chin- and Naga Hills and the Himalayas. A study of the various granite occurrences and their possible ages in the southeastern part of the continent reveals that the different mesozoic and tertiary structural zones can be traced southeast into the Sunda Land area and make the western part of Indonesia an excellent example of continental zonal outgrowth, mainly consolidated by the various diastrophic phases of the pacific orogeny.

A review of the stratigraphic and structural development of the Banda Geosyncline and a re-examination of the literature on the problem of the Banda Sea area lead to the conclusion that there existed in late paleozoic — early mesozoic time a landmass in the eastern part of Indonesia, occupying at least the present Banda Sea area, the zone of the outer Banda arc and the area occupied by the Sula Spur.

A process of regeneration of marginal parts of this land area started in the South (Timor) in permian — lower triassic time and spread to the North (Ceram) in upper triassic time, resulting in the formation of the so-called "Banda Geosyncline". The sequence of strata of this geosyncline shows no indications for participating in a pacific orogeny; stratigraphic gaps and changes in facies are the result of epeirogenic movements. The tertiary orogeny produced in the zone of the Banda Geosyncline intermediate type structures, assuming that the overthrust structures, reported from Timor and Ceram, are the result of gravitational tectogenesis in a subsiding basin. Chapters on the Sahul Shelf area and the occurrence of an important belt of variscian orogeny in eastern Australia and northern Queensland make it acceptable that the pre-cambrian nuclei of the Australian Continent should be continued over some distance to the North and Northwest, while the belt of variscian orogeny should be traced from northern Queensland to southern New Guinea, Ceram, the Sula Spur, the Aru Islands and Timor, including the late-paleozoic landmass in the Banda Sea area, which also should be considered as the result of the variscian orogeny.

The main conclusion of the paper, the important structural difference between the western and eastern part of the Indonesian Archipelago, forms the base for a preliminary geotectonic map of the area. The wellknown "Wallace line", between Borneo and Celebes, not only forms an important faunal boundary but is, according to this conception, also a very important structural boundary.

Several points are mentioned to emphasize the great differences between West and East Indonesia, which all can be explained by this synthesis. A few geological and geophysical problems are discussed from which it seems that they can be solved according this new line of thought.

GENERAL INTRODUCTION

The results of the tertiary alpine or himalayan orogeny, according to Westerveld *(74-75)* called the middle miocene Sunda orogen and the Moluccas orogen, shaped between the Late Cretaceous and Middle Miocene, are occupying the area between the Sunda and Sahul shelves. (fig. 1). These shelves, being the partly submerged extensions of resp. the southeastern edge of the Asiatic and the northern and northwestern edges of the Australian Continent, are considered to be younger additions to the older continental nuclei, the so-called cratons. In other words both continents have grown towards each other in these

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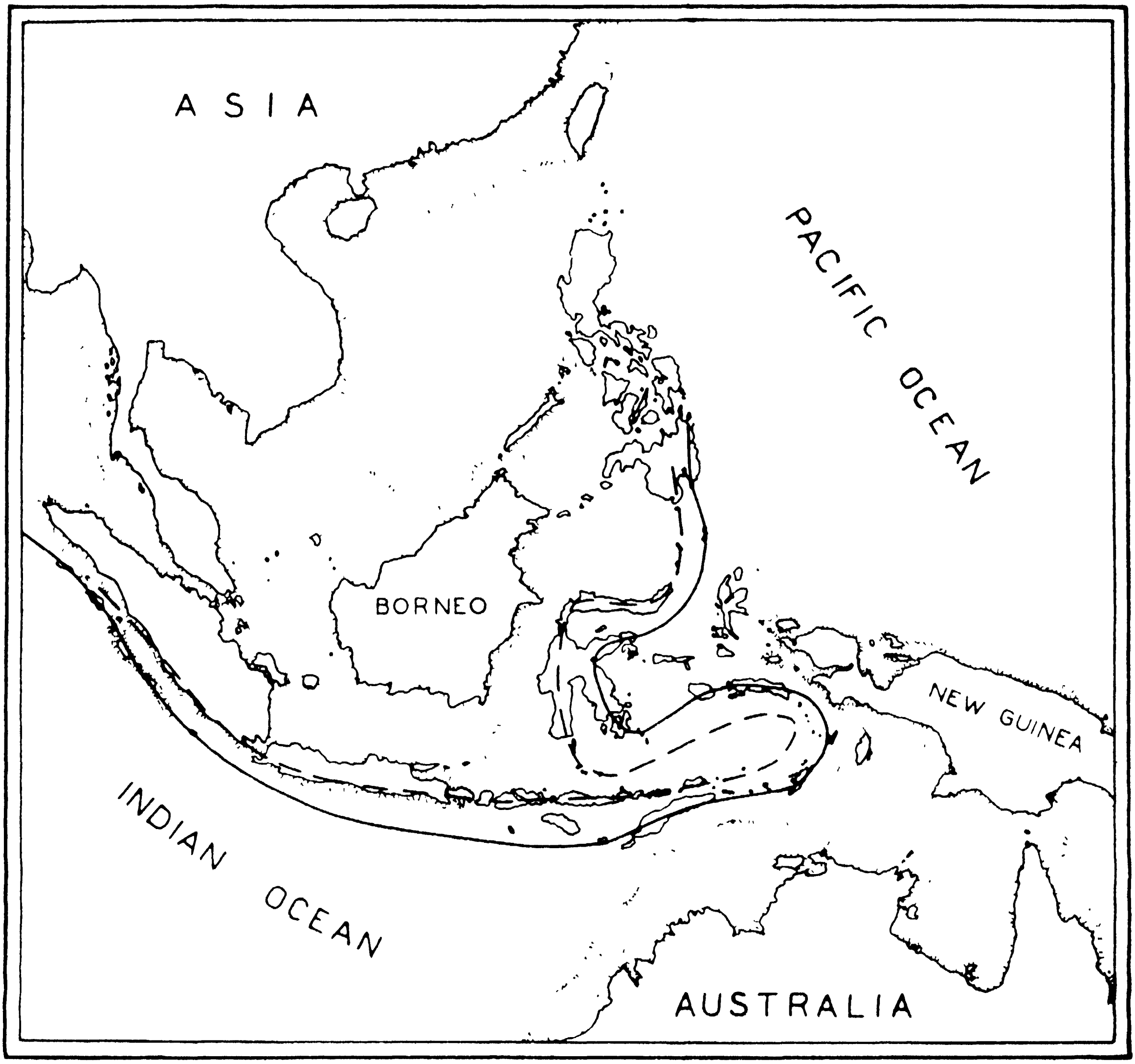

Fig. 1.—Sunda and North Australian Shelves with axis of Sunda Orogen (— — —) and Moluccas Orogen (————) according to Westerveld.

respective directions and the tertiary or himalayan orogenesis actually resulted in welding these two continents together with the Sunda and Moluccas orogens (= v. Bemmelens Sunda orogen) as a scar between them. So the Sunda Shelf area in the West and the Sahul Shelf area in the East are now separated by an intervening belt of deep-sea basins and island-festoons, of, geologically speaking, a rather young age.

The shelf-seas are generally less than 100 meters deep, although the edges of the shelves are indicated on the map by the 200 meter isobath, as is the common use. The islands emerging from the shelfseas are mostly less than 1,000 meters high, those on the Sahul Shelf being particularly much lower than those on the Sunda Shelf. These shelves largely are considered to be old peneplains which under certain conditions could be formed on such a large scale. They are only gently warped by later epeirogenic movements, being more or less stable land masses with a low seismicity, low isostatic gravity anomalies, and no active volcanoes.

Both shelf areas are usually considered as being formed in the same way and, what is more important, at the same time. The author agrees with the first supposition that both shelves have been growing steadily on account of the continuing orogenic processes which have in due course contributed to the enlargement of the respective continental nuclei, enlarging the cratons gradually, adding all the time more or less stabilized zones to the continent. It is, however, the author's opinion that both shelf areas were structurally not formed at the same time, at least not those, usually indicated as the Sunda and Sahul shelves. The formation of the Sunda Shelf is mainly the result of consolidation and growth during the various mesozoic phases of the pacific orogeny, while the Sahul Shelf, and particularly the area of it covered by the Arafura Sea and its extension further West is mainly the result of the variscian orogeny of which the western part, now occupied by the Banda arcs of the Sunda and Moluccas orogens, participated in a later, mainly mesozoic, process of transformation or as Stille *(51, 52)* calls it of regeneration. According to this author this process of regeneration implies a return of semi- or quasi- consolidated shelf areas into a geosynclinal stage, in other words a remobilization of cratonic areas which is in general only possible as long as the quasi-cratonic and not yet the fully-cratonic stage exists. By this process of regeneration the mesozoic Banda Geosyncline was formed out of which, mainly in tertiary time, the Sunda and Moluccas orogens were formed. The best example of regeneration is known from the structural history of the Alps. This area was once, together with the Central European foreland, transferred into a quasi-cratonic mass, but part of it was again unlike outer-alpine Central Europe, transferred into a mobile geosynclinal area, so that a new geotectonic cycle was started.

The purpose of this paper is to give an up-to-date picture of the general structural development of both shelf-areas, to draw certain conclusions about the process of the formation of these shelves and about the orogenic cycles responsible for their formation.

THE PACIFIC OROGENY IN WEST INDONESIA

INTRODUCTION

It was already in the 19th Century that von Richthofen drew attention to the fact that the eastern and south-eastern parts of Asia form an excellent example of the gigantic zonal structure of a continent, rejuvenating the further we remove from the old pre-cambrian nuclei of the continent which are gradually welded together into larger stable or quasi stable areas. During further development of geologic research in these regions this old statement proved to be true everywhere so that it is now generally accepted that going East these pre-cambrian nuclei are, still on the mainland, surrounded by paleozoic orogens. Then follows a mesozoic orogenic zone which is now partly represented by mountain ranges in the coastal areas of East Asia, partly by structures on the adjacent islands east and south-east of the continent. Still further east and south-east we reach the tertiary mountain chains, partly covered by the sea, in certain places even by a deep-sea, of which only the outer zone reaches above the level of the ocean and forms the outer continental fringes represented by arcs of islands. These border chains form the youngest orogens with deepsea-troughs in front, which surround these island arcs almost completely and form the true border with the Pacific Basin proper, a border in the geologic literature known as the "Andesite line". In few places, e g. in the Indonesian Archipelago, more detailed geological research has been carried out and a more detailed zonal structure could be fixed because older rocks, syntectonic plutons and postvolcanic phenomena particularly occur on the inner side and the younger folded sediments on the outer side of these orogenic zones.

STRUCTURAL IMPORTANCE OF THE PACIFIC OROGENY FOR SOUTHEAST ASIA

In a paper submitted to the session of the International Geological Congress in Moscow (1937), Vialov *(70)* separated the mesozoic phases of diastrophism as a separate orogenic system from the alpine-himalayan system under the name of pacific system emphasizing with this name the importance of this orogeny for the Pacific area.

In Central Asia the results of this mesozoic orogeny can best be studied in the Transhimalayan Ranges which follow the Southern border of Tibet, arriving in NW Yunnan. Here the W-E trend changes into a southern one and soon the system diverges, forming an eastern branch between the massifs of South China and Thailand-Cambodja, and a southern branch between those of Gondwana and Thailand-Cambodja. The former curves northward, forming the Pacific border of Asia (Teilhard de Chardin, *60*; Fromaget, *22*). The latter extends southward across

Burma (Shan States), the Mergui area and southeastward to the Sunda Land.

The best up-to-date review on the various orogenic phases was published by Rutten *(46)* in his paper on "Frequency and Periodicity of orogenetic Movements". For our discussion on the importance of the pacific orogeny causing the gradual development and growth of Southeast Asia the following mesozoic phases of diastrophism are of importance:

a. a labinian phase between the Middle and Upper Triassic, particularly important for the structure of Indochina (indosinian).

b. an old cimmerian phase between the Triassic and Jurassic, also of main importance for Indochina (indosinian).

c. a young cimmerian phase between the Jurassic and the Cretaceous which is particularly reported from the Pamirs, Kunlun, China, Burma, Thailand, Malaya and Indonesia (yenshanian).

d. an austrian phase between the Lower and Upper Cretaceous resulting in unconformities in the Hindukush, Japan and Indonesia (yenshanian).

e. a laramic phase between the Cretaceous and the Paleogene which up to now is reported from Japan, Central and Southern China and Indonesia (yenshanian).

The occurrence of these various mesozoic phases of diastrophism demonstrates clearly the rejuvenation of the folds to the South and Southeast with main results of the labinian and old cimmerian phases in Indochina and of the cimmerian, austrian, and laramic phases further South in Burma, Thailand, Malaya, Borneo and Sumatra.

In the "Pulse of the Earth" Umbgrove *(65)* publishes a world map upon which a chronological analysis of the continents is given. On this map the regions of older "alpine" diastrophism, in fact those dislocated by the mesozoic diastrophic phases are pictured as a separate orogenic cycle. From this map it can clearly be seen that the influence of the mesozoic orogeny was strongest in the area around the Pacific Ocean. Recent geological research in the areas along the western border of this ocean has proved that the influence of this orogenesis in the Japanese Islands, China, Formosa, the Philippines, Malaya and Indonesia is of far greater importance as is suggested by Umbgrove's map.

From the results of the geological exploration in the Central Asiatic Mountains by Norin, during the Chinese-Swedish-Expedition under the Leadership of Sven Hedin, between the years 1928-1931, it became clear that the mesozoic orogenic cycle plays also an important role in the Central Asiatic Mountain Ranges.

A gradual increase of the importance of this cycle of diastrophism towards the Pacific could be clearly investigated, in such a way, however, that the variscian orogeny remained the main period of deformation for these mountain ranges. Reviewing the publications on the structure of the eastern and southeastern part of China it is no surprise that geologists studying the structure in this part of the continent hardly ascribed any importance to the variscian orogeny for these regions, because the pacific orogeny caused the bulk of the structural features of this area.

Only rather recent Lee *(37)* emphasized at the 18th Session of the International Geological Congress in London (1948) the importance of the laramide movement and considers it as a very important event in China, and in certain provinces it is even the main mountain building movement. Only when we turn further West, e.g. in the region of the Tsinglingshan, we realize that we have to do with much older structures which were formed during the Lower and Upper Paleozoic.

In one of the Geological Memoirs of the Geological Survey of China (Serie A, Number 20, Chungking) entitled "On major tectonic forms of China" Huang *(29)* subdivides the mesozoic orogenesis in two phases, an older indosinian and a younger yenshanian phase, of which the first one comprises the time interval Middle Triassic-Lower Jurassic and the second cycle the remaining part of the Mesozoic. Huang subdivides the indosinian phase into two sub-phases which are the same as Stille's labinian (a) and old cimmerian (b) phases; the yenshanian phase is subdivided into three sub-phases, respectively corresponding with Stille's young-cimmerian (c) austrian (d) and laramic (e) phases. In the Triassic of Indochina two distinct unconformities are distinguished, an older one at the base of the Upper Triassic and a younger one at the base of the Jurassic. These two unconformities indicate the occurrence of two orogenic phases. According to Fromaget these are the most important ones in the area and are responsible for the mountain structures still occurring in Indochina. This indosinian (Fromaget, Huang) phase of mountain building resulted in rather strong folding, characterized by extensive overthrusts in various places, leading to the formation of extensive sheets and magmatic activity (granites).

The influence of this orogeny reached till southern and central Yunnan. Also in the southeastern part of China the results of young triassic diastrophism occur rather frequently and in northern China there exist in many places unconformities between the Jurassic and Triassic. Still further North unconformities between the older deposits and the jurassic coalseries in Jehol and Manchuria prove the occurrence of mountain building movements, the age of which could not yet exactly be determined.

Fromaget *(22)* is of the opinion that the entire Pacific border of the Asiatic Continent belongs to the Indosinides. But others, e.g. Teilhard de Chardin *(60)*, believe that both phases, as well the old as the young mesozoic, were active in the Pacific border region. The former should be responsible for the formation of the mountain system of Kwang-si with post permian—pre jurassic granites; the latter formed that of Kwangtung with post jurassic granites (e.g. those of Hongkong). Teilhard de Chardin distinguished on his map these two groups of granitic intrusions as resp. the Mongolian and Yenshan granites. The Yenshan granites often intruded into the Mongolian group. These two phases consolidated in the course of the Mesozoic the Pacific border of the Asiatic Continent. The younger tertiary and quaternary cycle emigrated further toward the Pacific Ocean creating the East Asiatic island festoons. From this we might conclude that the old mesozoic indosinian phase of orogeny was not only important for Indo-China but also for large parts of China. However, many years of geological research in E and SE Asia will still be required in order to obtain a clear picture of the real character and influence of this indosinian phase of mountain building, particularly because the results of the older phases were blotted out by the younger yenshanian disturbances, which were more important in these northern areas.

The yenshanian phase of orogeny is characterized by a distinct unconformity at the base of the Cretaceous. In the Western Hills of Peking this unconformity is not so well pronounced, but is much better developed in the eastern continuation of the Tsinglingshan. Unconformities of similar age occur in the area of the lower course of the Yangtse river. These pre-cretaceous unconformities form a frequently occurring feature in the geology of eastern China, the intensity of this phenomenon is, however, rather varying from place to place. This yenshanian phase of orogeny is too young to be considered as a post-phase of the variscian orogeny and to old to be included into, the alpine-himalayan orogeny.

Nevertheless it has been of such great influence on the local structure of eastern China that it should be distinguished as a separate phase. Because the results of this orogeny became first known from the Western Hills of Peking, which Chinese geographers indicate with the name Yenshan, geologists from the Geological Survey of China have described these phenomena as the result of the yenshanian orogeny. These yenshanian movements started already in upper jurassic time.

In West Yunnan (SW. China) the main folding took place after the Jurassic. The fact that neither here nor in the area of the Shan Plateau further to the South, cretaceous or old-tertiary deposits have been found, makes it rather difficult to give this folding phase an upper time limit. Several geologists consider the deformation of western Yunnan as a result of the himalayan or tertiary orogeny. The fact, however, that the old-tertiary deposits of North Burma, with thicknesses varying between 7,000 and 12,000 meters, are mainly of fluviatile or deltoidic origin and that the basal conglomerates of the Tertiary are composed of crystalline schists and gneises, indicate, that the crystalline massives of western Yunnan were already elevated areas before the beginning of the tertiary orogeny. We might conclude from this, that the western part of Yunnan was already submitted to diastrophic movements and emerged before the beginning of the Tertiary and it is very likely that this happened during the yenshanian cycle of orogeny. In Burma, geologists have come to similar conclusions and the dislocations of the Shan Plateau were considered by them as the result of the yenshanian orogeny. We conclude that the alpine orogeny as described and subdivided by H. Stille *(51)* in his "Vergleichende Tektonik" in young-, old-, and pre-tertiary stages, should at least in East Asia no longer be considered as a single period of orogeny but should in fact be subdivided in two mountain building periods, the pacific and the alpine-himalayan cycles, of which the first period can be subdivided in two phases, including two or more sub-phases each.

The first phase is the old-cimmerian, conform its structural importance for Indo-China indicated as the indosinian; the second phase is the yenshanian or, on account of its importance for the structure of China proper, the sinian phase. With their respective sub-phases they form the pacific cycle of orogeny which has been of such great importance for the consolidation of the eastern and southeastern Asiatic borderlands.

The second mountain building period, the alpine-himalayan orogeny has her main development in the Tertiary and is frequently also indicated as the tertiary orogeny. This orogeny is mainly responsible for the formation of the outer fringes and island arcs of the Asiatic Continent.

STRUCTURAL DEVELOPMENT OF THE SUNDA LAND AREA

The present Sunda Shelf area can be subdivided in an old central landmass, comprising the Malay Peninsula, the Riouw-Lingga Archipelago, Bangka and Billiton, the Karimundjawa-, Karimata-, Tambelau-, Anambas-, and Natuna Islands, the western part of Borneo, now forming an old peneplain, and the more labile marginal parts which still have been subjected to the various phases of the young pacific and alpine-himalayan orogenies, represented by the remaining parts of Borneo, Bawean Island, Java, Madura and Sumatra. It is the partly submerged southeastern outgrowth of the Asiatic continent, being connected with it by the Malay Peninsula and the Isthmus of Kra.

There exists no doubt about the gradual structural development of this Sunda Land area. Whether we accept the conceptions of Stille, Umbgrove, Westerveld, or van Bemmelen, they all come in their various publications and structural maps to a distinct zonal structure and rejuvenation in southeastern direction. Next to minor variations in the details of the various orogenetic zones there is a considerable difference of opinion in regard to the origin of this zonal structure as supposed by Stille, Umbgrove, and Westerveld on one, and of van Bemmelen, on the other side. The conceptions of the first group of scientists are based upon a gradual growth of the annamitic and indo-malayan chains around an old pre-cambrian massif, occupying Cambodia and eastern Thailand ("Cambodian mass" of Suess *(58)* and renamed "Indosinian mass" by Fromaget *(21)*, caused by orogenic forces acting since the Late Paleozoic and emigrating for one reason or another from the SE. part of the Asiatic Continent.

Van Bemmelen, however, is of the opinion that this zonal structure is caused by emigration of orogenic waves originating from an "undation centre", in this particular case his so-called "Anambas-centre", from which the various orogens spread outwards and successively mountain systems came into existence forming ever widening arcs. We will see that when eliminating the youngest narrow zones of outgrowth, the Sunda and Moluccas orogens of Westerveld, forming together van Bemmelens Sunda Mountain System, the remaining part of the Sunda Land area was formed as the result of the youngest (sinian or yenshanian) cycle of the pacific orogeny.

However, further South from Yunan, and in the Sunda Land area proper it becomes rather difficult to date the results of the various phases of the pacific orogeny e.g. in Thailand, Malaya and Indonesia. This will not say that they become less important in those areas but considerable gaps in the stratigraphic sequence of the Mesozoic make it often impossible to give the exact age of the phases of diastrophism. Fortunately in most of the areas where these gaps occur, denudation has advanced so much that we are able to use the occurrence of syn- or post-tectonic granites to obtain data about the relative age of the main folding phase. Also in these cases, however, gaps in the stratigraphy of a certain area usually allow only the dating of the maximum and minimum ages of the granite and of the phase of diastrophism with which they are connected. Absolute age determinations with radio-active methods will contribute considerably to solve the problem of the ages of the granites connected with the various phases of diastrophism, but up to now very little has been achieved in that line Schürmann *et al. (47)*.

In the southeastern coastal provinces of China, where jurassic sediments show strong diastrophism, the occurrence of granites in connection with this folding demonstrates clearly that the sinian (or yenshanian) phase of orogeny was much more active than further West.

During the 4th Session of the Pacific Science Congress at Bandung (1929) attention was drawn to the great importance of the occurrence of young mesozoic granites and a young mesozoic phase of mineralization for SE. Asia. In Thailand the Paleozoic is folded conformably but the proper age of the folding-phase cannot be investigated, but is definitely post-paleozoic. The various granite bodies which occur in the folded strata show all the same N-S trend as the folds. Usually they occur in the cores of the anticlines but locally they also break through the structures. Their occurrence points to a strong connection between the folding and the formation of these granites. The first phase of orogeny in Malaya occurred at the end of the Permo-Carboniferous, terminating the preceding geosynclinal evolution in the eastern part of the peninsula by an uplift and formation of plutonic rocks. To these older plutonics presumably belong parts of the igneous complexes in the eastern part of the peninsula (East of the Main Range), but later tectonics and magmatic activity render it impossible to distinguish these older granites. Thereafter, renewed geosynclinal subsidence caused the transgression of the sea and the deposition of a flysch-like formation of upper-triassic age. Intercalated polymict conglomerates contain detritus of the permo-carboniferous formation (e.g. pebbles of silicious shales with radiolarians, shales, acid eruptive rocks), and also boulders of pre-triassic granites.

Further West the unconformity between both formations is less clear, and locally sedimentation might have continued uninterruptedly (Klompé, *30*).

Then followed a second period of mountain building and intensive folding of triassic quartzites and slates together with the intrusion of granites still represent the most striking structural and magmatic features of the peninsula. These various granitic bodies show a similar position as those further North in Thailand. These are now exposed as the Main Range Massif, some 300 miles long and as much as 30-40 miles wide, rising in places to more than 7,000 feet above sea-level. This tremendous mass of granite represents only the exposed upper part of an enormous granitic root. The tin-granite batholiths of Bangka and Billiton further SE. some of the granite occurrences further East (Borneo) and those further North in Thailand are all eminencies on the back of the same granitic mountain root. Though it is not difficult to assign this folding together with the intrusion of the granite bodies a post triassic age, it is not possible to fix the age of this diastrophic and magmatic phase more accurately because no marine deposits of jurassic or cretaceous age have been discovered.

This shows that the Malay Peninsula forms part of the Pacific Mountain System, distinguished by Vialov *(70)*. We might tentatively date this major orogenic revolution in the Sunda Land area as "end of the Triassic", although it is also possible that it occurred in the Lower Jurassic. The intrusion of the tin granites presumably occurred later in the Jurassic, but before the Cretaceous. On account of the similar position of the Thailand granites we might also accept tentatively a post triassic, but pre cretaceous age for the diastrophic and magmatic phases in Thailand. In case this correlation is correct the main phase of orogeny in Malaya and Thailand is of the same age as the sinian (or yenshanian) orogeny of East China. Malaya forms the western part of the Sunda Land of which it forms an *integral* part to which younger diastrophic phases added younger orogenic zones and the whole process resulted in a steady outgrowth of the Asiatic Continent to the Southeast.

During geological investigations in West Borneo by Zeylmans v. Emmichoven and van Bemmelen *(77, 3)*, indications were found that at least the larger part, if not all, of the granites in this area have an upper jurassic age. In several places the granites are overlain by a lower cretaceous conglomerate in which pebbles of granite, while this type of granite also occurs intrusive in the possibly jurassic limestones of the West Borneo Mountain System.

When we accept that the granites of Thailand, Malaya and the Tin-islands, which are definitely of post triassic age, can be correlated with the bulk of the Borneo granites, than all these granites should be ascribed an upper jurassic age and should be considered to belong to the sinian (or yenshanian) phase of orogeny.

In the Indonesian Archipelago we are faced with the youngest zones of this gradual outgrowth of the Sunda Land area (e.g. SE. Asia). Here the youngest tertiary orogeny is developed in a beautifully arc-shaped zone which towards the N. can be traced into the mountain ranges on the mainland of Asia, towards the E. this zone is thought to have its continuation in the Banda arcs, than through Celebes and further North to the Philippines. This youngest zone of orogeny (Sunda and Moluccas orogens (Westerveld), or Sunda Mountain System (v. Bemmelen) brings the Sunda and Sahul shelves almost in contact with each other with only this young zone of diastrophism as a scar between both. In several of his publications and books on the structural development of Indonesia, van Bemmelen (*4*, fig. 73; *5*, fig. 10; *6*, fig. 12) publishes a sketchmap (fig. 2) on which the occurrences and ages of granitic rocks in the various orogenic zones of the Indonesian Archipelago are schematically indicated. From this map we see that the Barisan Geanticline is characterized by cretaceous granites with on the eastern side a zone of jurassic and West of it a zone of middle tertiary granites. Reviewing the situation of the various granitic bodies more in detail we find that jurassic granites are only known from two localities in East Sumatra (Tigapuluh Mts and Bt. Batu, close to Palembang) and tertiary granites only from two localities in South Sumatra (e.g. Bengkunat massif). All

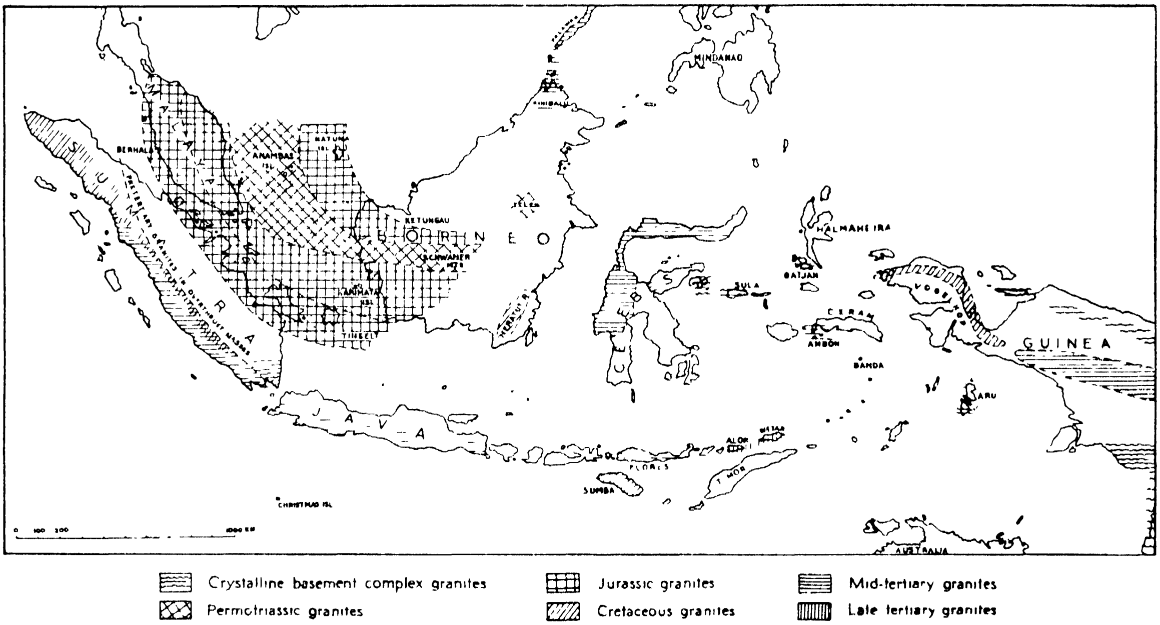

Fig. 2.—Distribution of granitic rocks in orogenic belts after van Bemmelen (1949).

other granites are with the exception of a few of uncertain age, believed to be of Upper Mesozoic age.[2] Only from three of these the Rawas, Gumai, and Garba granites, a definite cretaceous age could be established. The Rawas granites penetrate jurassic slates; the Gumai granite is transgressively overlain by an eocene conglomerate containing granitic material; and the Garba granite is intrusive in the cretaceous Garba Layers (van Bemmelen, *2*). From all the other occurrences we only know that they have a post triassic-pre tertiary age and that their petrographic character is different from that of the jurassic tin-granites further East, so that it is very likely that all these granitic bodies are Upper Cretaceous, characterizing the laramic or youngest mesozoic phase of the pacific orogeny.

A more carefull and closer determination of the age of these granites is not possible because in most of the areas where granites occur no jurassic or cretaceous deposits were found. On account of this it is possible that slight pre-orogenic movements occurred already in the Jurassic (young cimmerian) and continued during the Lower Cretaceous, leading to a paroxysmal orogenic and magmatic phase (laramic) in the Upper Cretaceous, resulting in a general geanticlinal uplift, folding, and the intrusion of granites mainly in the cores of the broad anticlines.

In Borneo, where in the western part the jurassic granites of the sinian orogeny are well developed, cretaceous granites occur only in the Meratus Mts. in the southeastern part and possibly also on Pulu Laut. In the Meratus Mts. the granite is younger than the jurassic Alino formation and the lower cretaceous Paniungan beds, but older than the upper cretaceous Manunggul formation. All other granite occurrences in North-, Central-, and East-Borneo are tentatively considered as of tertiary age.

From these occurrences in Borneo, the occurrence of tertiary granitic rocks on Java and the few localities of tertiary granite in S. Sumatra we conclude that another, still younger orogenetic zone, now forms the marginal border of the Sunda Land or a row of islands in front of it. Some parts of this youngest orogenic zone (Sunda-Moluccas orogen of Westerveld) have apparently

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[2] Musper *(40)* reports from Central Sumatra the occurrence of a pre-permian granite North of the Gk. Bulat. Recent fieldwork (1957) revealed, however, that the granite is only represented by a strongly weathered arkosic sandstone belonging to the tertiary Quartzsandstone Formation. The granite, possibly underlying this arkosic sandstone, is consequently overlain by tertiary quartzsandstones and not by permian limestones. It forms part of the large granite mass approximately 350 m. to the North, which is of cretaceous age.

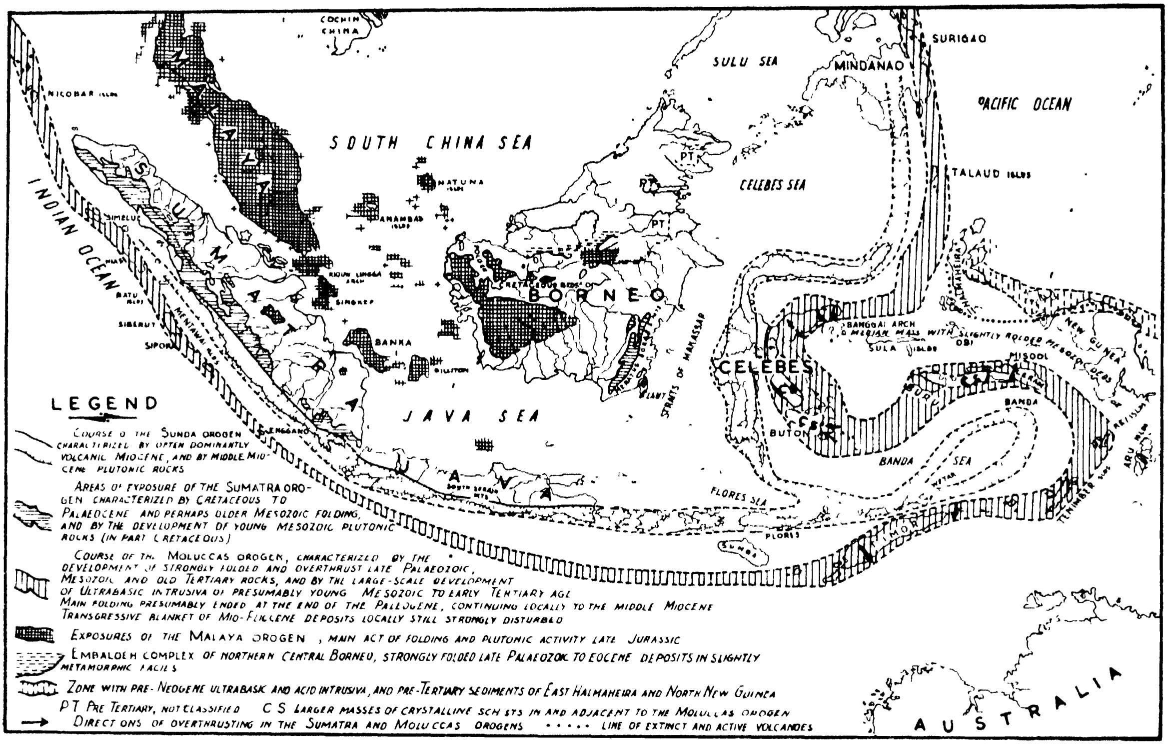

Fig. 3.—Westerveld's tectonic Scheme of the East Indies.

already been eroded deep enough to expose their syntectonic granites (S. Sumatra, Java, E. Borneo) while in others, e.g. on the islands off the West-coast of Sumatra denudation has not yet sufficiently advanced to expose these synorogenic granites. Westervelds tectonic sketchmap of the East Indies *(74, 75)* gives a fairly good impression of this gradual zonal outgrowth of SE. Asia. He distinguishes on his map (fig. 3) the following four orogens, which in ever widening arcs spread themselves towards the Indian Ocean:

a. The Malaya orogen with a main act of folding and plutonic activity in the Late Jurassic. It connects the folds of the Sunda Shelf area through the Malayan Peninsula and SW. Thailand with synchronous structure and plutonics of SE. and E. Burma (Shan States). It is built up largely by permo-carboniferous and upper-triassic sedimentary, and also volcanic rocks, penetrated by numerous masses of granites and tonalitic intrusives.

b. The Sumatra orogen, characterized by cretaceous to palaeocene and perhaps older mesozoic folding and by the development of young mesozoic plutonic rocks (in part cretaceous). Along the southeastern, southern and southwestern margins the folds of the Malaya orogen pass into a younger pre-tertiary mountain belt exposed in SE. Borneo (Meratus-Bobaris Mts.), the South Seraju Mts. in Central-Java, and in the main range of Sumatra. The folded cretaceous beds of Central-Borneo and SW. Sarawak occupy an intermediate position between the older folds of West Borneo and the younger ones of the Embaluh Complex, and might be compared orogenically with the folded Cretaceous of SE. Borneo (Meratus Mts.).

c. The Moluccas orogen, characterized by the development of strongly folded overthrusted late paleozoic, mesozoic, and old tertiary rocks, and by the large scale development of ultra-basic intrusiva of presumably young mesozoic to early tertiary age. The cretaceous and palaeogene folding and magmatic activity with subsequent lateral compression during the Late Tertiary, affected the zone now occupied by the outer row of islands West of Sumatra, by Timor and the outer

Banda arc, and by the vast area of the Eastarcs of Celebes, on a considerable scale.

d. The Sunda orogen takes an almost median position between the Moluccas and Sumatra orogens and appears as a scar of impressive length, healed by miocene volcanism. This belt developed into a longitudinal strip of zones of collapse, which were gradually filled up with a thick sequence of andesitic lavas, breccias and agglomerates, and by miocene sediments. At the end of the Miocene, this mixed series was rather strongly folded and subsequently intruded along its whole extension by dykes and bosses of andesitic and dacitic rocks, and by dioritic and granitic melts. Along its course it passes through the western coast ranges of Sumatra, the Southern Mountains of Java, the Lesser Sunda Islands, the loop-shaped inner Banda arc, the islands in the Flores Sea including Salajar, the Westarcs of Celebes, and finally through the Sangihe Islands into the central part of Mindanao.

The first two orogenic phases of Westerveld's scheme can be compared with those of the sinian or yenshanian cycle of the pacific orogeny, the two last ones with diastrophic phases of the alpine-himalayan orogeny.

CONCLUSIONS

The development of the pacific orogeny in SE. Asia clearly shows the great importance of this

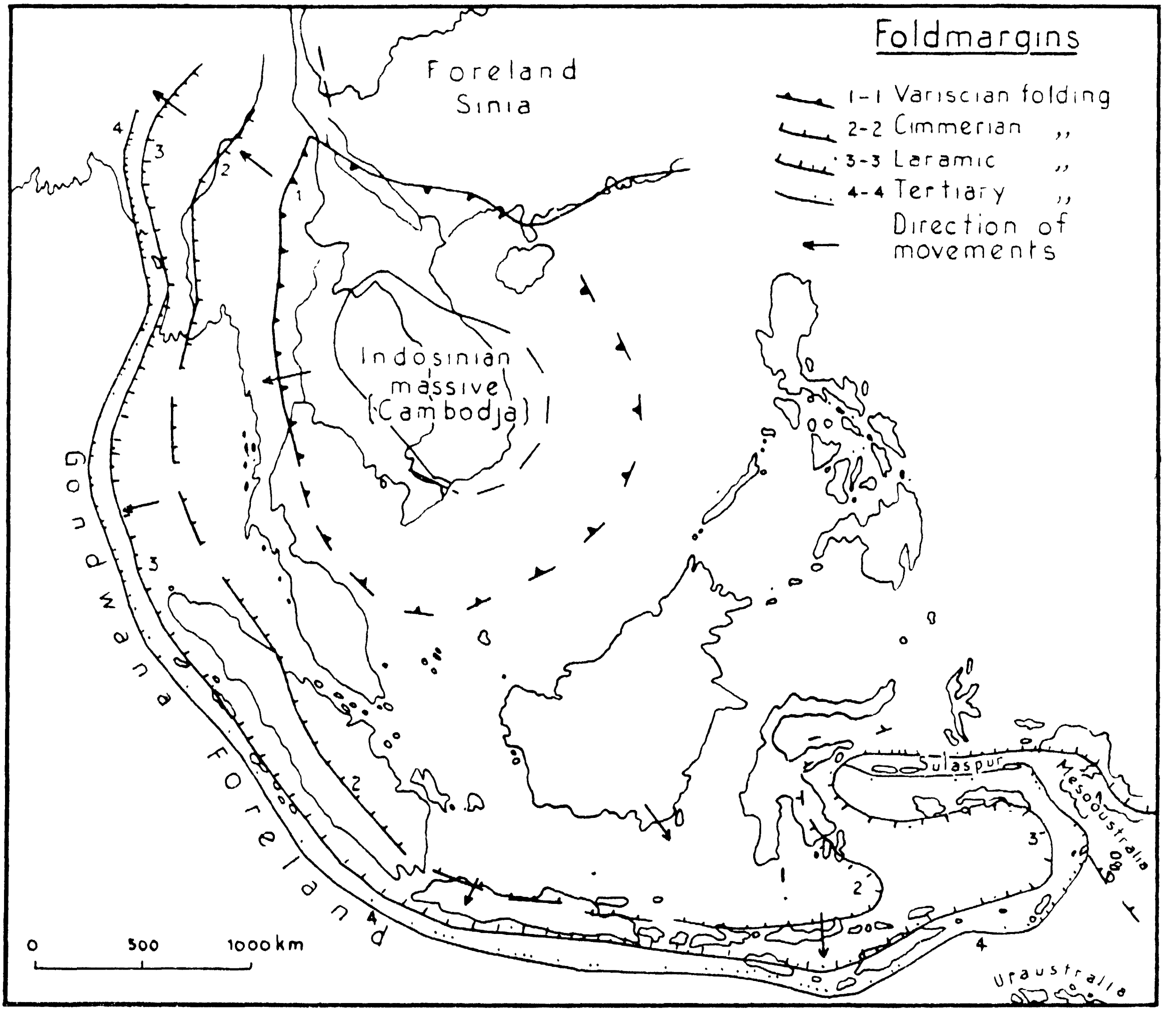

Fig. 4.—The zonal outgrowth of Southeast Asia (according to Stille, slightly altered by Klompé)

orogeny for the gradual consolidation of the borderlands of this part of Asia. The diastrophism of the Malayan orogen should be considered as the continuation of that known from the Asiatic mainland in Malaya, East Burma, Thailand, Yunnan and China. The Pegu Yoma of Burma forms a representative on the mainland of the Sumatra orogen. The Sunda and Moluccas orogens have their aequivalents in the Arakan Yoma, the Chin- and Naga Hills and the Himalaya. A study of the various granite occurrences and their possible ages in the southeastern part of the continent reveals that the various mesozoic and tertiary structural zones can be traced further southeast into the Sunda Land area and make this area to an excellent example of continental zonal outgrowth, mainly consolidated by the various diastrophic phases of the pacific orogeny. Summarizing, the following structural zones can be distinguished in this southeastern part of Asia (fig. 4): (Stille. *52*; Klompé, *31*).

1. The pre-cambrian and partly also caledonian, consolidated nucleus of Indo-China; Suess "Cambodian mass" *(58)* and renamed "Indosinian mass" by Fromaget *(21)*.
2. A zone of variscian orogeny, particularly important for Indochina and possibly reaching till the northeasternmost part of the Malaya Peninsula.
3. A zone of cimmerian orogeny including "Indosinides" and the sinian or yenshanian folds of E. Burma, Thailand, Malaya, Northeast Sumatra, Bangka, Billiton and West Borneo.
4. A zone of laramic folding which can be traced from Burma (Pegu Yoma) through Sumatra and Java to SE. Borneo (Meratus Mts.) and is possibly also developed in the folded cretaceous beds of Central Borneo and SW. Sarawak.
5. A zone of tertiary diastrophism which can be traced from the Himalayas through W. Burma (Arakan Yoma), Sumatra and Java to East Indonesia. From there the northern continuation of this zone might be looked for in the eastern part of Mindanao.

THE VARISCIAN OROGENY IN EAST INDONESIA

INTRODUCTION

The phisiographic character of the eastern part of the Indonesian Archipelago is entirely different from that of the western part and there is no doubt that a difference in structural development between these two parts is at the base of this striking difference.

The eastern part of Indonesia can be subdivided in the following structural units:

a. Melanesia (Pacific mass till the "Andesite line"),
b. The Irian-Halmahera orogenic zone,
c. The Sula Spur,
d. The tertiary Banda-Celebes orogenic zone,
e. The Sahul Shelf, and
f. The Australian Continent (Gondwana).

A discussion of the nature of the Pacific mass and the Irian-Halmahera orogenic zone is outside the scope of this paper. The author's conception in regard to this orogenic zone is amply discussed in his paper on: "The structural importance of the Sula Spur" (Klompé *30*, p. 24).

For a detailed discussion of the geology of the Sula Spur the author refers to the same article which was written as a contribution to the VIII Session of the Pacific Science Congress in Manila (1953).

In that contribution the Sula Spur is considered to represent the western end of a variscian folded belt. This consolidated spur is supposed not only to be responsible for the remarkable double-loop in the tertiary Banda-Celebes orogenic zone, but it also forms the structural boundary between this orogenic zone, South, and the Irian-Halmahera orogenic zone, North of the Sula Spur.

However, the conclusion in connection with the double-loop structure of the tertiary orogen was not entirely to the satisfaction of the author and in this second part a short discussion on the stratigraphy and structural features of the eastern part of the Banda Geosyncline will be followed by some speculations about the possible nature of the Banda Sea during the Mesozoic. The results of these suppositions will be considered in connection with the structural development of the Sahul Shelf as the marginal border of the Australian Continent. It is the authors opinion that this shelf zone occupied a more extensive area shortly after the variscian orogeny but that the western part was involved in a late paleozoic-early mesozoic process of regeneration by which the Banda Geosyncline was formed, out of which in tertiary time the Banda arcs were pressed up. The Sahul Shelf should be considered as a much older shelfcomplex than the Sunda Shelf and it is this feature which in a way should be put responsible for the remarkable difference in structure between the western and eastern parts of the Indonesian Archipelago.

THE PRE-TERTIARY DEVELOPMENT OF THE BANDA GEOSYNCLINE

INTRODUCTION

The central Banda Basin is in its eastern part surrounded by two nearly parallel arcs of islands, a volcanic inner arc and a non-volcanic outer arc. The inner arc consists of a number of small islands of which some still show volcanic activity, others are typical coral-islands (fig. 5). With the exception of the Gunung Api, which rises from the flat bottom of the basin at a depth of 4,500 m. all other islands rise from submarine ridges, which according to the bathymetric-map of the Snellius Expedition show an "en échelon" arrangement (e.g. the Siboga and Luymes ridges).

The outer arc is the result of a geanticlinal uplift, approximately 100-200 KM in width, built up of a series of crumpled mesosoic geosynclinal deposits with typical thrust-phenomena and without active volcanism. In the back part of this geanticline occurs a longitudinal depression.

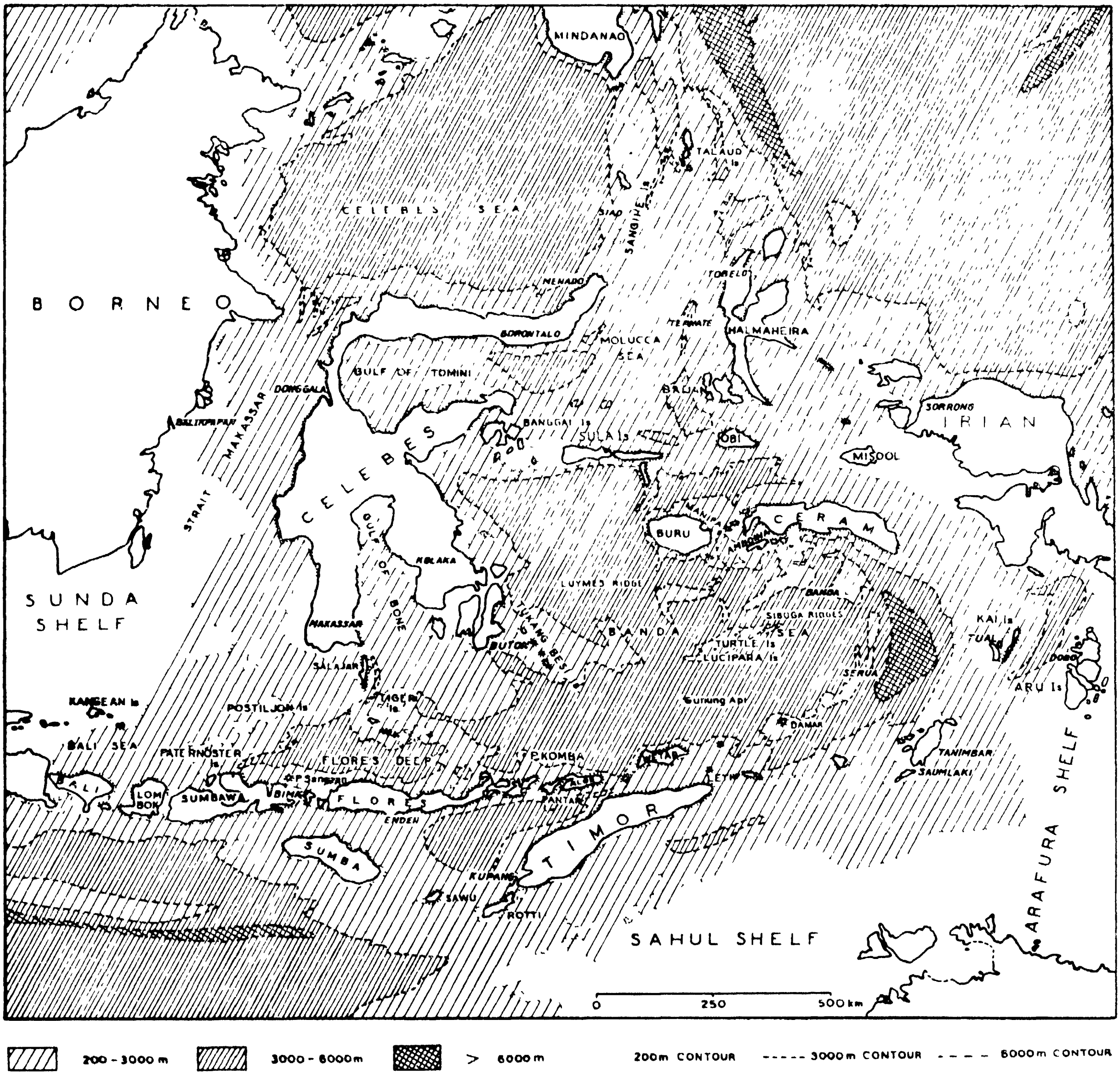

Fig. 5.—Bathymetric Chart of the Eastern Part of the Indonesian Archipelago.

In the Tanimbar Islands the width of this depression is a few tens of kilometers, in the Kai Islands it is about 100 kilometers wide and becomes rather narrow in the Bobot-Masiwang Graben in East Ceram.

The similarity in stratigraphic and geologic development of these islands and the upper triassic transgression occurring in most of them lead Wanner to the conclusion that they have developed from a more or less continuous sedimentary basin, since that time known in the literature as the Banda Geosyncline (fig. 6). Conceptions in regard to the actual course of this geosyncline are, however, rather varying, but in general, it is now accepted that, based on the distribution of the various mesozoic deposits and their facies, the Banda Geosyncline had her continuation via Buton into the SE. arm of Celebes and Umbgrove distinguishes in his publications a "Timor-East Celebes Zone" with a different geological development than the area of the Sula Archipelago, Obi and southern Irian.

This arc of islands is characterized by various remarkable phenomena such as the strong loop in the row of islands; the tertiary and recent uplift, so that reef-limestones now occur at some hundreds to a thousand meter above sea level; their strong negative gravity anomalies; the non-volcanic character in contrast with the volcanic character of the visible part of the inner arc. On account of these phenomena the different authors all agree that the structural development of this arc of islands is still in progress and that it is an ideal place to study the various phenomena accompanying tectonics.

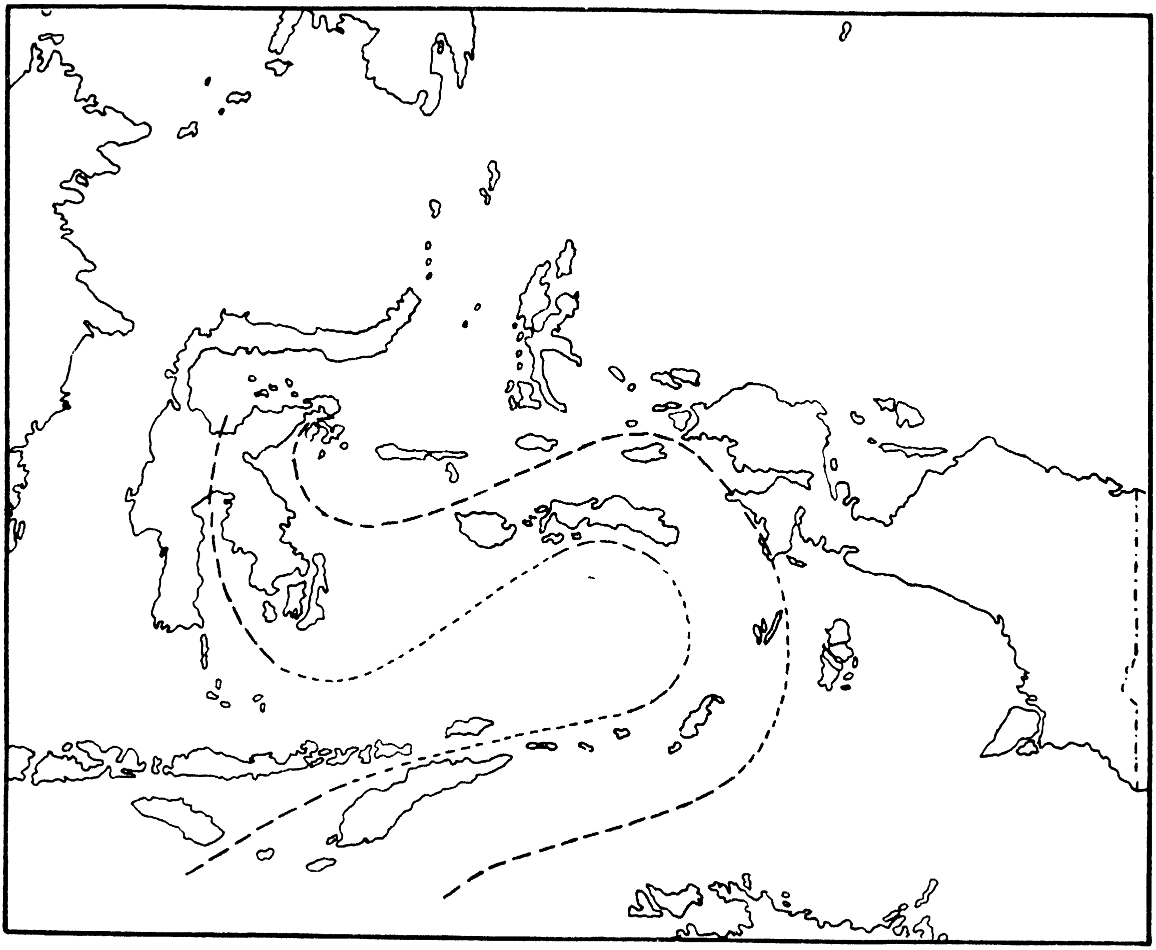

Fig. 6.—The Banda Geosyncline after Umbgrove (1938).

STRATIGRAPHY

Crystalline schists form the basement of the mesozoic-tertiary sequence deposited in this geosyncline. They are para-schists and gneisses mainly composed of micaschists, phyllites, quartzites and amphibolites. This basement is exposed on Timor, Kisar, Letti, Moa, Sermata, Dai, Babar, Tanimbar and Kai Islands, Tuir, Watubela Ceram, Buru, and Buton. Opinions about the possible age of these crystalline schists are rather varying. Wichmann *(76)* ascribed them an archaeic age; Hirschi *(28)* considered the schists of Portugese Timor as pre carboniferous, and Brouwer mentions the possibility of a relatively young age for these schists. On the island of Ceram there exists apparently a gradual transition between the crystalline schists and the weakly metamorphosed phyllites and these again are overlain by the non-metamorphic sediments of a graywacke series. Germeraad *(24)* reports from Central-Ceram the occurrence of *Lovcenipora* in the eastern continuation of the graywacke series so that the age of this series can be fixed as Upper Triassic. The graywacke series contains fragments of schists while the sandstones of this series are mainly composed of crystalline schist detritus. This, at least, points to a gap between the phyllites and the sediments of the Upper Triassic. Up to now such a hiatus could only be investigated in Central-Ceram, where Deninger *(16)* found upper triassic graywackes in immediate contact upon the schists, while Rutten stated that the schists were unconformably overlain by upper triassic sediments. From this the conclusion might be drawn that the age of the crystalline schists in Ceram should be at least pre upper triassic.

For Letti Molengraaff *(33)* has proved that there exists a gradual transition between the crystalline schists and the non-metamorphic fossiliferous, permian sediments. The occurrence of the genera *Agathoceras*, *Paralegoceras* and *Propinacoceras* point to a lower permian age for these sediments so that the crystalline schists of Letti should be considered Lower Permian or even older.

In the western part of Timor there are, according to de Waard *(71)*, at least ten localities North of the central depression where crystalline schists are exposed in characteristic, sharp ridged mountain areas, measuring 10 to 20 Km across, usually surrounded by soft sedimentary strata. The investigations revealed a predominance of basic, low-to medium-grade, regional metamorphic rocks in particular chlorite schists and amphibolites, and local occurrences of phyllites, micaschists, gneisses and granulites. Detritus of this schist complex occurs in the lower permian Kekneno series. The origin of the oldest structures in the area is doubtless closely associated with the formation of these metamorphic rocks, which developed during the regional metamorphic conditions of an orogenic cycle, preceding the pacific (mesozoic) and alpine (tertiary) orogenic cycles. Since a permian or pre-permian age is tentatively assumed for the crystalline schists of Timor (Brouwer, *12*), the variscian orogeny may be considered as the older orogenic cycle, in which these structures were formed (de Waard, *71*).

Wherever developed these crystalline schists form the base for the younger, mesozoic sequence of sediments; in the southern part of the geosyncline (Letti and Timor) they have been formed during metamorphic processes in lower permian or pre permian time, from those in the northern part (Ceram) it can only be said that this process occurred in pre upper triassic time.

Permian sediments are only known from Timor, Letti, Luang, Babar and the Tanimbar islands. On Timor they are represented by a great variety of sediments such as shales, sandstones, limestones, marls, tuffaceous marls and tuffs rich in all kind of fossils which permit a definite age determination. On Letti the Permian is represented by a series of fossiliferous graywackes and arkosic and quartzitic sandstones. The occurrence of the ammonite genera: *Agathoceras*, *Paralegoceras*, and *Propinoceras* places at least a part of this series into the Lower Permian. On the other islands the Permian is represented by crinoid-limestones containing brachiopods and bryozoa. The occurrence of permian deposits on these islands introduces the formation of the Banda Geosyncline (e.q. the regeneration of the area) which apparently started in the southern part of the area, close to the old nuclei of the Australian Continent.

Lower and middle triassic sediments occur only in Timor (fig. 7). On all the other islands of the Timor-Buru arc the Mesozoic begins with the *Upper Triassic*, developed in 5 different facies of which the so-called "Flysch facies" of Timor is the most important one. According to Wanner a very important upper triassic transgression occurred in the area with the result that also the northern part of the Banda Geosyncline developed as a sedimentary basin bordering the "Sula Spur" in the South.

A similar facies is also well developed in Ceram, where these neritic deposits reach thicknesses of

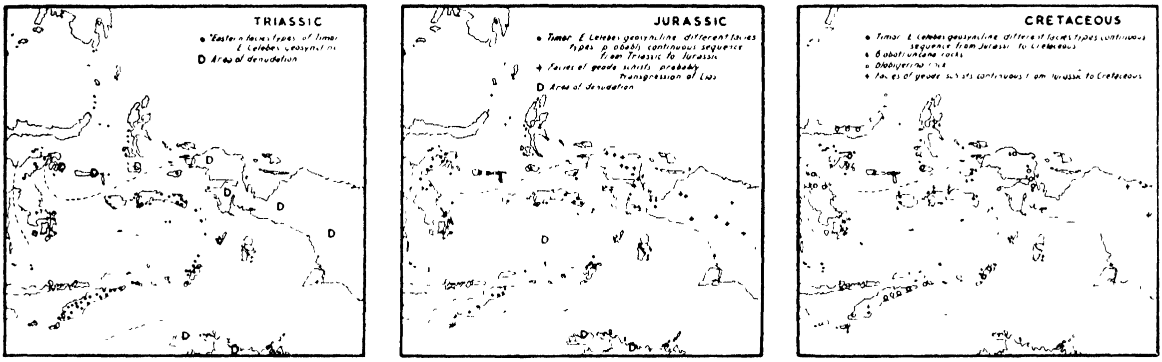

Fig. 7 —Mesozoic sedimentation in the Banda Geosyncline according to Umbgrove (1938).

800-2000 m and are indicated by Valk *(67)* as the "Graywacke Formation" (sandstones and conglomerates, shales, limestone, radiolarite and chert). Fossils give this formation a norian age. In West Ceram the rocks of this "Graywacke Formation" pass apparently gradually into the underlying phyllites. This would indicate a continuous sedimentation from the schists and phyllites till in the Mesozoic. On the other hand the occurrence of schist detritus in the triassic conglomerates points to an unconformity at the base of the triassic conglomerate (basal conglomerate). In connection with this, Rutten *(45)* considers it not inconceivable that in certain parts of Ceram or in adjacent areas, which are now covered by the sea a pre-triassic(= variscian) orogeny might have taken place, while in other parts of the island sedimentation has been continuous.

Wanner *(73)*, however, is of the opinion that the observed conformity is only an apparent one, caused by structural phenomena and that the Lower Triassic is missing while the Upper Triassic is transgressive.

The upper triassic "Flysch Series" of Timor and the "Graywacke Formation" of Ceram should be considered as similar deposits only with slight differences in facies while according to van Bemmelen (1949) the "Graywacke Formation" is richer in clastic material and in this connection deposited closer to the land than the "Flysch Series". The formation of such an extensive and thick flysch-graywacke series can only be explained by accepting that the sedimentary basin was situated close to (an) uplifted land area (s).

This facial similarity, in particular that of the flysch-graywacke series, enabled us to line out the original trend of the Banda Geosyncline. This outline becomes still better pronounced in jurassic time when, at a rather short distance from each other, two different facies begin to develop; a southern facies characteristic for the islands of the Timor-Buru-Buton arc and a northern one characterizing the Sula Islands, Obi and the southern part of Irian (= Sula Spur), thus demonstrating clearly the continuation of the Banda Geosyncline into the SE arm of Celebes and not by way of the Sula Islands into the Banggai Archipelago. On most of the islands there occurs a continuous sequence from the Triassic into the *Jurassic*. The Lower Lias is missing on some of the islands (e.g. Ceram and Buru), but there remains the possibility that the absence of this formation on these islands is caused by lack of information and that sediments of this age might still be found after more detailed investigations.

The *Cretaceous* is absent on most of the islands but according to Stolley *(55)* there has been a continuous sedimentation from the Jurassic into the Cretaceous. Also Brouwer reports the occurrence of Lower Cretaceous from eastern Ceram. Possibly the Lower Cretaceous was also developed on the other islands so that the supposed gap between the Upper Jurassic and the Upper Cretaceous might disappear as soon as more detailed stratigraphic information from the islands is obtained.

GRANITES

Granites occur on Timor in the southern and on Manipa, Kellang and Ceram in the northern part of the Eastern Banda Geosyncline. The Amboina (= Ambon) granites should be mentioned together with those from Ceram, but their position is more on the southern border or even outside the actual geosyncline of the outer Banda arc.

From the foreland granites have been reported from the Banggai and Sula Islands, Obi and the

Aru Islands; from the hinterland from Wetar, Alor and Flores in the South, and Ambon in the North.

De Waard *(71)* reports from Timor the occurrence of pebbles of medium grained granitic rocks from permian conglomerates and loose blocks of mylonized granite on the crystalline schists of the Nefanoe region.[3] Cataclastic granites east of Atapupu, have been reported by Brouwer *(12)*. According to de Waard these granites were intrusive in schists of the Palelo series and of paleozoic (variscian) age.

The age of the granites from Ceram and surrounding islands is still an unsolved problem, though Kuenen *(35)* is enclined to ascribe them a post triassic age, while van Bemmelen *(4)* considered them as Middle Tertiary (fig. 2). Martin discovered on Leitimor (S. Ambon) peridotite, followed by granite and a younger formation of sandstones, limestones, shales and probably diabase. Verbeek confirmed this sequence but ranged the diabase alongside the ancient peridotite. Kuenen *(35)* encountered this series on Hitu (N. Ambon) where many dikes of diabase and some larger intrusive bodies cutting the strata prove that the diabase is younger than the sedimentary rocks. So if Verbeek is right in placing the diabase and peridotite together, this demonstrates the greater age of the sandstones in comparison with the peridotite and granite.

Microscopic examination of the sandstones showed that quartzites and micaschists supplied large parts of the material for the sandstones. Verbeek's chief argument for considering the granites older than the sandstones, is thus refuted. The possibility, however, remains that at the time of the deposition of the sandstone material the granites, intrusive in the deeper parts of the schists, where not yet exposed to denudation. On the other hand the absence of detritus in the sandstones, derived from the peridotite, is strong evidence in favour of the greater age of the sedimentary series. Brouwer and Rutten are therefore of the opinion that these sedimentary rocks were formed from the weathering of ancient gneisses, micaschists, etc. and that the absence of contactphenomena is probably due to abnormal contacts between the plutonic rocks and the sedimentary series. In accordance with this their general conclusion is that the plutonic rocks are therefore probably younger than the triassic sediments and consequently of late mesozoic age.

Verbeek compares, of course, the granites of Manipa, Kellang, and Ceram with those from Ambon and is of the opinion that they are old, at least Permian. Based on the same arguments as those from Ambon, Rutten was at first also of the opinion that the Ceram granites were older than the overlying triassic sandstones but considered them later also as post triassic. Valk *(67)*, Germeraad *(24)* and van der Sluis *(49)* restudied the available literature and the collected rock specimen from Ceram and came again to the conclusion that the peridotite and gabbro are younger than Triassic and because the granite seams to be intrusive in these rocks it is of post-triassic age.

Resuming we conclude that there are various arguments in favour of a post triassic age of the Ceram and Ambon granites but it should be born in mind that the coupling of the peridotite and diabase by Verbeck rests on slender arguments and that neither the other arguments are absolutely watertight (Kuenen *35*, 60). Though Valk, Germeraad and van der Sluis accept also a post triassic age for the Ceram granites we should keep in mind that their conclusion is not based on new field evidence. There always remains the possibility that further fieldwork reveals a pre triassic (= variscian) age for these granites and that they are intrusive in the old crystalline basement. This is certainly a point worthy of further field investigations. On the other hand there also remains the possibility that, since most authors consider them as post triassic, the formation of them should be brought in connection with one of the phases of the tertiary orogeny like van Bemmelen *(4)* does on his map showing granite occurrences in Indonesia (fig. 2).

The granites in the foreland of the Banda Geosyncline include those on the islands of the Sula Spur and the Aru Islands. All these granites are clearly intrusive in the old crystalline basement. The granite of the Aru Islands is often compared with a similar boss at Mabaduan on the Southcoast of New Guinea and granites in the Cape York Peninsula of northern Australia. That the southern part of New Guinea does, in fact, still belongs to the Australian Continent has been quite definitely proved by oil-well drilling. The question of whether these granite bosses

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[3] During fieldinvestigations in 1957 a granite mass with an estimated area of 2 × 5 KM^2 was found North of the Moetis Massif on the border between Indonesian Timor and the Portugese enclave of Oeikoesi. The granite is intrusive in the crystalline schists and strongly influenced by a younger (tertiary) orogeny.

are of pre-cambrian, caledonian or variscian, or later age (and subsequently peneplaned) is not clear. Stille *(52)* marks his variscian front passing in a south-easterly direction from the northern Moluccas and Aru Islands towards western Queensland and considers these granites as variscian. A similar age was ascribed to them by Kölbel *(32)* and Glaessner *(25)*; Fairbridge *(17, 18)*, however, supposes a pre-cambrian age as well for the Mabaduan as for the Aru granite.

The granite on the islands of the Sula Spur, in the Dutch literature known as "Banggai granite", are characterized by red felspars and all are intrusive in the crystalline basement. Most authors ascribe them an upper paleozoic (= variscian) age (Verbeek *69;* Brouwer *9* and *10;* Rutten *45;* v. Bemmelen *4;* Klompé *30)*.

A granite occurrence on Batjan, West of Halmahera, is also considered as of upper paleozoic age (Rutten *45;* v. Bemmelen *4)*. When we suppose that the Mabaduan and Aru granites are intruded in the eastern continuation of the same crystalline basement as that of the Sula Spur, and there are no reasons to deny this, and that the process of metamorphism of this basement occurred during the same orogenic cycle, than we come to the general conclusion that these features are the result of a young paleozoic orogenic phase which was accompanied or followed by the formation of syntectonic granites. In that case it will be very likely that this phase forms part of the variscian orogenic cycle.

Granites in the hinterland occur on the islands of Wetar, Alor and Flores in the South and possibly we also have to include the granites of Ambon in the North. Those of the southern islands are doubtless all of tertiary age. Van Bemmelen on his map (fig. 2) even makes a distinction between those of Flores, belonging to the Middle Tertiary and those of Alor and Wetar being still younger, representing some of the youngest granites in the world. It has been mentioned before that van Bemmelen also ascribes the Ambon (and Ceram) granites a tertiary age, however, it is safer to consider their age for the time being as uncertain. It is doubtless correct that those younger granites are related to the tertiary orogenesis and the possibility remains that also the granites of Ambon and Ceram were formed during this last cycle of diastrophism. Upper paleozoic and tertiary granites occur within the area of the Banda Geosyncline (fig. 2). The paleozoic granites appear in the crystalline basement in the centre of the geosyncline (Timor) and the foreland (Sula Spur, Aru Islands). The tertiary granites occur on some islands (Flores, Alor and Wetar) in the hinterland of the outer Banda arc.

The Ambon and Ceram granites, first considered as of upper paleozoic age, later as post triassic, might even be of tertiary age thus belonging to the youngest orogenic cycle. With the possible exception of the Ambon and Ceram granites there appear no real mesozoic granites in the area from which we conclude that no pacific diastrophism took place and that the variscian and tertiary orogenic cycles are responsible for the metamorphism of the crystalline basement and the structural configuration of the present island arcs. A difference in age of the various granite occurrences in Indonesia characterizes the structural difference between the western and eastern parts of the Archipelago. In the western part mesozoic granites are prevalent and consequently the pacific (= mesozoic) orogeny should be considered as the main cycle of diastrophism in this western section. In the eastern part granites of this age are absent and those recorded are of paleozoic and tertiary age and therefore variscian and alpine cycles of diastrophism are responsible for the structural disturbances in the eastern section of the Archipelago.

STRUCTURE

A metamorphic series of para-gneisses and -schists below the permian and mesozoic strata, the unconformable position of sediments of various ages upon this crystalline basement, the occurrence of schist-detritus in triassic conglomerates and sandstones, and the development of a thick triassic flysch-graywacke series from which the clastic material can be considered as the denudation products of an existing mountain system, have lead several authors to the conclusion that the metamorphism of these pre permian sediments was caused by a young paleozoic orogenic phase in this part of the Indonesian Archipelago. This orogeny was also required to develop a certain amount of relief in the earth's crust in order to supply the huge amounts of clastic material building up the upper triassic flysch and graywacke series. It is reasonable to suppose that this young paleozoic phase formed part of the variscian orogenic cycle.

There are no indications for angular unconformaties in the sequence of mesozoic strata; disconformities between the Triassic and Jurassic and the Jurassic and Cretaceous have been reported but further detailed investigations might still reduce the number of these disconformities.

These gaps in the mesozoic sequence and the variation in facies, particularly well developed in Timor, can be explained by submerging and emerging movements of the bottom of the geosyncline. As a result not only variations in facies occur, but it is also possible that certain parts of the sequence were never deposited or were later eliminated by denudation.

Perhaps with the exception of the central part of Ceram, where according to Germeraad *(24)* the Upper Cretaceous passes gradually into the Eocene, a late cretaceous folding (post Senonian and pre Tertiary) has dislocated the various mesozoic deposits. This laramic orogenic phase should in this area be considered as a forerunner of the tertiary orogenesis, responsible for the structural pattern of this arc of islands.

In general it is accepted that one of the typical structural features of this island arc are the overthrust structures which have been studied on Timor and Ceram and which show thrusting features resp. in southern and northern directions. Based on recent research in Timor by D. de Waard *(71)* this author became convinced that Timor shows as well in a morphological as in a structural sense considerable differences with other orogenic areas. There hardly exists any similarity between the structure of Timor and that of other tertiary sheet-mountain systems of the alpine type, though "alpino-type" structures seem to predominate the tectonics of Timor. De Waard reports the following structural differences:

1. a virgation of the folds in a certain direction, which can be seen in nearly all alpino-type mountain systems, seems to be absent in Timor.
2. the Timor nappes are largely built up of soft, incompetent clayey and marly sediments.
3. masses of hard competent rocks, such as irregular complexes of crystalline schists and Fatu-limestones, are irregularly dispersed in the soft, incompetent beds.
4. the position of Timor in a zone of negative anomaly which possibly is related to the special character of the structure.

According to these differences the structure of Timor has her own characteristics and de Waard proposes to replace for Timor the expression "alpino-type structures" by "Timor-type structures". Though a certain succession of the various thrust series in Timor has been established by detailed surveying, it is, according to de Waard, difficult if not entirely impossible to fit these local detailed sections into the ideal general sections as constructed by Molengraaff and Brouwer. He concludes with the words that "the tectonics of Timor give the impression to be rather chaotic and can best be explained by gravity tectonics". Germeraad *(24)* illustrates the occurrence of important overthrusts in Central and East Ceram in a series of sections showing how a flysch nappe has been thrusted over various stratigraphic units and over the foreland in the North. He emphasizes, however, the fact that these sections should only be considered as a preliminary conception and that gravity tectonics in the triassic sediments might very well explain the irregular base of the sheet. More detailed research on Ceram and other islands of the arc might reveal similar chaotic structures as those described from Timor.

CONCLUSIONS

The geological and structural history of Timor illustrates very well the development of, at least, the southern part of the Banda Geosyncline. According to de Waard this history "includes two periods of orogenic activity, the first possibly in young palaeozoic times and the second largely of tertiary age. Between these major structural occurrences has been a long period of relative rest with tectonic events of lesser importance and geosynclinal sedimentation of Timor's overthrust series since the lower Permian and through most of the Mesozoic". The geological history may be summarized as follows de Waard, *(71)*:

1. Sedimentation of argillaceous and calcareous rocks in probably geosynclinal conditions; subsequent subsidence.
2. Early orogenic movements initiating the orogenic cycle; early orogenic or pre tectonic intrusion of basic igneous rocks.
3. Low to medium grade regional metamorphism; for at least the latter part of the time a synkinematic recrystallization i.e. contemperaneous with:
4. The main tectonic phase of the variscian (?) orogeny; syntectonic development of foliation, mineral parallelism, folded structures and microfolds. Formation of syn-orogenic granites (Klompé).
5. Upheavel and denudation, possibly since pre-permian times, since minerals and rock fragments of crystalline schists have been found in Kekneno sediments of permian and triassic age (de Roever *43*); the end of the orogenic cycle.

6. Sedimentation in geosynclinal environment since Lower Permian of various kinds of sediments of the different overthrust series to be. Regeneration of part of the quasi-consolidated variscian area (Klompé).
7. Early orogenic movements of lesser importance, initiating the alpine orogenic cycle, possibly the beginning of overthrusting movements and origin of zones of weakness in the schist basement; early orogenic intrusion of ophiolites, including gabbride and diabasic rocks, in and near the crystalline schists.
8. Pretectonic phases, including the laramide phase, apparent from the unconformity between the mesozoic Palelo series and the Eocene in the sedimentary cover of the schist complex and the savian (?) phase, according to the disconformity between the Eocene and the Lower-Miocene.
9. The main tectonic (styrian?) phase of the alpine orogeny in late miocene times; intense folding and overthrusting of tectonic units initiated in earlier phases; displacement of blocks of crystalline schists to exotic overthrust masses in permian and mesozoic sediments, main origin of ruptural and cataclastic structures, and of border distortions of pre-existing structures in the massifs.
10. Sedimentation since pliocene times, post-tectonic fold-and fault-movements of lesser importance (de Waard *71*).

Based on these conclusions the pre-tertiary stratigraphic and structural history of the eastern part of the Banda Geosyncline can be outlined as follows:

TERTIARY — Beginning of the tertiary orogenic cycle with a moderate laramic phase (= last phase pacific orogeny) with tertiary phases at the end of the palaeogene (savian) and a main phase in late miocene time (styrian).

CRETACEOUS — Uninterrupted sedimentation from the Jurassic into the Cretaceous. On Buru and Ceram in-and extrusion of alkali rocks. Intrusions of ophiolites in the deeper parts of the geosyncline.

JURASSIC — Continuous sedimentation from the Triassic into the Jurassic. In Buru in- and extrusions of porphyrites, diabases and their tuffs. Intrusions of ophiolites in the deeper parts of the geosyncline.

UPPER - TRIASSIC — On Timor developed in 5 different facies, on the other islands mainly developed as a flysch-and graywacke formation.

MIDDLE and LOWER TRIASSIC — Sedimentation only in Timor, Cephalopod facies.

PERMIAN — Sedimentation in Timor, Letti, Babar, and Selu (Tanimbar Isl.). The other islands formed at that time apparently a landmass. In Timor sedimentation accompanied by intrusions and extrusions of a trachy-basaltic nature, indicating that the real geosynclinal stage had not yet started. In Ceram intrusions of dacites and andesites, now occurring as dykes in the crystalline schists.

~~~~~~~~ Unconformity ~~~~~~~~

PRE-PERMIAN — Metamorphism of a paleozoic sequence of sediments into a series of para-gneisses and-schists, possibly caused by a phase of the variscian orogeny, thus forming the crystalline basement for a new geosynclinal series. Synorogenic granites. Deposition of a series of argillaceous and calcareous sediments.

THE BANDA SEA AREA, A LANDMASS IN LATE PALEOZOIC AND EARLY MESOZOIC TIMES?

This question forms since Verbeek's Report on the Moluccas *(69)* one of the most actual problems of the geology of the eastern part of the Indonesian Archipelago. Verbeek's own opinion is "that the deep basins and seas in the Moluccas, the Banda Sea included, are not the remainders of an old deep-sea, but that they have been formed by submergence of old landmasses in old-miocene time, yet mainly, during, or at the end of the Young-Miocene".

Paleogeographically there seems to be sufficient evidence for repeated land connections across the Moluccan region, reaching back into the Paleozoic. This paleozoic continent, called "Aequinoctia" after Abendanon *(1)*, seems to have stretched from Tasmania to Celebes. Its break-up began, according to the same author, in carboniferous time, though it is only in the Permian and Triassic that we encounter geosynclinal facies.

A "Sino-Australian Continent", postulated for jurassic times by Neumayer *(41)* is very improbable since more became known from the
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distribution of marine jurassic deposits in the Moluccas. Umbgrove *(63)* also considered the probability of a late mesozoic landbridge here, though perhaps only developed as island "stepping-stones" in places, for the floral differences alone between the mesozoic of Cathaysia and eastern Australia do not appear to favour a continuous connection. From the topographic point of view, Kuenen *(34)* has demonstrated that it is difficult to draw a hard and fast line between Australia and the Indonesian Archipelago. The Timor trough does not seem to posses the characteristics of an ancient structural "seam".

In the following some facts will be discussed in order to contribute some information to the problem about the existence of a late paleozoic and early mesozoic landmass in the present Banda Sea area.

The rather thick and voluminous upper triassic flysch and graywacke series on nearly all the islands of the outer Banda arc have doubtless been deposited close to an extensive land area. Zwierzycki *(78)* is of the opinion that this land area was located in the present Banda Sea, and Smit Sibinga *(50)* is of the same opinion. With the exception of a few papers on the geology of Ceram and Timor no advances of recent geological fieldwork in these islands have been published since the appearance of Zwierzycki's, Smit Sibinga's and Umbgrove's papers, so that only a re-examination of the existing literature forms the base of our speculations.

Zwierzycki *(78)* mainly bases his conclusion on the distribution of the Triassic in the area: "the Lower and Middle Triassic being only developed in Timor while all other triassic localities belong to the Upper Triassic. Only in the Timor area the sea remained unchanged and an uninterrupted permian—jurassic sedimentation took place. All other localities show the influence of an extensive upper triassic transgression. Close to the island of Timor we have to look for a shelf area which possibly separated a southern deepsea basin from a northern shallow sea area, or litoral zone". His general conclusion is that there existed in Lower-and Middle-Triassic a landmass North of Timor which became submerged during or after the upper triassic transgression.

Smit Sibinga *(50)* subdivides the sediments in the Banda Geosyncline in the following three zones:

a. a zone of litoral sediments, deposited in the immediate neighbourhood of the old shoreline,

b. a geosynclinal zone of shallow-water sediments, containing deposits of coal, oil, and asphalt, and

c. an exterior zone of bathyal to abyssal sediments.

According to this author we find in Timor the facies of litoral sediments (Fatu facies and the Halobia shelf facies) in the NNW. part and the outer zone of bathyal and abyssal sediments (Cephalopod facies) in the central part of the island. In agreement with this position Smit Sibinga concludes to the possible occurrence of a landmass in the area North of Timor in upper triassic time. The distribution of the upper triassic fauna in Ceram indicates also that there must have been a landmass at that time South of Ceram so that the Timor-Banda Geosyncline surrounded a landmass, now occupied by the Banda Sea.

Umbgrove *(63)* has dointed out that the present distribution of the various triassic facies should not be considered as the normal distribution shortly after their deposition but that it is the result of thrusting movements during the tertiary orogeny so that from this present situation no conclusions should be drawn about the possible course of a triassic coastline. In order to get near this problem the original distribution of facies in the area should be studied and investigated properly. The occurrence of areas of denudation on the inner side of the Timor-Ceram arc in triassic and jurassic time, is closely related to pre tertiary folding and vertical movements in the area. Umbgrove concludes to the following two possibilities: either folding and subsequent denudation at the end of the Triassic (early cimmerian) or in the Lower Cretaceous (late cimmerian). In the first case denudation products could be supplied to the Banda Geosyncline in jurassic time in the second case, however, this was possible neither in triassic, nor in jurassic time. According to Umbgrove *(63)* we cannot make it acceptable that in triassic time denudation products were supplied to the Banda Geosyncline from a former landmass in the Banda Sea and consequently he is of the opinion that there existed in early mesozoic time a vast area of denudation along the northern, northeastern and southeastern borders of the Banda Geosyncline which comprised at least northern Australia, New Guinea, Obi and the Sula Islands, and probably also the Banggai Archipelago. His opinion is based upon the lacking of marine triassic sediments in these islands and the occurrence of an unconformity in the Triassic of Misoöl.

On these islands, however, marine Upper Jurassic is developed and in connection with that it is impossible that these islands represented in upper jurassic time a landarea supplying material to the Banda Geosyncline. According to Umbgrove the only possibility remains in northern Australia, where no marine jurassic deposits are known and were possibly never deposited. He emphasizes the possibility that in West and Central Borneo folding took place towards the close of the Triassic (early cimmerian) so that this area might have acted as a supply area for the Banda Geosyncline.

Summarizing we conclude that according to Zwierzycki and Smit Sibinga there must have been an upper triassic landmass in the present Banda Sea area but that Umbgrove is of the opinion that the area of denudation should not be looked for in the present Banda Sea but in the northern, northeastern and southeastern border-regions of the geosyncline, while in jurassic time only Australia and possibly West and Central Borneo have acted as suppliers to the Timor-Ceram zone.

It has been mentioned before that the present distribution of facies in the Timor-Ceram arc is no longer in accordance with the original sedimentation but that the present situation is the result of tertiary orogenic movements (overthrusting, or gravitational tectonics). In case it could be proved that e.g. on Ceram the sediments become coarser further to the South, than the conclusion could be drawn that at least the clastic material should have come from a land-area in the South. In connection with this it is of importance to study the structural features of these islands. It is in general understood that thrusting movements in the Timor-Ceram arc have been directed towards the North, East, and South. Assuming that these various overthrust movements are the result of a simple lateral compression in the earth's crust it becomes clear that the highest thrust-masses have been transported furthest and that their original accomodation was inside the Banda arc. In case it could be proved that these highest thrustmasses, as far as facies concerns, must have originated from places closest to the area of denudation, it would become clear that the main area of denudation should also be looked for at the inner side of the Banda arc.

From Ceram we know that the basement is formed by crystalline schists followed by the Graywacke Series. This series forms a kind of transition zone between the phyllites in the South and the Upper Triassic in the North. Germeraad *(24)* discovered *Lovcenipora* in samples of the eastern continuation of the Graywacke Series. This fossil has also been found in the upper triassic Flysch Formation from which we might conclude that the Graywacke and Flysch formations are of the same age. According to van der Sluis *(49)* the two formations only have a difference in facies and van Bemmelen *(4)* is of the opinion that the Graywacke Series contains more clastic material and has thus been deposited closer to the land than the Flysch. According to the present distribution of these two formations we find that in West Ceram the Graywacke Series occurs more frequently in the southern part of the island than the Flysch, consequently the southern sediments of West Ceram have been deposited closer to a land area than the northern ones. In connection with this the following remarks by Rutten (*44*, p 38) are of importance: "Close to Atiahu, on the Southcoast, there are conglomerates in the Triassic mainly built up of pebbles of crystalline schists. In these conglomerates occur boulders up to ½ m^3 in size of a coralline triassic limestone. These conglomerates have been formed close to the coast where, during their deposition, triassic reef-limestones were destroyed by the surf and included in the conglomerate. This process clearly proves the deposition of landwaste close to the present southcoast of the island and it is possibly true that the further North we go the sediments were deposited further offshore".

For the structure of West Ceram Valk *(67)* is of the opinion that a normal contact between the Graywacke Series and the Upper Triassic Flysch was never observed. Everywhere we find the Graywacke Series thrusted in northern direction against and over the Flysch, which means that the more clastic deposits were originally deposited further to the South, which means closer to a land-area.

It is impossible to make a similar reconstruction for the central part of Ceram, the structural position of the Graywacke Series in comparison to the upper triassic Flysch is not clear so that no dependable conclusions about the original distribution of facies can be drawn. Beside that, it is the opinion of Germeraad that gravitational tectonics complicated the structural picture considerably and made it impossible to reconstruct in a similar simple way the original facies distribution. Stratigraphy and structure of eastern Ceram are not yet cleared so that it is also impossible to reconstruct for this part of the island the original distribution of the triassic facies.

As far as Timor concerns we have seen already that, according to Smit Sibinga, the litoral Fatu and Flysch facies and the Halobia facies were originally bordered in the South by a zone of bathyal and abyssal sediments (Cephalopod facies), which indicate the occurrence of a landmass North of the geosynclinal basin, but in general the structure is here too complicated to allow a reconstruction of the original distribution of the triassic facies. Recent field investigations in Timor have convinced de Waard *(71)* that gravitational tectonics plays an important role in explaining the structural features of Timor, which makes it, of course, all the more difficult, if not entirely impossible to unravel this complicated structure and also to reconstruct the original distribution of the various types of sediments in this part of the Banda Geosyncline.

Little is known about the structural features of the other islands of the outer Banda arc so that it is not possible to use the geology of these islands to reconstruct a general distribution of facies over the whole area.

Weber (in Umbgrove *63*) makes the following interesting remark in consideration to the occurrence of an old landmass in the Banda Sea area: "On account of the absence of index-fossils the stratigraphic position of certain finegrained white rocks, closely connected with radiolaria-hornfels, occurring on Tanimbar and Ceram has not yet been cleared. Lithologically these rocks show great similarity with quartzsandstone containing *Macrophalites*, *Belemnopsis* and *Aucella* occurring on Misoöl and belonging to the Lower Malm (Oxford). This sandstone is very pure and contains only little mica and clay. Because the two main occurrences (Tanimbar-Ceram) of this sandstone are at distances of 400-600 Km in N-S direction from each other, it is logic to suppose that a landmass of equal lithologic (and possibly also stratigraphic) character must have occupied the present Banda Sea in jurassic time. Coarser grained quartzsandstones, possibly also of jurassic age, have been encountered at the entrance of the Bay of Kolonedale and show a great similarity to rocks from the small island Tobea, North of Moena". From this remark we conclude that the landmass was emerging in triassic time and still existed as such in the Upper Jurassic, submerging must have taken place in post jurassic time.

This also demonstrates clearly the great importance of sediment-petrographic data for such problems, but also that an increase of our elementary knowledge of the pre tertiary history of the Greater and Lesser Sunda Islands will be of the greatest importance for obtaining an insight into the mesozoic history of the Banda Sea area.

Though a study of the original distribution of the various types of sediments in triassic time in West Ceram contributes only little to the solution of the problem on the occurrence of an old landmass in the Banda Sea area and to that of epeirogenic movements in this area at the end of the Triassic, I believe that there are sufficient arguments to accept that the thick and voluminous Graywacke Series and upper triassic Flysch sediments have originated from an emerging landmass situated on the inner side of the outer Banda arc.

However, much more information on the stratigraphy and structure, type and direction of the movements of the Banda Geosyncline should be obtained before this problem can be solved satisfactory.

The supposition of the occurrence of a late paleozoic—early mesozoic landmass does not include that all clastic sediments have derived from it. With Umbgrove the author is of the opinion that in the Upper Triassic also clastic products from the Sula Islands, Obi, West New Guinea and northern Australia have contributed considerably to the gradual filling-up of the subsiding Banda Geosyncline.

The old landmass was peneplained in early mesozoic time, submerged since than along faults and now forms the floor of a deepsea basin. This is completely in agreement with Kuenen's supposition (*34*) that the Banda Basin belongs to a group of basins caused by faulting. The gravimetric map of this area shows that the Banda Sea area has a positive anomaly which possibly means that submergence and faulting are the possibilities for re-establishing the broken isostatic equilibrium. Nothing definite can be said about the time of submerging but this definitely happened in post jurassic time. According to Kuenen *(34)* the development of the present strong relief of the East Indies was accomplished in miocene and post miocene time. Direct evidence, as to the age of formation of the present deep depression is not available. Nevertheless there are two arguments in favour of a comparatively recent development. In the first place, Umbgrove points out, that there occur since the Mesozoic no stratigraphic indications of deeper facies in any division of the geological timescale, in the entire archipelago. In the second place, Molengraaff drew attention to the fact that the miocene folds of Timor are cut off obliquely by the present coast, which is directly fronted by the deep basins. These basins thus appear as the counterparts of the rising geanticlines to which they run parallel. From these two facts it becomes evident that the present deepsea relief of the Indonesian Archipelago is a characteristic feature that must have originated during the recent geological past (Umbgrove *64*). Kuenen *(34)* arrived at an analogous opinion about the origin of these deepsea basins and exhaustively argues that the deepsea basins originated recently by the subsidence of "continental" (sialic) areas.

THE SAHUL SHELF AREA

While in a geographical sence Australia is an isolated landmass, inspection of a bathymetric map shows that it stands upon the same submerged shelf or platform with New Guinea and Tasmania, and that the combined continental mass is separate and distinct from the continent of Asia. About the mutual relations of these two continents during geological time much difference of opinion exists, but there are certain grounds on which former land-connections between them have been claimed. There are geologists who consider that the present contiguity of SE. Asia and Australia has only been attained since mesozoic time. There can, however, be no doubt of the continuity of Australia with Tasmania and New Guinea in tertiary time, but apart from this there are evidences of extensions of the continent, in both East and West beyond present limits, in the geological past.

In the West the fact that folded geological formations ranging in age from Pre-Cambrian to Tertiary, deposited in the Westralian Geosyncline are truncated by the Western Australian

Fig. 8.—Geotectonic Sketchmap of Northwestern Australia and the Sahul Shelf after Fairbridge (1952).

coastline is in itself an indication of former extension into the Indian Ocean (David *15*, Vol. I, p. 686).

The westernmost part of the northern connection between Australia and New Guinea, the Sahul Shelf, forms in its position between Australia and Asia, facing the Indonesian Archipelago, a critical zone. "Matters of fundamental importance to Australian-Asiatic geotectonics and palaegeography are bound up in this region". "Nothing is known directly of the geology of the Sahul Shelf since no continental rocks are exposed on it. So we must look for analogies on the adjacent mainland".

With these words Fairbridge respectively closes and opens his description of the structure and geological relationship of the Sahul Shelf area in one of his many publications on this area (Fairbridge *19*). It is particularly this author which made geologists familiar with this part of the continental shelf North of Australia and the following summary on the structure and geological relationships of this shelf area is based on Fairbridge's publications *(18, 19, 20)*. According to this author *(19)* the northern Australian continental shelves are divisable conveniently into three; the Rowley Shelf (West of Cape Leveque); the Sahul Shelf (sensu stricto); and the Arafura Shelf (East of Cape van Diemen, but not including the Gulf of Carpentaria, which is contiguous to it) (fig. 8). Most Dutch geologists (e.g. Brouwer *8*; Zwierzycki *79*; Kuenen *34*), referring in their publications to the Sahul Shelf, take it to cover the entire northern border of Australia, extending 2,000 miles from North-West Cape and Exmouth Gulf in the West to West New Guinea and Torres Strait in the East, including even the shelf-sea, extending West of the "Birdshead" of New Guinea to Misoöl. Fairbridge, however, restricts this name to the central part only, an area 500 miles long and 200 miles across.

This shelf area is, particularly by Dutch geologists, often considered as the counterpart of the Sunda Shelf which extends on the Asiatic side of the Indonesian Archipelago. This comparison might be a sound one from a geomorphological point of view but from this synopsis it will become clear that the structural features and geology are certainly not the same. On the Arafura Shelf the Aru Islands represent the only continental shelf island so far out. Most authors now agree that they belong structurally to the Australian-New Guinea continental block (Gregory *26*; Fairbridge *18*). Verbeek (*69*, p. 175) described the Arun Islands as a low miocene-pliocene limestone plateau, entirely horizontal, but much jointed and dismembered into blocks and recemented by a cover of young coral limestone. The mio-pliocene beds are very gently folded (Tayama *59*). Coarse grains of terrigenous minerals in the otherwise calcareous sediments (quartx, mica, felspar) indicate that the basement is not far off, and in one small locality near Sia (Serani), Tissot van Patot *(62)* found granite (according to van Bemmelen, *4*) which Zwierzycki compared with a similar boss at Mabaduan on the Southcoast of New Guinea. As has been stated already Fairbridge accepts a pre-cambrian age for both granite occurrences but several geologists, including the author, ascribe them an upper-paleozoic age.

As far as the quaternary history of the islands concerns, there are several significant features. Firstly the essentially "Australian" character of the Aru Fauna and flora; secondly, there are no emerged pleistocene coral-reefs on Aru (Kuenen *33*), and thirdly there are the peculiar "sungeis", which are deep channels crossing the islands from side to side. Wallace (1857) suggested that they were remnants of drawned stream beds; others, however, (Verbeek *63*; Brouwer *7*; van Straelen *56*) have concluded that these initial lines of weakness were due to jointing or perhaps even faulting. From this quaternary material the conclusion can be drawn that the Aru Islands represent the summit of a broad ridge. This inconspicuous rise, called Merauke Rise, extends from the Aru Islands to Prins Frederik Hendrik Island (fig. 9) and from there along the Oriomo axis of southern New Guinea via Torres Strait to the York Peninsula of Australia. On this Merauke Rise, representing the margin of the continental shield of Australia some isolated exposures of the pre-tertiary basement complex are found, covered by a thin veneer of tertiary and quaternary sediments (granite basement on Aru Islands and Mabaduan in South New Guinea). This rise which was slowly arched up from the Arafura Shelf towards the close of the Pleistocene might also be considered as a relict still showing the original trend of an older mountain system possibly of variscian age in conformity with the age of the occurring granites. Also the initial lines of weakness on the Aru Islands, possibly caused by faulting, are showing a similar E-W trend. It is apparent that the Aru Islands belong structurally to Australia, although they differ from the major units of northern Australia in view of their age.

The surface of the Sahul Shelf is far from even. It lacks the smooth contours of the Sunda Shelf.

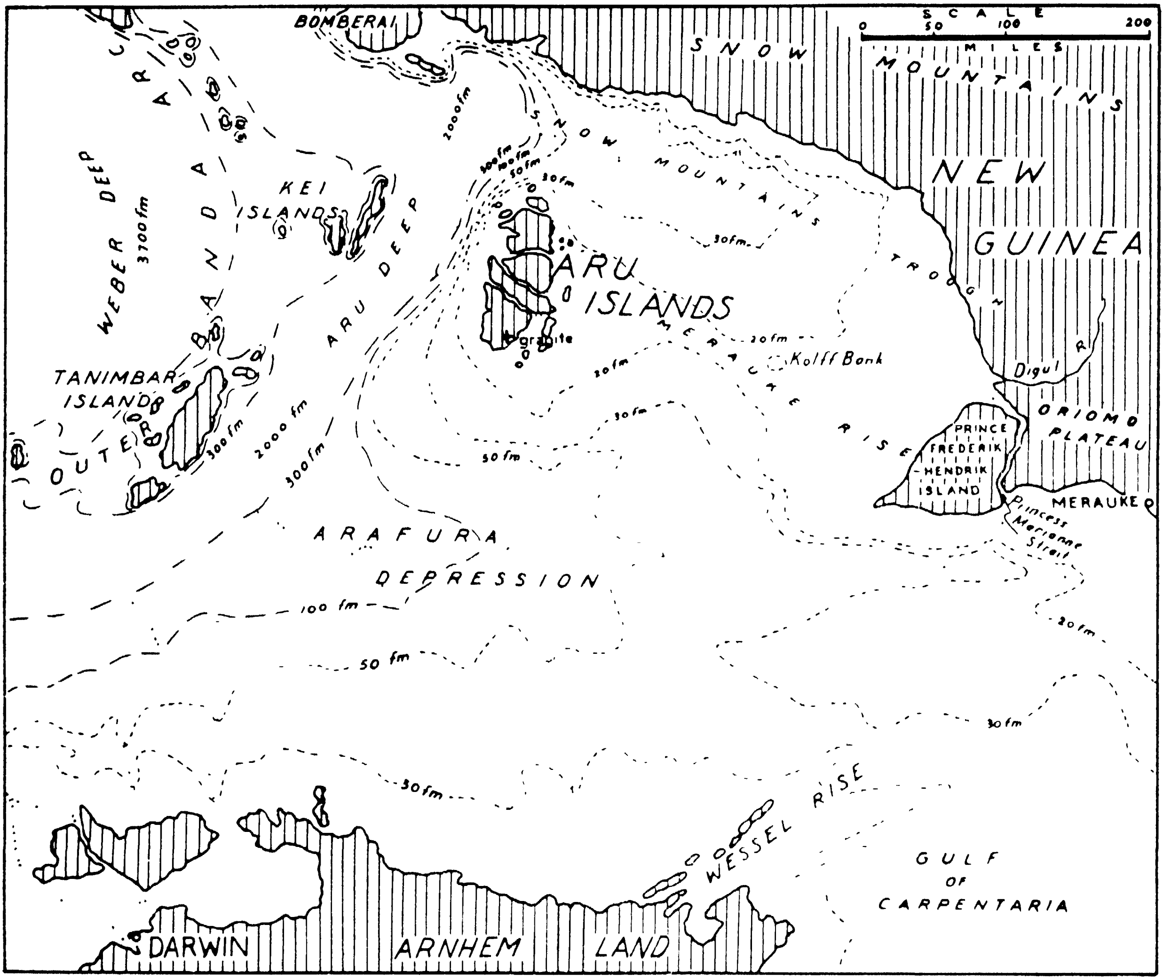

Fig. 9.—Bathymetric chart of Arafura Depression showing "Merauke Rise" and "sungei's" of the Aru Islands (Fairbridge 1951).

On the contrary, the Sahul Shelf is divided into many flat-topped plateaus and terraces, in places with submarine "cuestas" sloping down the shallow basins or depressions (fig. 8).

Since the Aru Islands form the only exception of continental rocks exposed on the shelf area we have to look for analogies on the mainland in order to obtain some information about its geology and structure. One of the most important papers on the geology of the Australian Continent in recent years is a study of the tectonic trends by Hills *(27)*, who assayed a first attempt at a structure pattern for the older pre-cambrian rocks (fig. 10). Fairbridge *(17)* extended Hills' tectonic pattern to cover the whole Australian-New Guinea-New Zealand area in a broad way (fig. 11). He adopted Stille's idea of Eo-, Paleo-, Meso-, and Neo-Australia, but modified the outline sketches prepared by Kölbel, *32*; Stille, *52*; and Glaessner *25* considerably. "Structurally the northern part of Australia consists of a number of major tectonic blocks, which are marginal to the great pre-cambrian shield and show alternating positive and negative tendencies to rise or sink during post archaean times. Only the early pre cambrian rocks of this region are extensively folded, metamorphosed, and intruded by granites. All subsequent sediments are flat-lying or gently folded, and hardly at all metamorphosed. The folding is restricted to narrow, active belts asso-

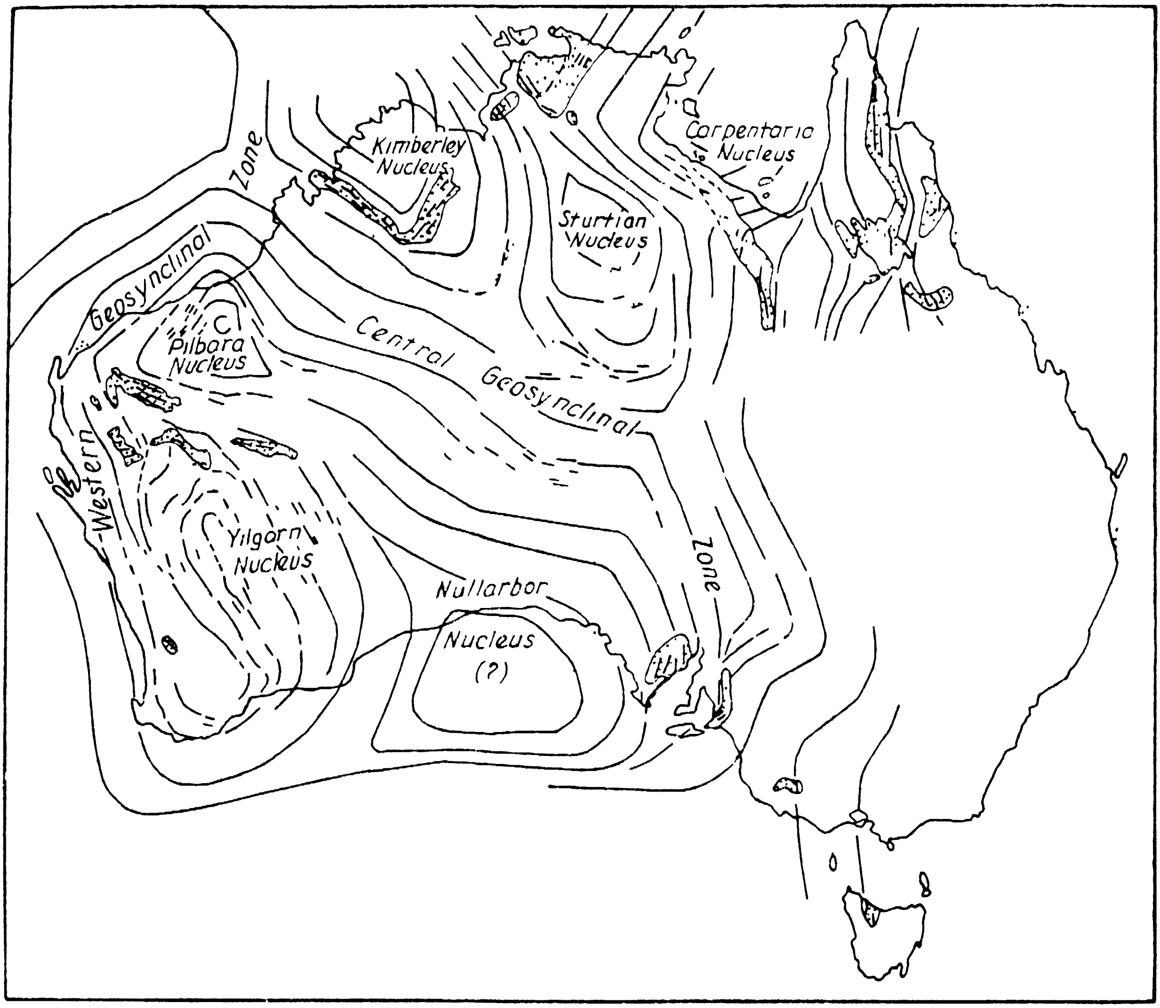

Fig. 10.—The pre-Cambrian nuclei of Australia after E.S. Hills (1945).

ciated with the margins of the blocks, which are generally bounded by major normal-faults, monoclines or broad warps. Post Archaean diastrophism is thus mainly epeirogenic, with restricted fragmentation (taphrogeny) and fault-folding of Saxonian type" (Fairbridge *19*, p. 14) "These pre cambrian blocks are marginally overlapped by a series of younger basins ("paraliageosynclines" in the terminology of Marshall Kay 1951; "paralic basins" of Tercier). These represent broad downwarps of the continent, being now filled up to 20,000 feet of sediments ranging in age from the paleozoic to the Quaternary. Locally these sediments are heavily faulted and gently folded (Germanotype tectonics), but nowhere are they affected by major orogenic compression" (Fairbridge *20*).

From West to East the following structural units of the mainland can be distinguished (figs. 10 and 11):

a. Pilbara Block.
b. Canning or Desert Basin.
c. North Kimberley Block.
d. East Kimberley and Western Rivers Basins.
e. Arnheim Block.
f. Carpentaria Depression.
g. Carpentaria Block.

Only some of Fairbridge's *(19, 20)* general conclusions in regard to the geology of these various

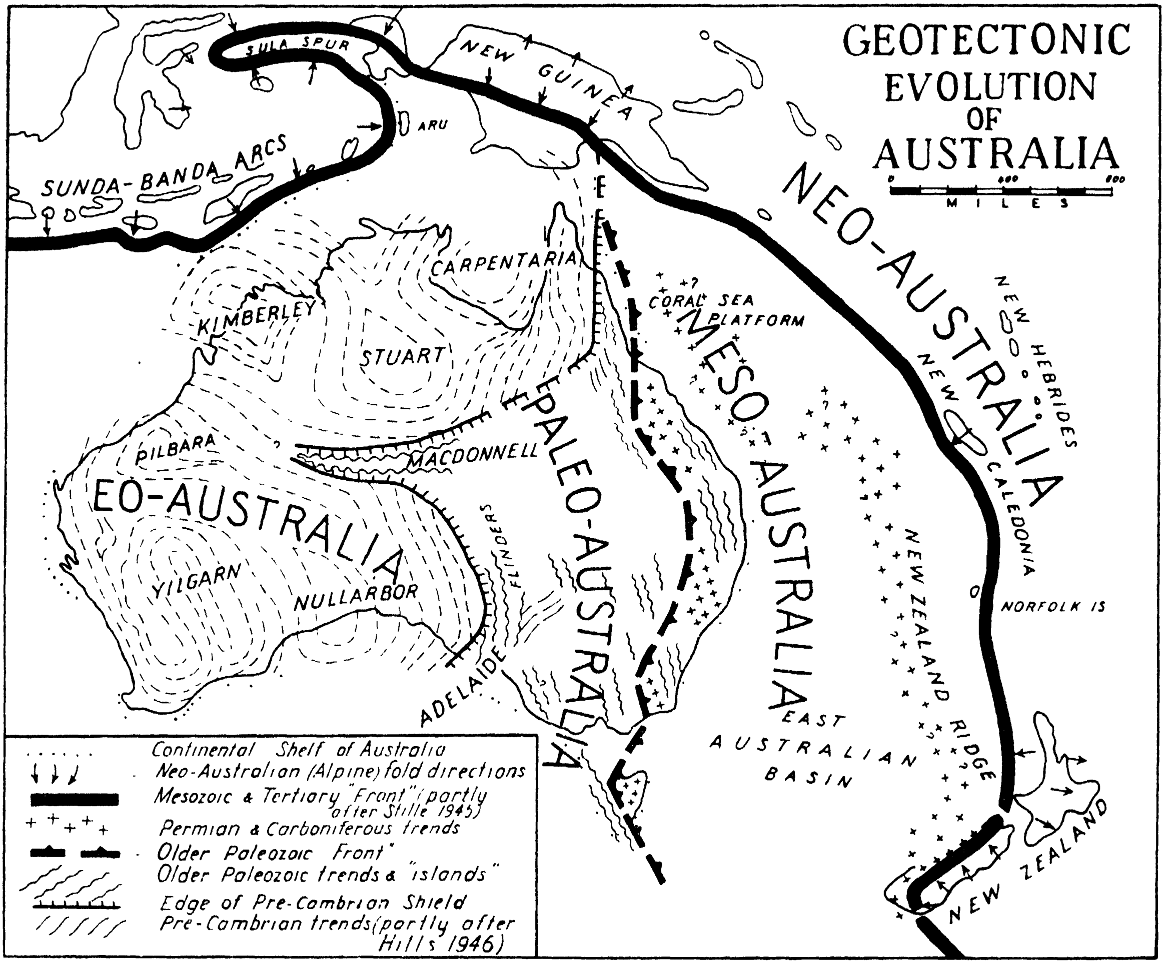

Fig. 11.—Eo-, Paleo-, Meso-, and Neo- Australia according to Fairbridge (1950).

structural units will be mentioned here. The adjacent continent of the North Australian Shelf area consists of a number of topographically, structurally, and stratigraphically well marked blocks and basins, which can be traced into the shelf area, were depressions and rises are arranged opposite the basins and blocks of the continent so that the histories of the continental shelves are directly related to the tectonic history of the adjacent continent. The deep-sea basins in turn seem to lie opposite the broad shelves and the continental basins, while the deep-sea ridges lie in the same trends as the pre cambrian structural "grain" of the mainland. From this it may be concluded that the features of the deep-sea floor are intimately related to those of the continent, a point recently re-emphasized by Cloos *(14)* and Lees *(38)*.

Stratigraphic and paleogeographic data indicate that much of northern Australia and its continental shelf region have been continental since Archaean times. Paleogeographic and faunistic connections suggest that this continental area (either as land or shelf) formerly extended far to the Northwest including the northern Moluccas in mesozoic times and possibly even reaching to Celebes in the Late Paleozoic. The geosynclinal evolution of the Timor-Banda arc set in with the Permian and Trias, apparently encroaching on the old continent. From Timor south-westwards, however, there is nothing to suggest that the present limit of the continental shelf (and slope) has not approximated to the margin of the continent for very long periods (Fairbridge *19*, p. 29).

In connection with his gravimetric research of the East Indies, Vening Meinesz made also an examination of the adjoining Timor Trough and in a few places extended it into the shelf. This was enough to show that on the Sahul Shelf there is generally a regional isostatic anomaly of less than plus 50 milligals, comparable to that of the

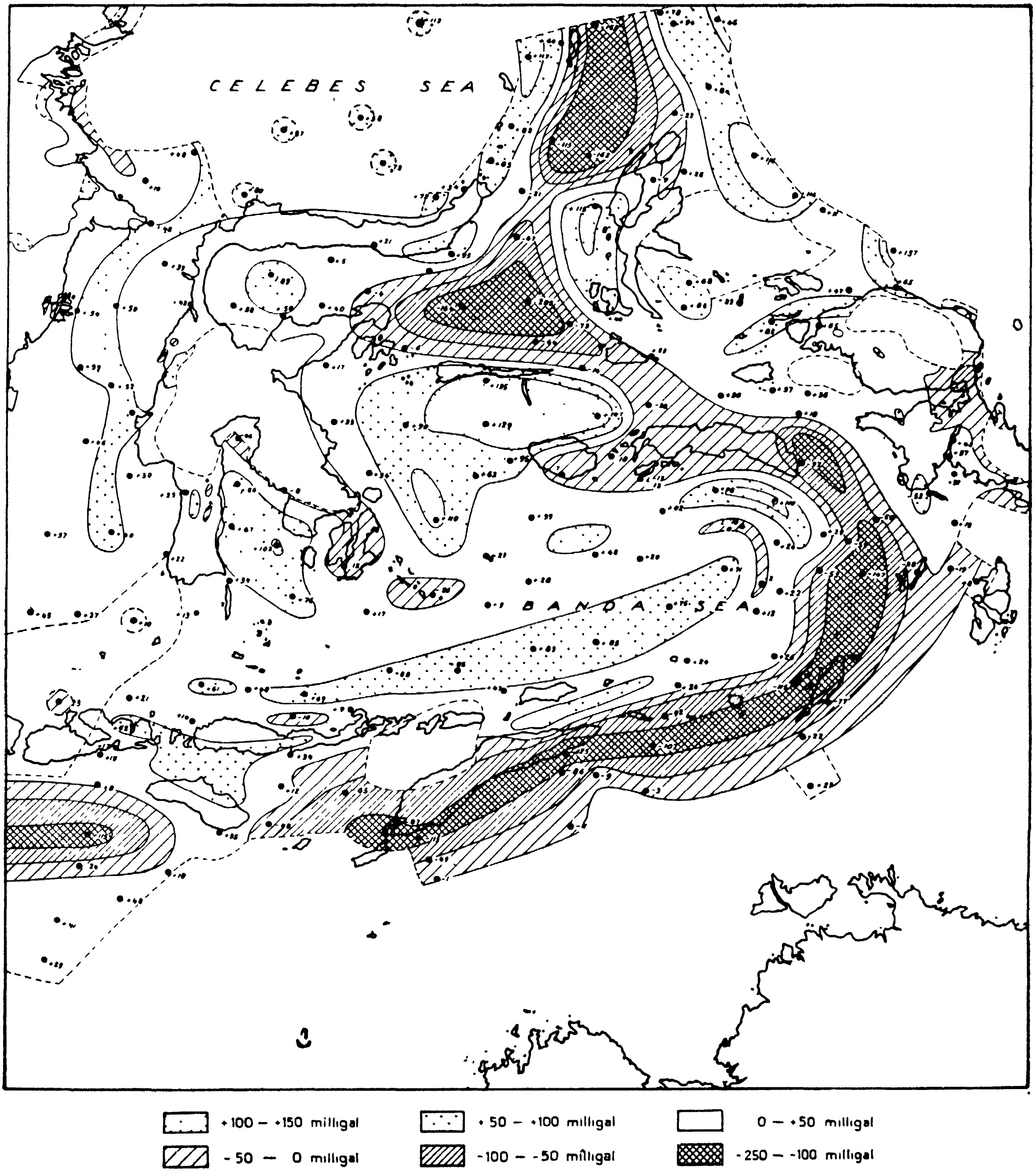

Fig. 12.—Isogam Map of the Eastern Part of the Indonesian Archipelago (Scale 1:10,000,000).

Sunda Shelf (fig. 12). The Timor Trough anomalies are quite characteristic of continental margins (Vening Meinesz *68*). While the bathymetric curve slopes down from the shelf edge to the floor of the Timor Trough, the gravity anomaly curve maintains a high course (mostly on the positive side) for a considerable distance beyond the shelf edge before it plunges to the negative. Actually it reaches its lowest at a point roughly coinciding with the Southcoast of Timor (over minus 100 milligals), after which it rises steeply again to a notable positive anomaly in the interior of the inner Banda arc. It gives the impression that the continental structure and material of the Sahul Shelf continue out beyond the actual edge of the shelf. (Fairbridge *19*, p. 20).

In reviewing the evidence of the belt of negative anomalies coincident with the belt of the outer Banda arc and its "foredeep", the Timor Trough, Kuenen (*34*, p. 62) writes: "The Australian Continent influences the direction of the line of negative anomalies, but hardly in character or intensity. There is nothing in the gravity field to indicate either that the Australian block was forced up against the arcs, or that the outer Banda arc was originally a regular curve and was subsequently moulded up against the already existing slope of the continent".

Fairbridge ends his paper on the structure and geological relationship of the Sahul Shelf with the following general conclusion (*19*, p. 24): "There seems to be evidence for concluding that the present geomorphologic relationship of the outer Banda arc to the Timor-Aru Troughs and the Sahul-Arafura shelves is a relatively recent (i.e. late tertiary and quaternary) phenomenon. The relationship between the mesozoic-tertiary mobile zone and the semi-rigid foreland appear to follow out a normal transition in the northern Moluccas, though are obscured in the Timor Trough-Sahul Shelf sector.

In the Banda arcs there is no sign of the borders of the ancient Australian Continent, which may have extended much further North and West than it does today".

VARISCIAN OROGENY IN AUSTRALIA AND ADJACENT AREAS

Sometimes a comparison is drawn between India and Australia. India, dominated in the North by the huge arc of the Himalayas and fronted by the depression of the Indo-Gangetic plain, beyond which stretches the old pre cambrian mass of Peninsula India. This last has its counterpart in the present Australian Continent and the first in the mountains of New Guinea and the island-festoon which stretches from it to New Zealand. The intervening depression is represented by the deeply foundered Tasman and Coral Seas, the shallow Arafura Shelf and the lowlands of southern New Guinea.

This comparison, however, is not very satisfactory because it has now become clear that the Australian Continent was built out to the East and Northeast by repeated deposition followed by folding and uplift of the geosynclinal sediments, around a pre cambrian nucleus. A corresponding phenomenon has not been reported from the northern border of the pre cambrian mass of Peninsula India.

A first attempt at a very broad tectonic classification of Australia was made by E. Suess in his "Face of the Earth" *(58)*, when indicating the successive belts of alpine folding in New Guinea—New Hebrides—Fiji—New Zealand, as the First, Second, and Third Australian arcs; the paleozoic folds of eastern Australia he indicated as Australian Cordillera, and recognized to the west of these a broad tableland, similar to the pre cambrian cores of other continents.

In more recent time several authors have reviewed the geotectonic evolution of Australia (David *15*; Kölbel *32*; Fairbridge *17* and Hills *27*), and in the following the conceptions of Kölbel (*32*) and Fairbridge (*17*) on the occurrence of variscian orogeny in eastern Australia will be discussed in connection with a possible extension of this zone to the Northwest.

In the general recapitulation of Volume 7/8 of the "Geotektonische Forschungen" dealing with "Die tektonische Entwicklung der pazifischen Randgebiete II", Stille (*52*, p. 276) remarks that there occur in the western border region of the Pacific only two areas from where important variscian orogenic activity is reported. These areas are eastern Australia and Peninsular Indo-China. In eastern Australia the bretonic, middle and upper variscian phases have been active. It is remarkable that in Australia the variscian folds do not show advancements towards the continent against which the virgations are generally directed but, on the contrary, show a continuous retreat in the direction of the Pacific. The results of the variscian orogeny must have reached till New Caledonia and New Zealand and possibly occupied the whole section of Neo-Australia (fig. 13). On account of the conformity in the permian-triassic series of New Caledonia the folding should

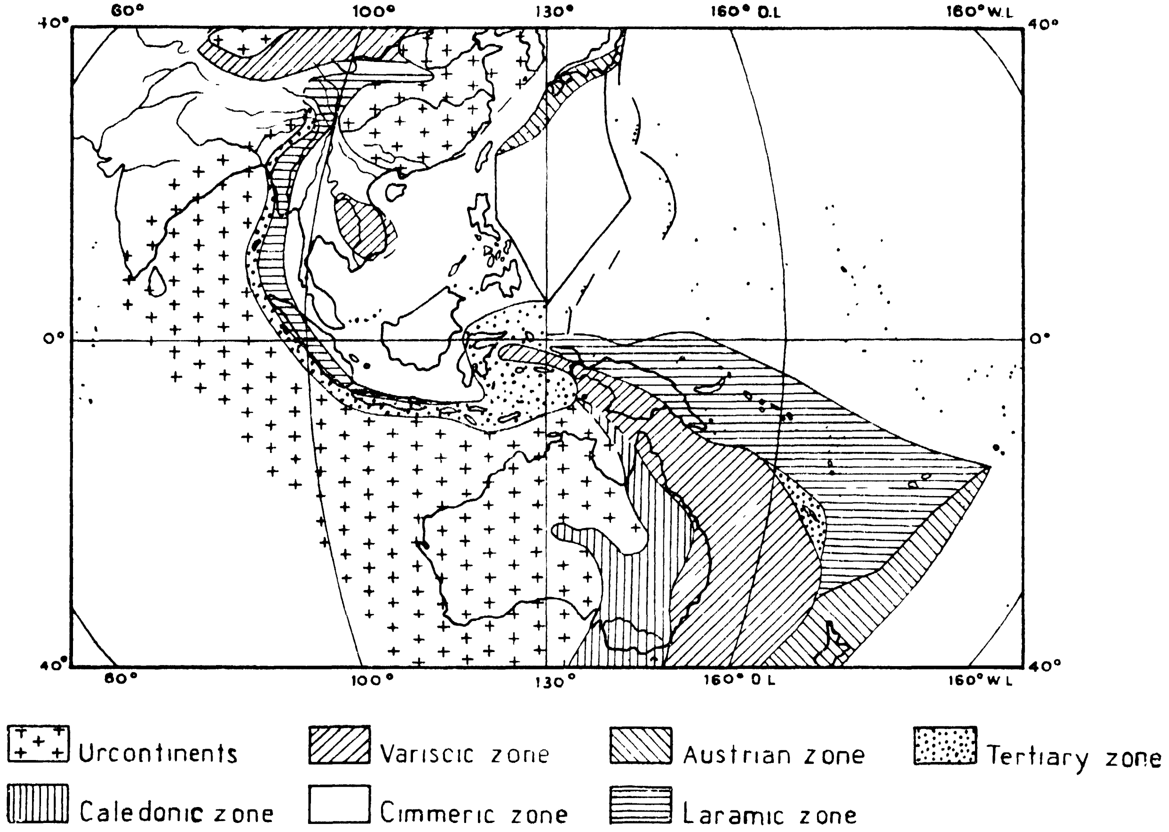

Fig. 13.—Orogenetic zones in the SW. Pacific after Stille (1945).

have taken place in middle variscian time and the same can be expected for New Zealand.

To the Northwest this folding, inclusive the intrusive activity, extended till in New Guinea and further West till in the Sula Spur (Klompé *30*). In the remaining part of the Indonesian Archipelago variscian folding seems to be absent because the dominating magmatic activity was in upper paleozoic time exclusively of the initial type.

In this same volume of the "Geotektonische Forschungen" Kölbel (*32*, p. 187) discusses in the chapter on the geotectonic evolution of Australia the following occurrences of variscian phases of orogeny in the Eastern part of Australia (fig. 14): The results of the bretonic phase (IIIa) are found in the southeastern part of New South Wales and possibly also the foldings in the Hodgkinson, Palmer, and Pascoe drainage areas of Queensland and in eastern Victoria are of the same age.

In New England (northeast New South Wales) and South of Townsville (eastern Queensland) the Carboniferous and partly also the Permian, are stongly dislocated. A strong middle variscian phase (IIIb) is reported from the western part of New England, while considerable upper variscian movements (IIIc) are known from eastern Queensland and New England from where also contemporaneous intrusions and ore deposits are known. In his short review on Australian geotectonics, Fairbridge (1950), though adopting the Stille idea of subdividing Australia in Eo-, Paleo-, Meso-, and Neo-Australia (fig. 11), modified considerably the outline sketch prepared by Kölbel (fig. 14). Comparing both conceptions we see that Fairbridge restricted his Meso-Australian belt to a much narrower zone near the eastern seaborder of Australia, bounded in the West by a tectonic line running from the Bowen Basin in Queensland to the Hunter Valley (S. of New England). In the North the part of Kölbels Meso-Australia of the Cape York Peninsula is included in resp. Paleo- and Eo-Australia, while in the South the border between

Fig. 14.—Eo-, Paleo-, and Meso- Australia according to Kölbel (1945) IIIa bretonic, IIIb middle variscic, IIIc young variscic.

Meso- and Paleo-Australia is drawn much further to the West, while here also the eastern part of Tasmania is included in Meso-Australia. The rocks in this belt were folded and intruded by granites during the various phases of the variscian revolution. Parts of this zone are covered by younger deposits, but these are nowhere intensely folded. Younger faulting has produced monoclinal and associated folds, but these are not truly orogenic in character. The eastern limits of this belt are, for the most part, buried beneath the Tasman and Coral Seas and New Zealand geologists are of the opinion that it extends as far East as the deep submarine ridge West of New Caledonia. A small amount of late cretaceous folding in the extreme East of Queensland might be mentioned but from the general character of post paleozoic earth-movements it seems that these folds are simply associated with the block-faulting of Meso-Australia.

The differences of opinion between Kölbel and Fairbridge on the age of diastrophism in the Cape York Peninsula will be discussed more in detail as they are of particular interest in regard to our conception on the continuation of the belt of variscian orogeny in northwestern direction toward the Indonesian Archipelago. Characterizing the part of Eo-Australia in "Problems of Australian Geotectonics", Fairbridge *(17)* mentions that Eo-Australia not only covers the whole western part of Australia but reaches even as far as northern Queensland. In this respect his conception differs considerably from the earlier representation by Kölbel *(32)*, which depicts a paleo- and meso-australian zone in northern Queensland. The only argument, mentioned by Fairbridge, to support his idea is the occurrence of pre cambrian metamorphics and granites in northern Queensland with a possible extension of these to Torres Strait, Mabaduan on the South-east of New Guinea and the Aru Islands.

Kölbels conception is based on a careful examination of the existing literature. According to him the so-called "Drummond Revolution" (Reid *42*) belongs at the earliest to the bretonic, possibly even to the middle variscian orogenic phase, dependent on the age ascribed to the Aneimites Series which can be compared with the lower carboniferous Kutting Series of New South Wales which possibly also includes the Upper Carboniferous. In the Drummond Mts. the Lower Carboniferous of the Upper Star Series with *Lepidodendron veltheimianum* is unconformably overlain by the permian Lower Bowen Series.

In the Hodgkinson — Palmer area the upper devonian Lower Star Series with *Lepidodendron australe* are conformably and very strongly folded together with the Gothlandian of Chillagoe (Bryan *13*; Reid *42*). The various folds trend N. to NNW. and partly even NW. to WNW. At Mt. Mulligan, northeast of Chillagoe these highly dislocated layers are unconformably overlain by the Permian.

In the Pascoe River area, on the Cape York Peninsula, metamorphic schists are overlain by non-metamorphic, but folded beds with *Lepidodendron* and *Cordaites*. Here, apparently, two diastrophic phases occurred, one before and one after the deposition of the younger carboniferous sequence. The age of the first phase is questionable, but that of the second one is definitely bretonic or middle variscian, like in the other sections of the same belt. Intrusions and ore deposits accompanying this orogenic phase are unknown but possibly the gold and tin deposits in the hinterland of Cairns and Cooktown, the silver-lead occurrences and copper ores of Chillagoe, Herberton and Clermont are connected with the "Drummond Revolution".

Also David and Browne (*15*, p. 325) recognize the end of the Lower Carboniferous as an important epoch (the great Kanimbla epoch) of orogeny and plutonic intrusion, being the greatest and most important in the history of the Tasman Geosyncline. According to these authors "the incidence of the movement appears to have extended from Cape York to the South of Tasmania, a distance of more than 2,000 miles, and to have affected the whole of the zone of paralic sedimentation, together with some of the marine zone to a total width of about 600 miles. Not merely were the carboniferous strata folded but also the upper devonian, and in places middle and lower devonian beds as well. The total thickness of carboniferous and devonian strata subjected to folding was moderate, and over most of the area involved probably less than 10,000 feet. The resultant uplift in the orogenic belt was not necessarily very great, and indeed there is some reason for believing that a series of ridges or mountain ranges may have been formed with belts of scarcely folded and only slightly uplifted sediments between. Along the margins of differential uplift there was doubtless some readjustment by faulting. As a result of the orogeny the upper carboniferous geosyncline was severally contracted, and restricted to a relatively narrow coastal belt".

This short survey shows that there are sufficient arguments in favour of Kölbels interpretation that the NE. part of Queensland has been strongly dislocated by various phases of a variscian orogenic cycle, which foldaxes trend in N. to NNW. (Hodgkinson-Palmer area), NW. to WNW. (Chillagoe area), and NNE. to NE. (Pascoe area) directions. In a paper on the "Geotectonic Position of New Guinea", Glaessner recognizes 12 elementary units in the structure of the island of which the description of the southern stable area is particularly important to us (*25*, p. 858). "This area is characterized by shallow granitic basement, cropping out only near the southernmost point of the island, and disappearing northward under a thin cover of late tertiary sediments, mainly in limestone facies, and alluvium. It has long been recognized that the southern part of New Guinea belongs to the Australian Continent from which it is separated only by the shallow marine transgression of Torres Strait. Owing to this separation and the sedimentary cover it is impossible to recognize within the geologically "Australian" part of New Guinea distinctions between the tectonic elements of the adjacent part of Australia. Their distribution suggests, however, that part, if not all, of the stable area of southern New Guinea lies in the continuation of the folded geosynclinal zone of eastern Australia rather than on the pre-cambrian Shield. It seems likely that folded paleozoic sediments, intruded by granites, continue in a northwesterly direction towards the folded ranges of western New Guinea, where silurian (?), devonian, and younger paleozoic sediments appear. There could still be room for an extension of the pre-cambrian Shield underneath the tertiary veneer in southwestern New Guinea. On the other hand, the Great Artesian Basin extends to the southern and eastern shores of the Gulf of Carpentaria and over the western part of Cape York Peninsula. It is possible that the mesozoic strata of this basin reach New Guinea and that they mask there, as they do on the Australian mainland, the borderline between shield and geosyncline". On Fairbridge's geotectonic sketchmap the southern part of New Guinea is included in Eo-Australia, forming part of the pre-cambrian Carpentaria Block. The main reason for not accepting a younger, variscian cycle of orogenesis for this stable part of New Guinea is that the trend of such a zone would be "quite contrary to the pre-cambrian "grain" of Arnheim Land and north Queensland" (Carpentaria Block, Hills *27*; Fairbridge *18*, *26*). In his geotectonic sketchmap (fig. 11), however, he sketches the "grain" of the northern part of the Carpentaria Block parallel to the strike of the continuation of a variscian zone passing through this area to the Sula Spur, as accepted by others (Stille *52*; Klompé *30*).

Since more details about the structural features of the pre-cambrian continental blocks have been obtained it is now generally accepted that these blocks are composed of pre-cambrian consolidated nuclei, welded together by younger pre-cambrian and post-cambrian orogenies. They show the features of a huge "porphyroblastic gneiss", in which the porphyroblasts are represented by the old nuclei and the surrounding, younger zones represent the matrix, smoothly surrounding these porphyroblasts. Good examples of such structures can be observed in the African and Australian Shields and the Indian Peninsula, where the "grains" of the different nuclei and orogenic zones are often quite unconformable to each other.

CONCLUSIONS

A review of the pre tertiary stratigraphic and structural development of the Banda Geosyncline and the re-examination of the literature on the problem of the Banda Sea area have lead the author to the conception that there existed in late paleozoic — early mesozoic time a landmass in the eastern part of the Indonesian Archipelago, occupying at least the present Banda Sea area, the zone of the outer Banda arc and the area North of it, called the Sula Spur (Klompé *30*).

A process of regeneration of marginal parts of this land-area started in the South (Timor) in permian-lower triassic time and spread to the North (Ceram) with the result that a new geosynclinal area, the so-called "Banda Geosyncline" was introduced in Indonesian geology. The various strata deposited in this geosyncline show no signs of participating in the pacific orogenesis, stratigraphic gaps and changes in facies are the result of movements of an epeirogenic character. This regenerated zone should be considered as transitional and of only semi-mobile character and should be distinguished as an "intermediate area" and evolves tectonically with intermediate type structures (Saxonian or Germanotype of Stille), but which do not reach the degree of mobility that results in granitization or plutonic injection.

The influence of the tertiary orogeny on the Banda Geosyncline has produced intermediate type structures, assuming that the overthrust structures on Timor and Ceram are the result of gravitational tectogenesis in a descending basin. The chapters on the Sahul Shelf area and the occurrence of an important belt of variscian orogeny in eastern Australia and northern Queensland make it acceptable that the pre-cambrian nuclei of the Australian Continent can be traced to the North and Northwest over certain distances of the Sahul and Arafura shelves, while the belt of variscian orogeny (Meso-Australia) should be traced from northern Queensland (Cape York Peninsula) to southern New Guinea, Ceram, the Sula Spur, the Aru Islands and Timor, including the late paleozoic landmass in the Banda Sea area which also should be considered as the result of the variscian orogeny.

THE STRUCTURAL CONTRAST BETWEEN WEST AND EAST INDONESIA A NEW STRUCTURAL SYNTHESIS

The various conclusions reached in the first and the second part of this paper lead to the general and main statement that there is not only a great difference in a geomorphologic and faunistic sense between the western and eastern part of the Indonesian Archipelago but that there also exists a great difference in structure, which, of course, contributes to explain the geomorphological differences.

The general conclusion drawn from this structural review of the Indonesian Archipelago is, that the structure of the section West of Strait Makassar (the Sunda Shelf area) is mainly the result of different phases of the pacific orogeny setting out from the pre-cambrian and variscian consolidated mass of Indochina and surrounded by a fringe of tertiary orogenic structures.

In the eastern section of the Archipelago the variscian orogeny resulted in the development of an extensive landarea Northwest of the Australian Continent. In late paleozoic-early mesozoic time a process of regeneration started in the marginal zone of this land area leading to the formation of a so-called "intermediate area". Mesozoic epeirogenic and tertiary orogenic movements in this "intermediate area" and young tertiary-quaternary epeirogenic movements in the whole eastern part of the Archipelago are mainly responsible for the present structural and bathymetric picture of this part of the Archipelago. According to this conception Strait Makassar forms a line of demarcation of the first order and forms actually the boundary between Asia and Australia.

In 1860 Wallace stated in his classical essay: "The western and eastern islands of the Archipelago belong to regions more distinct and contrasted than any other of the great zoological divisions of the globe". The boundary line between both faunal realms, known as "Wallace line", has since been much criticized as well as defended and from this synopsis it becomes clear that the "Wallace line" is also according to geologic structure a very important boundary.

In the following points some of the most striking differences between the western and eastern part of the Indonesian Archipelago are given:

1. In the western part there are no indications for a variscian orogeny while in the eastern part results of variscian orogeny have up to now been reported from the Sula Spur area, Ceram and Timor.
2. Unconformities in the mesozoic sedimentary cycle have been met with in many localities of the Sunda Land area, while there has been an undisturbed mesozoic sedimentation in the Banda Geosyncline, only interrupted from time to time.
3. The western part is characterized by a strong pacific orogeny while, with the exception of some epeirogenetic movements, no mesozoic orogenic phases have been active in the eastern part of the Archipelago.
4. Many occurrences of mesozoic granites have been reported from Sumatra and Borneo and some of the smaller islands, while in the eastern part of Indonesia only paleozoic and tertiary granites occur.
5. The Sunda Land area shows a steady zonal growth in southwestern, southern and eastern direction; East Indonesia does not show any indications for such a regular growth, in the contrary, part of the quasi-consolidated variscian landmass participates in a process of regeneration and in consequence transfers part of this area into a zone suitable to renewed, in this case, tertiary orogenesis.
6. In the Sunda Shelf area there are many high islands which rise steeply as nunataks from the floors of the shelf sea; the only islands out on the Sahul and Arafura shelves are the low Aru Islands, from which might be concluded that the erosive forces were possibly longer active here than in the West.
7. On the isogam map of Indonesia we see that the western part of the area shows a very steady positive gravity anomaly, while the eastern part shows a very great variation as well in positive as in negative anomalies.

It is with great hesitation that the conclusions of this paper, resulting in the statement that there exists a great structural difference between the western and eastern part of the Indonesian Archipelago, will be used as a base for a new structural synthesis of this area. For this reason the accompanying structural sketchmap (fig. 15) should only be considered as a preliminary effort to illustrate the authors ideas in a general way.

In this preliminary geotectonic sketchmap the western part of the Indonesian Archipelago is shown as an outgrowth of the southeastern part of Asia. The map shows the various areas influenced by paroxysmal diastrophism of resp. the variscian, cimmerian, laramic and tertiary cycles and phases of orogeny, centred around the old pre cambrian nucleus of Indochina. It shows how the main part of the Sunda Land area is mainly built up by the pacific orogeny, fringed in the West, South and East by a more or less continuous zone of tertiary diastrophism. On this same map is shown that a considerable part of eastern Indonesia, embracing the southern part of New Guinea and its continuation in the Sula Spur, the areas of the Banda Geosyncline and the Banda Sea and parts of the Sahul and Arafura

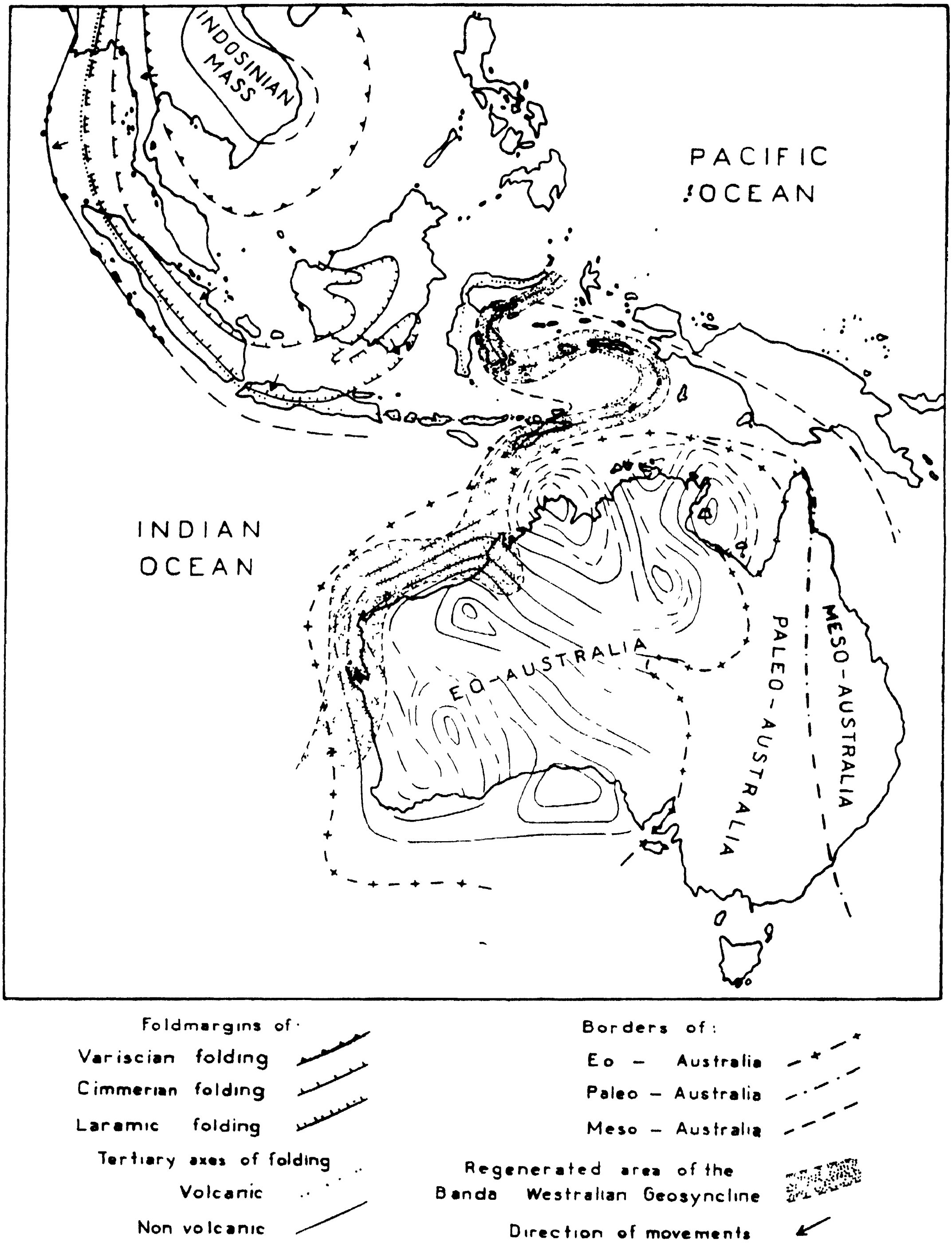

Fig. 15.—Preliminary Sketchmap of the Geotectonic Evolution of Australasia according to Klompé (1957).

shelves, were dislocated, but not consolidated, by the variscian orogeny. This part forms what Stille has called an "intermediate" or "quasi cratonic" area. Regeneration of marginal parts of this intermediate area has created the possibility for the formation of a geosynclinal ("parageosynclinal") basin, the Banda Geosyncline. During the tertiary orogenesis the sequence of strata, deposited in this half circular troughshaped basin was deformed to what is presently known as the outer Banda arc. Various problems related to the geology and geophysics of the Indonesian Archipelago will be solved supposed this or any further modified structural picture of the Archipelago, based on this conception, is accepted as a working base. In the first place this conception gives a satisfactory explanation for the great contrast between the western and eastern parts of Indonesia of which the most striking points have been enumerated before.

Most recent structural maps of Indonesia show a number of structural zones which are often traced over the entire Archipelago. In Westerveld's tectonic scheme of the East Indies (fig. 3) as well the Sunda as the Moluccas orogens are reproduced by belts from almost the northern end of Sumatra and the islands off the Westcoast till in the Philippines. The author is of the opinion that these two zones certainly have the value of showing some common characteristic features (such as e.g. volcanic and non-volcanic) but that they do not represent uninterrupted orogenic zones resulting from continuous geosynclines. The first tectonic schemes of the alpine orogene in the Mediterranean also tried to arrange the various mountainsystems into continuous belts (Suess *58*; Termier *61*; Kober 1912; Staub *53*, *54*; Stille *51*) but since the structure of these mountainsystems became better known it is now generally believed that it is not possible to trace a certain mountainsystem simply over the whole Mediterranean area (de Sitter *48*). It is true that certain mountainsystems have some characteristics in common but one goes to far connecting up all mountainsystems in the Mediterranean, based on the occurrence of certain rocktypes, like e.g. Kober does with his "metamorphides". Only two cases in which a simple continuation cannot be accepted will be mentioned here and both can be explained very well in accordance with this conception. In the first place the interruption of the zone of negative anomaly South of Sumba has never been explained in a satisfactory way, this conception not only gives an explanation for this interruption but might possibly also give an acceptable explanation for what Umbgrove has called the "Sumba Problem".

In the second place the volcanic zone of the inner Banda arc is on Westerveld's scheme connected up with the volcanic zone of the Lesser Sunda Islands on one side and with the partly extinct and partly still active volcanic zone of resp. western and northern Celebes on the other side. According to the author, however, this volcanic inner Banda arc cannot be compared with the volcanic zone of the Lesser Sunda Islands and Celebes and should certainly not be connected with these parts into one continuous zone. Our preliminary map shows that there might exist some relation between the volcanic zone of western and northern Celebes and the one from the Lesser Sunda Islands.

Kuenen *(35)* in his paper on the geology of the Islands Ambon and Haroekoe writes in connection with this (pp. 44 and 45): "The inner Banda arc is generally drawn along the volcanic islands of the Banda-Sea as far as Banda and thence curving sharply to the Schilpad-and Lucipara-Islands and Gn. Api North of Wetar. The depth-chart of the Snellius (fig. 5), however, shows that between Manoek and Banda the ridge of the inner Banda arc is not clearly continuous and that there is definitely no connection with the ridge bearing the Schilpad- and Lucipara-Islands. Gn. Api lies quite apart and morphologically it forms no part of the arc. Even the northern Siboga-ridge is separated from the Banda shoal. From a morphological point of view the continuation of the Banda arc is formed by the Oeliasers, although the connection is not a distinct one. It might be urged that the absence of active volcanoes on the Oeliasers and Ambon is a reason for disregarding this connection and for terminating the inner arc at Banda. But the volcanicity of Wetar and neighbouring islands—also at a point where the arcs are close together—has been extinct for a long period also, probably quite as long as that of the Oeliasers, yet nobody doubts that Wetar forms part of the arc. Although the conception of a volcanic inner Banda-arc becomes increasingly vague when applied further East of Java than the island Panter, it is my opinion that, if extended to include the Banda Group, there is no reasonable argument for not including the Oeliasers, Ambon, the submarine cone in Strait Manipa and Ambelau". "The Outer Banda arc is traceable to Sanana (southernmost of the Sula Islands) as a unit but not further although of course the invisible tectonic structures continue. In the same manner the inner arc ends as a distinguishable unit where it merges into the outer arc in Boeroe".

From these paragraphs the conclusion can be drawn that Kuenen favours the idea that the inner volcanic Banda arc begins in Strait Manipa and ends on Wetar and conform this point of view the inner Banda arc is represented in this preliminary tectonic scheme.

With regard to the position of Sumba, Umbgrove (*65*, p. 189) remarks: "Obviously the island does not belong to the volcanic inner arc. Neither in stratigraphy nor in structural history is it intimately related to the islands of the outer arc, such as Timor and Roti" and consequently Westerveld does not include this island either in the Sunda, nor in the Moluccas orogen. Umbgrove (*66*, p. 42) adds to that: "In our opinion Sumba is the exceptional example of a sort of terrain that elsewhere subsided so as to form the bottom of one of the series of deepsea furrows between the outer and inner arcs".

In fact very little is known about the geology of Sumba and what is known is not exactly in harmony with each other. In a rather recent report on the Geology of West-and Central-Sumba, Laufer and Kraëff *(36)* describe the pre tertiary rocks as a slate formation, probably some thousand of meters in thickness and subjected to strong orogeny. The only fossils are poorly preserved plant remains. When compared with European sections, the rocks appear to be paleozoic rather than mesozoic. The orogeny can only be dated as being pre tertiary, as the slates are covered transgressively by eocene sediments, which are only slightly dislocated (tilted). Magmatic intrusions probably accompanied this orogeny, which account for the quartz-gabbros and granogabbros and the great granodiorite massif of Tanadaro.

In "The Geology of Indonesia" van Bemmelen (*4*, table 106) summarizes the pre tertiary geology of Sumba as follows:

Geological Period.	Formations and fossils.	Diastrophism and igneous activity.
Pre Tertiary (at least partly jurassic).	Partly marine flysch facies, partly non-marine flood plain or delta deposits, with volcanic constituents (Inoceramus and an ammonite).	Strong folding, followed by uplift and igneous intrusions and extrusions. (Volcanic activity on a slowly subsiding basement.

Whereas Laufer indicates in his report that the strongly folded slate formation is sooner paleozoic than mesozoic, is van Bemmelen's opinion that it is at least partly jurassic. In the first case the results of the variscian orogeny would have reached in the South as far West as the island of Sumba and the Tanadaro granodiorite would be of late paleozoic age. In the second case, however, it has to be accepted that the influence of the late mesozoic, possibly laramic, folding phase has reached further East than Central-Java and in that case the Tanadaro granodiorite would be of late mesozoic age. Because our knowledge about the geology of Sumba is still in a preliminary stage, the structural position of the island has been left an open question in our structural scheme.

It is not only from this part, but also from other areas of the Indonesian Archipelago that more information should be gathered and that various geophysical and geological phenomena should be studied more in detail before a more reliable scheme based on this conception can be produced. One of the first problems that ought to be studied is the exact status of Strait Makassar, which in this geotectonic synthesis forms such an important boundary.

REFERENCES

(1) Abendanon, E.C., 1915/1918, Geologische en geografische doorkruisingen van Midden Celebes. I (1915); II (1915); III (1917); IV (1918).

(2) Bemmelen, R.W. van, 1932, Toelichting bij blad 10 (Batoeradja) Geol. Kaart Sumatra, 1 : 200,000. Bandung 1932.

(3) ———, 1939, De geologie van het westelijke en zuidelijke deel van de Westerafdeling van Borneo. Jaarb. Mijnw. 1939, Verh. pp. 187-319.

(4) ———, 1949, The Geology of Indonesia, Vol. IA, General Geology. The Hague: Government Printing Office.

(5) ———, 1952, De Geologische Geschiedenis van Indonesia. The Hague: Van Stockum en Zoon.

(6) ———, 1954, Mountain Building. A study primarily based on Indonesia, region of the world's most active crustal deformations. The Hague: Martinus Nyhoff.

(7) Brouwer, H.A., 1917, Over de ouderdom der eruptiefgesteenten in de Molukken.

Akademie Verslagen, **25**: 1004-1017, Amsterdam.

(8) Brouwer, H.A., 1919, Geologische onderzoekingen in Oost-Ceram. *Tijdschr. Kon. Ned. Aardr. Gen. 2*, **36** (6): 715, Amsterdam.

(9) ———, 1923, Bijdrage tot de geologie van het eiland Batjan. *Jaarb. Mijnw. Verh. II*, 73-105, The Hague.

(10) ———, 1924, Bijdrage tot de geologie der Obi-eilanden. *Jaarb. Mijnw. Verh.*, 5-62, The Hague.

(11) ———, 1926, Geologische onderzoekingen op de Soela eilanden I and II. *Jaarb. Mijnw.* 1920, Verh. II, Den Haag 1921 and *Jaarb. Mijnw.* 1925, Verh. I, Den Haag 1926.

(12) ———, 1942, Summary of the results of the expedition. Geol. Exped. to the Lesser Sunda Islands under leadership of H.A. Brouwer, **4**: 345-402.

(13) Bryan, W.H., 1925, Earth-movements in Queensland. *Proc. Royal Soc. of Queensland*, **37** (3).

(14) Cloos, H., 1948, Grundschollen und Erdnähte. *Geol. Rundsch.* **35** : 133-154.

(15) David, T.W. Edgeworth and Browne W.R., 1950, The Geology of the Commonwealth of Australia. London: Edward Arnold and Co.

(16) Deninger, K., 1918, Zur Geologie von Mittel-Seran (Ceram) *Palaeontographica* 4, 3, 2, 1918.

(17) Fairbridge, R.W., 1950, Problems of Australian Geotectonics. *Scope (J. Sc. Union Univ. of Western Australia)*, **1** (5).

(18) , 1951, The Aroe Islands and the Continental Shelf North of Australia. *Scope*, **1** (6).

(19) ———, 1952, The Sahul Shelf, Northern Australia; its structure and geological relationships. *Journal of the Royal Society of Western Australia*, **37**: 1-34.

(20) ———, 1955, Some bathymetric and geotectonic features of the eastern part of the Indian Ocean. *Deep Sea Research*, **2**: 161-171.

(21) Fromaget, J., 1934, Observations et réflexions sur la géologie stratigraphique et structurale de l'Indochine. *Bull. Soc. Geol. Fr.* pp. 101-164.

(22) ———, 1937, Essai sur la structure et la tectonique de l'Indochine. Rept. XVIIth Intern. Geol. Congr. Moscow; **2**: 459-518, Moscow 1939.

(23) Fromaget, J., 1952, Apercu de nos connaissances sur la Géologie de l'Indochine en 1948. *Proc. XVIII-th Session Intern. Geol. Congr.* **13**: 63-78.

(24) Germeraad, J.H., 1946, Geology of Central Seran. Geol. petrogr. and paleont. results of explorations carried out in 1917-1919 in *Ceram by Rutten* and W. Hotz. *Third series No. 2*, Utrecht.

(25) Glaessner, M.F., 1950, Geotectonic position of New Guinea. *Bull. Am. Ass. Petr. Geol.* **34**: 856-881.

(26) Gregory, J.W. and others, 1924, The Geology of the Aru Islands. *Geol. Mag.* **61**: 52-72.

(27) Hills, E.S., 1946, Some Aspects of the Tectonics of Australia. *Journ. Royal Society N.S.W.* **79**: 67-91

(28) Hirschi, H., 1907, Zur Geologie und Geographie von Portug. Timor. *Neues Jahrbuch* etc. Beil. Bd. **24**: 460-474.

(29) Huang, T.K., 1945, On major tectonic forms of China. Chungking, *Mem. Geol. Survey of China.* Series A, number 20.

(30) Klompé, Th. H.F., 1954, The structural importance of the Sula Spur (Indonesia).
a. *Ind. J. f. Nat. Sc.* **110**: 21-41, Bandung.
b. *Proc. VIII-th Pac. Sc. Congr. 1953*, II, A, 869-891, Quezon City.

(31) , 1955, On the supposed Upper Paleozoic unconformity in North Sumatra.
a. *Ind. J. f. Nat. Sc.* **111**: 151-166, Bandung.
b. *Leidse Geologische Mededelingen* **20**. 120-134, Leiden.

(32) Kölbel, H., 1945, Die tektonische Entwicklung Australiens. In Geotektonische Forschungen, No. **7/8**: 154-209, Berlin.

(33) Kuenen, Ph. H., 1933, Geology of coral reefs. The Snellius Expedition in the eastern part of the Neth. East Indies 1929-1930. Vol. V, Geol. Results, part 2, Utrecht.

(34) ———, 1935, Geological interpretation of the bathymetrical results. The Snellius Expedition, Vol. V, Part 1, Leiden.

(35) ———, 1949, Ambon and Haroekoe. *Verh. v. h. Ned. Geol. Mijnb. Gen. Geol. serie*, **15**. The Hague.

(36) Laufer, F. and A. Kraëff, 1957, The Geology and Hydrology of West- and Central Sumba and their relationship to the water-supply and the rural economy. *Publikasi Keilmuan* No. 33, serie Geologi Bandung.

(37) Lee, G.Y., 1952, The laramide movement in China. *Report of the XVIII-th Session Intern. Geol. Congr.* 1948. Proc. **13**: 284, London.

(38) Lees, G.M., 1953, Evolution of a shrinking earth. *Quart. J. Geol. Soc.* **109** : 217-257, London.

(39) Molengraaff, G.A.F., 1915, Geografische en geologische beschrijving van het eiland Letti. *Jaarb. Mijnw. Ned. Ind.* **43** (1): 1-87, The Hague.

(40) Musper, K. A. F. R., 1929, Beknopt verslag over uitkomsten van nieuwe geologische onderzoekingen in de Padangsehe Bovenlanden. *Jaarb. Mijnw.* Verh. 265-331, Batavia.

(41) Neumayer, M., 1883, Ueber Klimatische Zonen während der Jura und Kreidezeit. *Denkschr. K. Akad. Wiss. Math.- Nat. Kl.* **18** : 277-310, Wien.

(42) Reid, J.H., 1930, The Queensland Upper Paleozoic Succession. *Queensland Geol. Surv. Publ.* 278, 1-96.

(43) Roever, W.P. de, 1940, Geological investigations in the southwestern Moetis Region (Netherlands Timor). Geol. Exp. Lesser Sunda Islands. **II** : 240, Amsterdam.

(44) Rutten, L.M.R. and W. Hotz, 1918-1920, De geol. expeditie naar Ceram. *Tijdschr. Kon. Ned. Aardr. Gen.* 35-37, (eleven reports) Amsterdam.

(45) ———, 1927, Voordrachten over de geologie van Nederlandsch Oost-Indié, 839, pp. 243 figss. Wolters, Groningen-Den Haag.

(46) ———, 1949, Frequency and periodicity of orogenetic movements. *Bull. Geol. Soc. Am.* **60** : 1755-1770.

(47) Schürmann, H.M.E. A.C.W. Bot, E. Niggli, F.G. Houtermans and J. Geiss, 1955, Preliminary note on age determinations of magmatic rocks by means of radioactivity. *Geologie en Mijnbouw, New Ser.* **17** : 217-224, The Hague.

(48) Sitter, L.U. de, 1956, Structural Geology, 552, pp. Mac Graw Hill Book Co. Ltd., New York, London, Toronto.

(49) Sluis, J.P. v.d., 1947. Bijdrage tot de geologie van Oost Seran. Thesis, Utrecht.

(50) Smit Sibinga, G.L., 1928, De geologische ligging der boven-triasische olie- en asfaltafzettingen in de Molukken. *Nat. Tijdschr. v. Ned. Ind.* **88** : 111, Batavia.

(51) Stille, H., 1924, Grundfragen der vergleichenden Tektonik. Gebr. Borntraeger, Berlin.

(52) Stille, H. und Fr. Lotze, 1945, Geotektonische Forschungen, Heft 7/8. Gebrüder Borntraeger, Berlin.

(53) Staub, R., 1924, Der Bau der Alpen. *Beitr. Geol. Karte d. Schweiz.*

(54) ———, 1928, Der Bewegungsmechanismus der Erde. Gebr. Borntraeger, Berlin.

(55) Stolley, E., 1934, Zur Kenntnis des Jura und der Unterkreide von Misol. I. Stratigr. Teil. *N. Jahrb. f. Min.* etc. 71 B, 470.

(56) Straelen, V. van, 1933, Résultes scientifiques du voyage aux Indes Orientales Néerlandaises, Introduction. *Mem. Mus Roy. d.' Hist. Nat. Belgique*, 222 pp.

(57) Suess, E., 1886, Das Antlitz der Erde I-III, Wien und Leipzig.

(58) ———, 1908, The Face of the Earth. Oxford (Clarendon).

(59) Tayama, R., 1936, Topography, Geology and Coral Reefs of the Aru Islands in the Dutch East Indies. *Contr. Inst. Geol. Pal. Tohoku Imp. Univ.* **20**: 1-35, Sendai.

(60) Teilhard de Chardin, 1937, A map of the younger eruptive rocks of China. *Bull. Geol. Surv. of China*, **16**, Nanking.

(61) Termier, P., 1911, Les problèmes de la Géologie tectonique dans la Méditerranée occidentale.

(62) Tissot van Patot, J.W., 1908, Een viertal tochten door het eiland Terangan (Aroe eilanden) in Maart en April 1907. *Tijdschr. Kon. Ned. Aardr. Gen.* **25**: 77-93, Amsterdam.

(63) Umbgrove, J.H.F., 1935, (with contributions of Fr. Weber) De pre-tertiarre Historie van den Indischen Archipel. *Leidse Geol. Med.* **7**: 119-155. Leiden.

(64) ———, 1938, Geological History of the East Indies. *Bull. Am. Ass. Petr. Geol.* **22**: 1-71.

(65) Umbgrove, J.H.F., 1947, *The Pulse of the Earth.* Second Edition, The Hague: Martinus Nyhoff.

(66) — — —, 1949, Structural history of the East Indies. Cambridge Univ. Press, 63 pp.

(67) Valk, W., 1945, Contributions to the geology of West Seran. Geol. petrogr. and paleont. results of explorations carried out in 1917-1919 by L. Rutten and W. Hotz, 3 ser. Geology No. 1, Utrecht.

(68) Vening Meinesz, F.A., 1934, Gravity expeditions at sea. Vol. II: The interpretation of the results (with the collaboration of J.H.F. Umbgrove and Ph. H. Kuenen). Delft.

(69) Verbeek, R.D.M., 1908, Molukken Verslag. *Jaarb. Mijnw.*

(70) Vialov, O.S., 1939, Die Mesozoische Faltung in Asien. *Report of the XVII Session of the International. Geological Congress 1939*, **2** : 563-573. Moscow.

(71) Waard, D. de, 1954, Contributions to the Geology of Timor. V. Structural development of the crystalline schists in Timor. Tectonics of the Lelan Asu Massif. *Ind. J. f. Nat. Sc.* **110** : 143-154, Bandung.

(72) Wallace, A.R., 1860, On the zoological geography of the Malay Archipelago. *Journ. Linn. Soc.* **4** : 172-184, London.

(73) Wanner, J., 1931, Mesozoicum. Feestbundel Martin. *Leidse Geol. Med.* **5** : 567-610, Leiden.

(74) Westerveld, J., 1949, Fasen van Gebergtevorming en Ertsprovincies in Nederlands Oost-Indië. *De Ingenieur.*

(75) — —, 1952, Phases of mountain building and mineral provincies in the East Indies. *Report of the 18th Session of the International Geological Congress*, **13** : 245, London.

(76) Wichmann, A., 1882/1887, Gesteine von Timor. *Samml. Geol. Reichsmus.* **2** : 1-72, Leiden.

(77) Zeylmans van Emmichoven, C.P.A., 1939, De geologie van het centrale en oostelijk deel van de Westerafdeling van Borneo. *Jaarb. Mijnw.* Verh. **68** : 7-186, Bandung.

(78) Zwierzycki, J., 1925, Overzicht der Triasformatie in Nederl. Indië. *Verh. Geol. Mijnb. Gen. Geol. Serie*, **8** : 633-648, The Hague.

(79) , 1927, Geol. overzichtskaart van de Ned. Ind. Archipel. Schaal 1: 1,000, 000. Toelichting bij Blad XX (Aroe, Kei en Tanimbar eilanden). *Jaarb. Mijnw.* **56** (1): 319-335. Batavia.

MESOZOIC OROGENIES IN THE ISLAND OF SUMATRA AND THEIR ORE-DEPOSITS

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(Abstract)

The geological structures of the Indonesian Archipelago are due to the fact that it is located at the -intersection of two global mountain systems. The structures are governed by folding processes which took place throughout the ages at this very weak spot in the earth's crust. Although tectonic forces were never completely at rest, two main periods of movements bringing ore-deposits of economic importance in the island of Sumatra can be distinguished.

The mainly cassiterite, gold, wolframite and bauxite deposits in Indonesia belong to the oldest Mesozoic tectonic unit in the Western part of the Archipelago which is of Upper Jurassic age. (It is called the Malayan orogen by Westerveld.)

Evidences of a Cretaceous tectonic unit in the island of Sumatra are the pyrometasomatic iron-ore and gold-silver deposits of the so-called Sumatran orogen.

An outline is given concerning the development of both orogenies in relation to their mineral wealth brought in Sumatra.

NOTES ON MESOZOIC OROGENY IN WEST BORNEO

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The Mesozoic formations known in West Borneo (West Sarawak and West Kalimantan) are of Triassic, Upper Jurassic, and Lower and Upper Cretaceous age. The Mesozoic geological history of the area is summarized in table 1.

LATE PERMIAN OR EARLY TRIASSIC FOLDING

Granite at many places in West Borneo is believed to have been emplaced in late Permian or early Triassic times. At Tenting Bedil in the Strap Valley of West Sarawak the age has been estimated by the zircon method (Roe, *6*). Granite, forming the Jagoi and Kisam Ranges (southwest of Bau) and the small headlands of Tanjong Batu and Tanjong Pandan (North of Lundu) is similar in composition and is believed to be of the same age as that forming Tenting Bedil (Wilford, *8*, 76). Many granite batholiths in West Kalimantan (especially in the Schwaner Mountains and the southwest) are attributed by Zeylmans van Emmichoven to the same period (*9*, 137).

It seems probable that the emplacement of the granite was accompanied by fairly strong folding movements, since the Upper Triassic beds apparently lie unconformably on rocks of Permian or Carboniferous age. Zeylmans van Emmichoven attributes formation of phyllite and marble in the 'Permocarboniferous' of West Kalimantan to orogenesis in the early Triassic period (*9*, 192-193).

TRIASSIC SEDIMENTS

Triassic sediments and volcanic rocks occur in the Sadong Valley of West Sarawak, whence they extend West into the Sarawak River Valley, and South into the Sekajan and Landak Valleys of West Kalimantan. Fossil molluscs in shales indicate an Upper Triassic age (Krekeler, *4* and *5*; Haile, *2*, 21-22; Wilford, *8*, 43). The rocks are

Table 1.
Mesozoic geological history in West Borneo.

System		Sedimentation		Orogeny and epeirogeny	Igneous activity
		Southern area (Sarawak, Sadong, Sekajan, Landak, and Seberuang Valleys)	Northern area (Lupar, Saribas and upper Kapuas Valleys)		
Cretaceous	Upper	Limestone, marl, shale, tuff, sandstone, conglomerate and radiolarian chert—in shelf facies	Shale and graywacke, with tuff and radiolarian chert in southwest—in geosynclinal facies	Slow subsidence in southern area: rapid subsidence in northern area	Tuff and tuffite deposited in southern area; basic lavas and tuffs extruded, and dolerite sheets intruded, in northern area
	Lower		Possibly some sedimentation, including formation of limestone	Slow subsidence in southern area	
Jurassic	Upper		unknown		
	Lower	UNCONFORMITY; EROSION		Folding?	
Triassic	Upper	Shale, sandstone, conglomerate, and coal—in estuarine and neritic facies	unknown		Extrusion of acid lavas and tuffs
	Lower	UNCONFORMITY; EROSION		Folding?	Intrusion of granite?

shale, feldspathic sandstone, conglomerate, rare coal seams, and, in places, interbedded acid lavas and tuffs.

POSSIBLE LATE TRIASSIC OR EARLY JURASSIC FOLDING

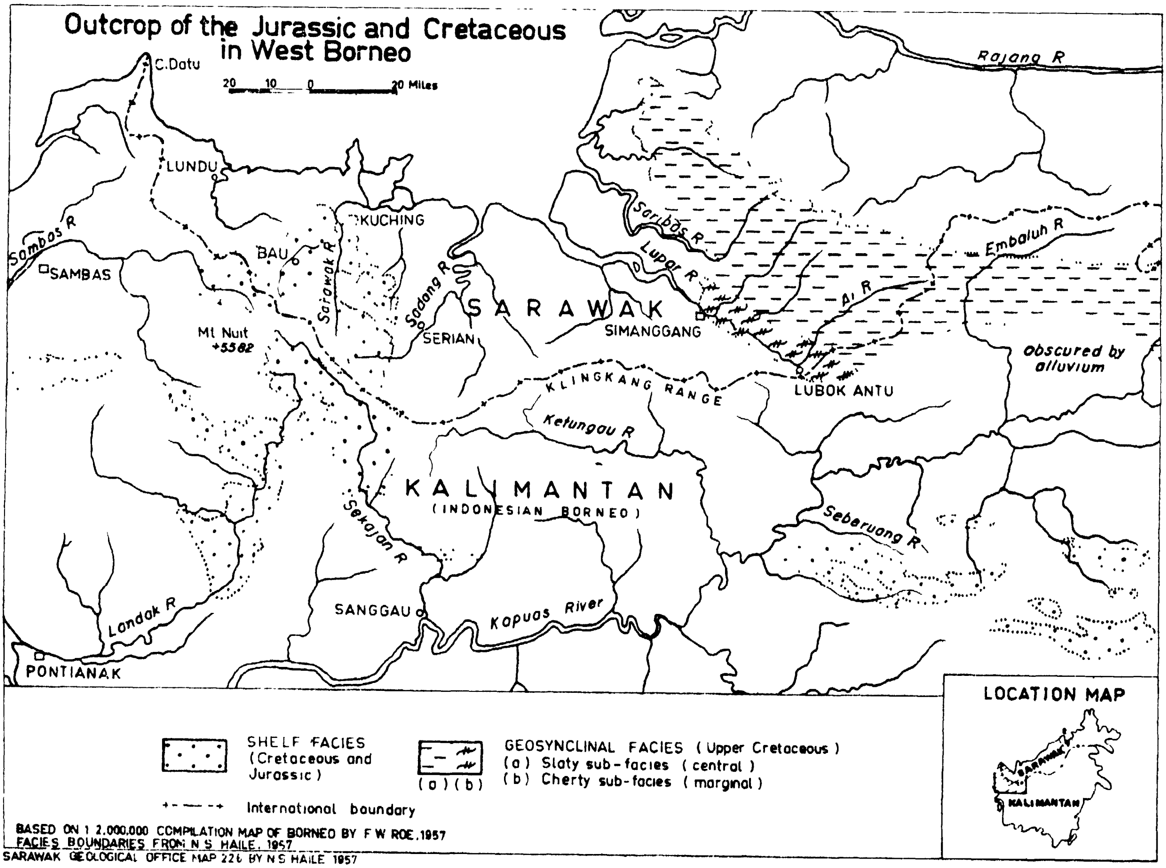
The Upper Triassic rocks are overlain by sediments of jurassic and Cretaceous age. The Triassic, Jurassic, and Cretaceous sediments are all moderately folded, and Wilford records (*8*, 90) that in many places the strike of the Triassic sediments coincides with that of nearby Jurassic and Cretaceous sediments. The junction between the Jurassic and Triassic has not been observed; Wilford suggests that it is unconformable and that folding movements probably occurred at the beginning of the Jurassic period (*8*, 93).

UPPER JURASSIC TO UPPER CRETACEOUS SEDIMENTS

The late Mesozoic sediments in West Borneo occur in different facies in two separate areas. The *southern area* comprises the Sarawak, Sadong, Sekajan, and Landak Valleys, and the Seberuang Valley in the middle Kapuas area (see map); the *northern area* comprises the Lupar and Saribas Valleys, and the far headwaters of the Kapuas. Sediments of Upper Jurassic to Cretaceous age the southern area are predominantly calcareous, and occur in shelf facies; Upper Cretaceous rocks in the northern area are shale, slate, phyllite, graywacke, and, in places, radiolarian chert and rare limestone.

SOUTHERN AREA

The Jurassic and Cretaceous sediments of the *Sarawak and Sadong Valleys* comprise of massive limestone, which occurs as lenses as much as 1,000 feet thick or more, shale, marl, sandstone, graywacke, conglomerate, radiolarian chert and tuff. They are considered on palaeontological evidence to range from Upper Jurassic to Upper



BASED ON 1 2.000.000 COMPILATION MAP OF BORNEO BY F W ROE, 1957
FACIES BOUNDARIES FROM N S HAILE, 1957
SARAWAK GEOLOGICAL OFFICE MAP 22b BY N S HAILE 1957

Table 2.

Relationship of the facies of the Jurassic and Cretaceous in West Borneo.

	Shelf Facies (Southern Area)		Geosynclinal Facies (Northern Area)	
	Sekajan and Sarawak Valleys	Seberuang Valley	Slaty sub-facies (central)	Cherty Sub-facies (marginal)
UPPER CRETACEOUS	Thin limestone beds, marl, and radiolarian chert Calcareous tuffite, graywacke, grey and green shale	Sandstone, arkose, limestone, radiolarian tuff, tuffaceous agglomerate and conglomerate	Hard shale, slate, phyllite, and graywacke	Shale, graywacke, tuffite, radiolarian chert and rare limestone
LOWER CRETACEOUS	Massive limestone, shale, sandstone, and conglomerate	Marl, shale, feldspathic sandstone		Limestone?
UPPER JURASSIC	Massive limestone, chert, and marl. Basal sandstone			

Cretaceous (Cenomanian); no evidence of post-Cenomanian members has been found. Wilford concluded (*8*, 66) that the Jurassic and Cretaceous sediments of the Sarawak and Sadong Valleys were deposited in a shallow sea partly overlying a shelf.

The Jurassic and Cretaceous sediments of the Landak and Sekajan Valleys in Kalimantan are contiguous with and similar to those of the Sarawak and Sadong Valleys, although more littoral conditions occur to the South. They have been described by Zeylmans van Emmichoven, from information provided by F.X. Krekeler (Zeylmans van Emmichoven, *9*, 98-101):

> '. . . in the middle reaches of the Sekajan, the Cretaceous was laid down in a narrow, shallow basin between the Permocarboniferous massifs (composed largely of acid plutonic rocks) of the Kembajan Mountains and the Landak Border Mountains. Along the fringes of these massifs the Cretaceous consists of coarse to fine-grained polymict feldspathic sandstones, which alternate with coarse clastic conglomerates . . . and lenses of *Orbitolina*-bearing limestones. East and north of Kampong Balai Karangan (on the Sekajan River) and along the Rubin River to the Sadong (Kajan tributary), the Cretaceous transgresses over the Permo-carboniferous—Triassic with an identical basal series. These coarse clastic, locally calcareous, sediments, in a clear beach facies, give way, in the direction of the Sekajan River, partly by intercalation, to finer clastic marly deposits, which were laid down further away from the coast . . .'

Jurassic rocks are known in West Kalimantan only from small areas in the Landak and Sambas Valleys (Zeylmans van Emmichoven, *9*, 82-84).

The Seberuang Cretaceous, in the Middle Kapuas, has been mapped in some detail by Zeylmans van Emmichoven *9*, 85-97). The sediments are about 10,000 feet thick, and almost the whole of the Cretaceous system is believed to be represented (Valanginian to Senonian). The sediments are marl, shale, sandy limestone, conglomerate, sandstone, and arkose, with acid to intermediate tuffs and tuffaceous agglomerate.

NORTHERN AREA

Cretaceous sediments occupy about 1,760 square miles in the Lupar and Saribas Valleys, occurring in a belt about 34 miles wide and extending east-southeast into the Kapuas headwaters. They have been described in detail by the writer (Haile, *3*, 33-49). No elements older than Cenomanian have been found, with the exception of a fragment of limestone in a volcanic conglomerate, which contains a foraminifer of probable Lower Cretaceous age. The sediments occur in two sub-facies of contrasting lithology: a *cherty subfacies* in the south forms a belt 8½ miles wide, of shale and sandstone, and rare limestone, with associated altered basalt, dolerite, gabbro, tuff, tuffite, and radiolarian chert; and a *slaty sub-facies* in the north consisting of hard shale, slate, phyllite, and graywacke. The rocks are intensely folded, probably isoclinally, and the thickness cannot be measured; it is certainly great, probably more than 30,000 feet.

CONDITIONS OF DEPOSITION OF THE JURASSIC AND CRETACEOUS

The Jurassic and Cretaceous in the southern area appear to have been laid down on an unstable shelf. The conditions of deposition of the Seberuang Cretaceous are considered by Zeylmans van Emmichoven to have been preponderantly littoral-neritic with beach and lagoon deposits, and occasionally to have approached a neritic character; the Jurassic and Cretaceous in the far West, as we have seen, is neritic in the North, with beach deposits in the South.

The Cretaceous in the northern area is a typical geosynclinal (flysch) series. The slaty sub-facies was probably laid down in the central part of a geosyncline, and the cherty sub-facies along the margin. These facies differences are related to the regional structure of west Borneo. The older, mostly pre-Jurassic, rocks, forming the western part of Borneo, appear to have formed a stable block since Jurassic times. This concept of a 'continental core' or 'continental triangle' has been developed by van Bemmelen (*1*, 19; pl. 13, fig. 138), who visualizes the core as being formed by Crystalline Schists (probably pre-Carboniferous) invaded and largely replaced by granite of Permo-Triassic, Jurassic, and Cretaceous age. He defines it as a triangular area with its base along the west coast of Borneo from Cape Datu on the north to Cape Sambar on the south, and its apex in the Müller Mountains, about the centre of the island. The northern side he defines as running southeast from Cape Datu, through Mount Nuit and the Madi Plateau to the Müller Mountains. The most significant change in lithology and tectonics occurs, however, along the line of the Lupar Valley, further North, where it is therefore more appropriate to place the northern side of the 'continental core' (see Haile, *3*, 91-100). Shelf conditions obtained along the northern margin of this 'continental core' in Jurassic and Cretaceous times, while further North a great geosyncline developed in the Cretaceous.

EPEIROGENIC MOVEMENTS IN THE CRETACEOUS

The main epeirogenic movements in the Cretaceous were slow with interrupted subsidence on the shelf (southern area) from early Jurassic to late Cretaceous times, and rapid subsidence in the geosyncline (northern area), probably beginning in the Cenomanian. Thick conglomerates occur in the Seberuang Cretaceous about the base of the Cenomanian, which may mark uplift in the southern area, occurring at the same time as, and compensating for, the beginning of rapid subsidence in the northern area. In the northern area sedimentation continued uninterrupted into Eocene times, and there is no evidence in West Borneo of an orogeny in the Cretaceous.

REFERENCES

(*1*) Bemmelen, R.W. van, 1949, The Geology of Indonesia. Government Printing Office, The Hague.

(*2*) Haile, N.S., 1954, The geology and mineral resources of the Strap and Sadong Valleys, West Sarawak, including the Klingkang Range coal: *Brit. Borneo Geol. Survey Mem.* **1**.

(*3*) Haile, N.S., 1957, The geology and mineral resources of the Lupar and Saribas Valleys, West Sarawak: *Brit. Borneo Geol. Survey Mem.* **7** (*in press*).

(*4*) Krekeler, F., 1932, Over een nieuw voorkomen van fossiel-houdend Palaeozoikum in Midden-West Borneo. (Voorloopige Mededeeling): *De Mijningenieur*, p. 167, translated in *Brit. Borneo Geol. Survey Bull.*, **2**, 1955.

(*5*) Krekeler, F., 1933, Aanvullende Mededeelingen omtrent het voorkomen van Palaeozoicum in West-Borneo: *De Mijningenieur*, p. 191 translated in *Brit. Borneo Geol. Survey Bull.*, **2**, 1955.

(*6*) Roe, F.W., 1955, Radio-active age determinations of West Sarawak igneous rocks: *Brit. Borneo Geol. Survey Ann. Rept*, 76-77.

(*7*) Roe, F.W., 1957, Sketch-map showing the geology of Borneo (compilation 1:2,000, 000. (in preparation)

(*8*) Wilford, G.E., 1955, The geology and mineral resources of the Kuching-Lundu Area, West Sarawak, including the Baumining district; *Brit. Borneo Geol. Survey Mem.*, **3**.

(*9*) Zeylmans van Emmichoven, C.P.A., 1939. De geologie van het Centrale en Oostelijke deel van de Westerafdeling van Borneo: *Jaarb. Mijn. Ned-Indië*, pp. 8-186, translated in *Brit. Borneo Geol. Survey Bull.*, **2**, 1955.

THE LATE MESOZOIC SAKAWA OROGENY

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The Mesozoic crustal movements were immensely clarified in Japan in the past 30 years. It is now thoroughly ascertained that the Sakawa cycle of orogeny[1] which followed the Permo-Triassic Akiyoshi cycle on the continental side of the Japanese Islands is most responsible for her architecture. The Eo-Nippon cordillera in the Jurassic period was the embryonic geanticline which developed into the Sakawa axis. The Sakawa orogeny was commenced on the inner or the continental side with the Oga phase at the transitional epoch from Jurassic to Cretaceous. Broadly speaking, the orogenic acme was shifted from the inner to the outer side and the Barremio-Aptian Oshima phase was spasmodic for the whole Sakawa orogeny. The Sakawa cycle was completed with the batholithic invasion of the Chugoku granite, causing the extensive Akitsu culmination at about the transition from Cretaceous to Tertiary through which most of Japan was emerged.

Previously *(8)* I have pointed out that the Palaeozoic Chichibu geosyncline was divided into the inner and outer sides by an axial elevation in the Permo-Carboniferous period. It was, however, an auxiliary axis. The late Palaeozoic foldings along the axis, as seen in the southern Kitakami mountains (Minato, *21*), were local phenomena. The principal axis of the Permo-Triassic Akiyoshi mountains is indicated by the Hida gneiss and the Sangun metamorphosed zone (1951).

It is quite evident that the Nagatoro metamorphosed zone and the Ryoke injection zone indicates respectively the mio- and plio-magmatic zone of the Sakawa axis, instead of the Akiyoshi axis as deemed by Gorai *(11)*, because the Maizuru zone and the Mino, Kinki and other arcs of the Akiyoshi folded mountains are clearly truncated by the Ryoke injection zone. This conclusion is further confirmed by the fact that neither discontinuity in the grade of metamorphism nor structural discordance exists either between the Nagatoro schists and the non-metamorphosed rocks on their southern side or between the Palaeozoic and the pre-Sakawa Mesozoic formation in the Chichibu zone.

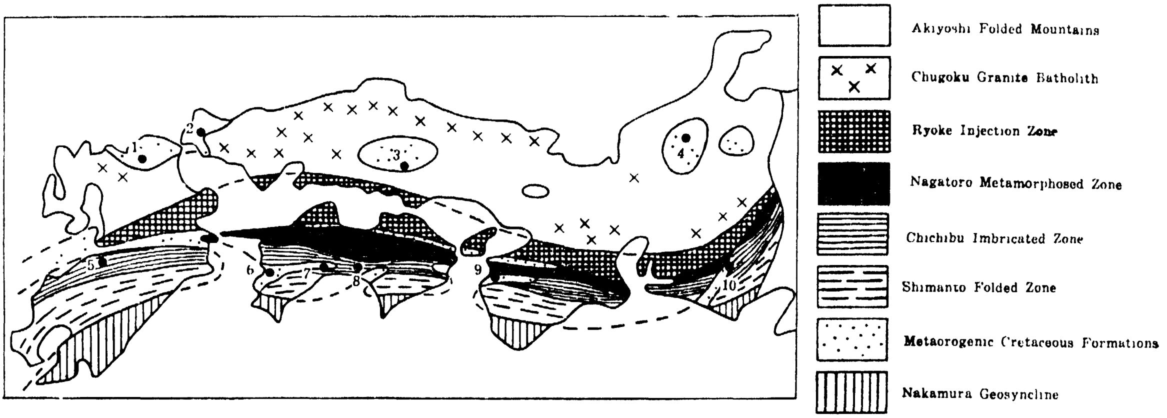

Fig. 1.—Tectonic map of West Japan in the Cretaceous period.

1. Wakino in Tsukushi Region.
2. Toyora Basin in Prov. Nagato
3. Oga in Kibi Plateau.
4. Tetori Basin in Hida Block.
5. Yatsushiro in Province Higo.
6. Uwajima in Shikoku Island.
7. Sakawa in the same island.
8. Ryoseki in the same island.
9. Yuasa in Province Kii.
10. Misakubo in Akaishi Mountains.

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[1] The term, orogenic cycle, means here a genetical series of geological phenomena by which a geosyncline was developed into a system of folded mountains. In Japan the Chichibu geosyncline turned out the Akiyoshi mountains by the Permo-Triassic cycle and the Shimanto geosyncline became the Sakawa mountains by the Jurasso-Cretaceous cycle.

In the late Triassic period the metamorphosed axis and the folded zone of the Akiyoshi mountains were located in the inner side of Japan, whereas the outer side belonged to the peri-and extra-orogenic zones of the mountains. The geomorphological and tectonic differences from the Akiyoshi axis to the Shimanto geosyncline on the Pacific side is explicitly shown by the change in facies and thickness of the Upper Triassic formations and their stratigraphic relation to the older ones(Kobayashi, *11*).

There is no sign of the Eo-Nippon cordillera in the palaeogeography at that time, but in the Jurassic period there is no doubt that inland basins were separated from the Pacific ocean by the cordillera (Kobayashi, in these proceedings).

The regional metamorphism has presumably taken place in the core of this geanticline. Subsequently the Nagatoro schists and phyllites were folded and intruded by the Besshi ultrabasic rocks. Still later, acidic magma has been injected lit-par-lit in the rear part of the cordillera, yielding the Ryoke gneiss. At length the Ryoke zone was thrust upon the Nagatoro metamorphics. This phase of dislocation is called "Kashio", because the Kashio mylonite was produced along the Median Tectonic Line.

As pointed out already (*8*), a strong crustal deformation was produced not merely in a short time-interval indicated by a discordance. The amount of deformation increases by repeated crustal movements of not only short intervals but also longer durations when sediments were accumulating. It is interesting to see that the sequence happens to be unbroken or only a little broken where a post-Sakawa syncline lies on a Sakawa syncline. Such a synorogenic conformity or disconformity in the intra-orogenic zone is, however, local. As a rule it transmits soon into a clino-unconformity within a short distance.

These stratigraphic aspects can now be illustrated in greater detail than I have formerly shown. In Nagato and Tsukushi the late Mesozoic crustal deformations can be analysed into 8 stages of development, namely, those of (1) the Toyora-Toyonishi interval, (2) the Toyonishi epoch, (3) the Toyonishi-Wakino transition, (4) the Wakino epoch, (5) the Wakino-Inkstone interval, (6) the middle Inkstone epoch, (7) the Inkstone-Yawata interval and (8) the post-Yawata age (Matsumoto, *16*, 51).

The paralic Toyonishi and limnic Wakino series are typical orogenic sediments. The Wakino lake had been brought to being before the Toyonishi embayment turned out land. This transitional epoch was the climax of the Oga disturbance. The Inkstone series which overlies them disconformably is distributed extensively and the discordance becomes stronger where it covers the Toyora and older formations.

While the discordance at the base of the Ryoseki series is angular in the northern Yuasa basin, in the Ryoseki basin it overlies the Permian

The Cretaceous and Upper Jurassic formations in Japan. (U: Uwajima in Shikoku Island).

Age	**Series**	**Southwest Japan**					**Northeast Japan**		
		Hida	**Tsukushi**	**Higo**	**Kii**	**U.**	**Kitakami**	**Hokkaido**	**Akitsu**
Upper Senon.	**Hetonai**							**Hakobuchi**	
Lower Senon.	**Urakawa**		**Yawata**	**Himenoura**	**Toyajo**	**Nanyo**	**Kuji**	**Up. Yezo**	**Izumi**
Turon. Cenoman.	**Gyliak**		**Inkstone**	**Mifune**	**Kanaya**			**Mikasa Sandst.**	**Sakawa**
Albian Aptian	**Miyako**	**Akaiwa**		**Yatsushiro** **Hinagu**	**Miyako**		**Miyako**	**Mid. Yezo**	
Upper Neocom.	**Oshima**		**Wakino**	**Oshima**	**Oshima**	**Upper Shimanto**	**Oshima**		**Oshima (Kashio)**
Lower Neocom.	**Ryoseki**	**Itoshiro**	**Toyonishi**	**Ryoseki**	**Ryoseki**		**Ayukawa**	**Low. Yezo**	**Oga**
Malm	**Torinosu**	**Kuzuryu**	**Toyora**	**Torinosu**	**Torinosu**		**Hashiura**	**Sorachi**	
Age	**Series**	**Akiyoshi Mts.**		**Sakawa Folded Mountains**				**Yezo Geosyncline**	**Phase**

disconformably. Thus the influence of the pre-Ryoseki movement on the outer side was much different among places. In central Shikoku it is clearly demonstrated that the embryonic folding grew gradually through the early Cretaceous period. The palaeogeographic changes were great at the Oshima and Sakawa phases not only in the sedimentary basins but also in their background (Kobayashi, Huzita and Kimura, *13*).

In the Yatsushiro district in Higo the Sakawa phase can be splitted into two subphases where the earlier one at the middle Miyako epoch was stronger than the later one (Matsumoto and Kammera, *20*). In Shikoku, on the contrary, the early subphase is insignificant and only the later one or the Sakawa phase proper is distinct. Thus the paroxysm came earlier in Yatsushiro on the inner side than in the Sakawa and other basins on the outer side of the Chichibu imbricated zone.

In the Yuasa and a few other basins the pre- and post-Sakawa formations form the syncline-on-syncline structure. Although the discordance is weak between them, the base of the Gyliakian formation in the Yuasa basin is well marked off by a boulder conglomerate. It is further remarkable that the Miyakoan formation directly overlies the Palaeozoic on the south side of the basin and the Urakawan on the Palaeozoic on the other side with an angular unconformity (Matsumoto, *16*). In the Akaishi mountains the Oshima or Miyako series of Todai incorporates with the older formations in the imbricated structure of the Chichibu zone, whereas the Gyliakian of Misakubo rests on the imbrication unconformably and forms an open syncline.

In the Shimanto folded zone the Lower Cretaceous and older formations are extensive and all folded together intensely, whereas the Upper Cretaceous Nanyo formation is restricted to occur near Uwajima in western Shikoku. Further to the South there was the Nakamura geosyncline where the Cretaceous and Palaeogene formations were accumulated.

It is difficult to correlate the metamorphism and plutonism in the deeper zone with the crustal deformation in the shallower zone. However, it can be judged that the Nagatoro metamorphism has taken place mainly in the Jurassic period, because it occurred in the core of the Eo-Nippon cordillera and because the metamorphic rocks are sometimes met with in the Ryoseki conglomerates. As seen in Shikoku, granitic rocks sporadically increase in size and number in the Miyakoan conglomerate. This fact suggests that the Kashio phase of dislocation was slightly earlier than the Oshima phase, if they are not coeval. In central Kyushu the Ryoke gneiss and Nagatoro schists are overlain by the upper Miyakoan or Gyliakian series.

Subsequent to the Kashio phase the Chichibu zone was imbricated and the Shimanto zone folded. In the Kii peninsula the Nagatoro zone thrust itself upon the Chichibu (Kimura, *7*) and the northern Chichibu belt thrust again upon the southern Chichibu with low angles (Shiida, *23*; Kimura, *7*).

Because the western wing of the Sakawa mountains was imbricated by various thrustings, there must have been an obstacle in front. The northern wing on the contrary, was shifted toward the Pacific basin by itself. The Kwanto mountains at the junction with the west wing were sharply bent toward the south. At the same time the Nagatoro zone was thrust upon the Chichibu zone, forming the Ogiriyama Decke (Fujimoto, *4*). In the north of the Kwanto tectonic line the domain of the Ryoke injection expanded into the Nagatoro zone or the Abukuma mountains.

The southern and northern part of the Kitakami mountains belongs respectively to the Nagatoro zone and the Chichibu-Shimanto zone. There the strata are not much metamorphosed and the axes of foldings generally high angled.

In the southern Kitakami mountains the Ryosekian Ayukawa series overlies the Jurassic and is overlain by the Oshima series both disconformably. The last (2,200 m. thick) is rich in volcanic material and overlies the Permian of Ofunato with a weak discordance. They are all strongly folded by the Oshima orogeny. In the northern Kitakami the basal conglomerates of the Miyako series abbut with the folded Neocomian and older rocks and the series (250 m.) is gently tilted to the east. At Kuji the Urakawa series (600 m.) dips no more than 15 degrees and is disconformably overlain by the Palaeogene (Onuki, *22*).

In Central Hokkaido the Sorachi group which is built up mainly by andesitic and basaltic tuffs, siliceous shale and Radiolarian chert, indicates an intense volcanism within the Yezo geosyncline. It is overlain by the Yezo group (5,000 m.), unconformably in part. The ammonite-bearing mudstone facies is prevalent in the group, but the Trigonian sandstone of Mikasa wedges into the middle part from the west, showing the Gyliakian regression caused by the upwarping of the Kitakami zone in the Sakawa phase. The Hetonaian Hakobuchi sandstone (900 m.) represents the

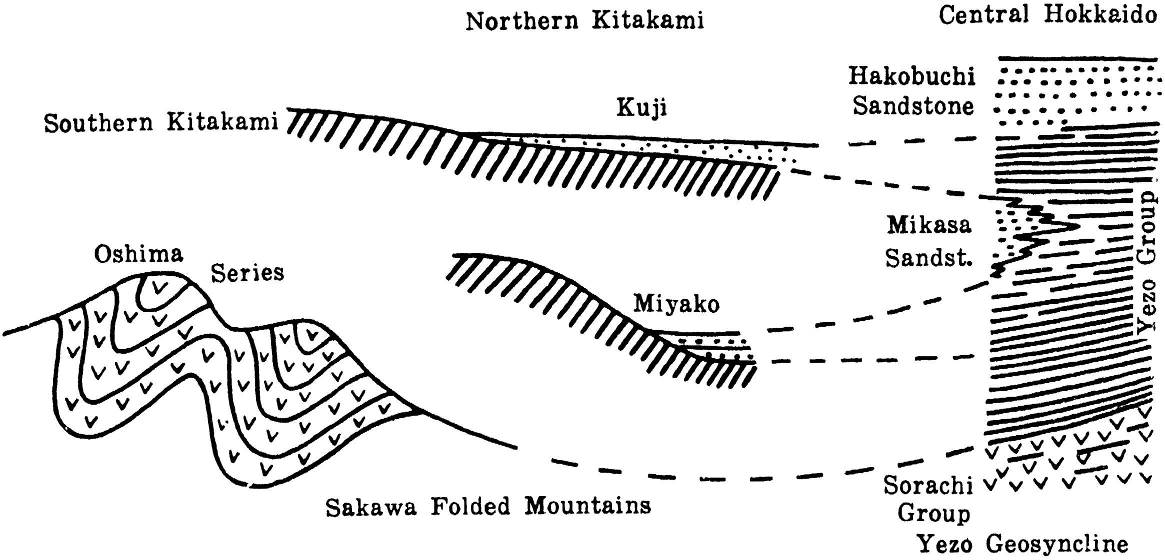

Fig. 2.— Simplified sections showing the relation between the Sakawa folded mountains and Yezo geosyncline.

regression at the closing of the Cretaceous period. It is disconformably overlain by the Palaeogene of the Ishikari coal-field (Matsumoto et al.. *19*).

The modification of the Akiyoshi mountains by the Sakawa orogeny is quite different between the granitized Hida zone and the non-granitized Yamaguchi zone and between the basement rocks and blanket formations. The well consolidated gneiss zone suffered from compressive block movement. The Tetori series on such blocks is nearly horizontal or only gently undulated except for their boundaries where it is abruptly flexured and cut by faults. These faults are mostly reverse in vertical section and diagonal to the Akiyoshi trend in plan (Kobayashi, *8*).

In the non-granitized terrain the Upper Triassic and Jurassic formations form structural basins or brachysynclines which are regardless of the arcs of their basement. It happens, however, that these blankets are folded almost as strong as their basement and the structures of the supra- and sub-formations are subconcordant. This kind of deformation is met with in the Hida plateau in the non-granitized zone near its boundary with the granitized zone.

It is certainly interesting to see the similarity of the post-orogenic modification between the Akiyoshi and Sakawa mountains which suffered respectively from the Sakawa orogeny and the middle Tertiary Oyashima disturbance. The Palaeogene and older sediments in the Nakamura geosyncline are strongly folded. The deformation of the Upper Cretaceous formation becomes weak in the Shimanto and northern zones. Its folds are almost closed in the south but wide open in the north of the Uwajima area. The open folds of the post-Sakawa formation can also be seen in the Yuasa and Misakubo areas in the Chichibu zone. It happens, however, that the Upper Cretaceous formation is disturbed almost as much as the Lower Cretaceous one. The deformation in such intensity is, however, confined to the meta-orogenic ditch which was later folded in between the two sides by strong compression. In the well granitized Ryoke zone the Cretaceous formation is either simply tilted or gently undulated.

In the inner zone of West Japan the Wakino and later formations are quite different from the Toyonishi and older ones in the intensity of deformation, because the orogeny was strongest in the Oga phase. The volcanism has taken place in the zone through the Cretaceous period, but most active in the Inkstone epoch. In the early stage andesite and porphyrite were prevalent, but later liparite and quartz-porphyry took their place. In the Kitakami mountains the eruptions of andesite took place in the Oshima epoch and liparitic ones in the Gyliakian or later.

Finally there took place the batholithic invasion of the Chugoku granite on a large scale, causing extensive culmination near the end of the Cretaceous and the beginning of the Tertiary period. The Palaeogene formations on the granitized basement in northern Kyushu are not much folded and generally undulated, faulted or flexured. Except for the Nakamura geosyncline, where the boundary between the Cretaceous and Tertiary systems is obscure, the Senonian is disconformably overlain by the Palaeogene formation. In Japan there is no sign of orogeny between them.

In the maritime province of USSR. the Oga phase is marked off by the basal conglomerate of the Valangian stage which is transgressive. The Nikanian coal-bearing in Ussuri is composed of limnic or paralic sediments of Neocomian age and is unconformably overlain by the tuffaceous Nikan, the approximate equivalent of the Inkstone series. There were crustal movements before the Aptian and Emscher which corresponds to the Oshima and Sakawa (or Izumi) phase. While the Senonian is extensive in Japan on the Pacific side, it is limited in the maritime province as well as on the continental side of Japan. The passage beds from Senonian to Palaeogene are rich in volcanic material and yield fossil plants resembling the Laramie flora. The Werchojansk mountains in which the Lower Cretaceous and older formations are folded may be referred to the Sakawa system of folded mountains.

In Korea there are two folded zones. In the Heinan zone extending from North Korea to the Liaotung peninsula (Kobayashi, *10*), the Triassic Shorin folded mountains were considerably modified by the late Jurassic movement called Taiho by Konno (1928). Simultaneously, the Triassic embryonic foldings in the Yokusen geosyncline in South Korea has been greatly developed till at length the complicated imbricated structure was built up in the Kwangwoun-do or Kogendo limestone plateau (Kobayashi, *9*).

Wong (1927) was the first in China to point out the importance of the late Jurassic movement. He denominated it "Yenshan movement" on the basis of the discordance at the base of the Tiaochishan-Chiulungshan formation in the Western Hills of Peking. Since then, her Mesozoic history was immensely clarified, but unfortunately the term, Yenshan movement, had been used in too different ways that it became most confusing. Namely, it means all of the Mesozoic movements in China (Ting, 1929; Hsieh, 1936, 37), the middle Mesozoic ones (Teilhard de Chardin, 1943), the late Mesozoic ones (Wong, 1927; Y.Y. Lee, C. Li, and S. Chu, 1935; Huang, 1945, 52) or just the late Jurassic one (Wong, 1927; Lee, *14*). Under the circumstances it may be appropriated to return to the original designation.

The pre-Tiaochishan movement is now known to be middle Dogger, instead of Malm in age (Comp. Comm., etc., 1956). Accordingly its equivalent is the Gishu, instead of the Taiho, movement in Korea and the Hida, instead of the Oga, movement in Japan. This possibly means that the late Mesozoic movements commenced earlier on the continent than on the festoon islands, although the non-marine Mesozoic biostratigraphy must be established before this will be concluded. At all events, the late Mesozoic movements are most influential for the Koreo-Chinese Heterogen (Kobayashi, *9*) comprising Korea and the main part of China (Huang, *6*). The movements there occurred were, however, synorogenies sympathetic with the Sakawa orogenic cycle in the peri-continental geosyncline.

The orogeny was accompanied by volcanism and plutonism, as summarized by Teilhard de Chardin (1938, 40). His Yenshan granite in China, however, may not be late Jurassic in age, but synchronous with the Bukkokuji granite (Tateiwa, 1924) in Korea and with the Chugoku granite in Japan. They on the whole indicate the batholithic invasion in a grand scale in the hinterland near the end of the orogenic cycle. The age of the granite is in a range from late Cretaceous to early Tertiary.

The late Mesozoic orogeny bears the great importance not only in Eastern Asia, but also in Southeastern Asia. In Taiwan the Sakawa orogeny is indicated by the unconformity at the base of the Cretaceous Pihou formation and its basal conglomerate containing schists and gneiss. The chert-bearing Permo-Triassic formation called Danau (in part), Tuhul, or Pahang indicates the southern extension of the Shimanto geosyncline from Japan to the Malayan peninsula through Luzon, Palawan and Borneo. In central Borneo the Neocomian overlies transgressively the strongly folded Bojan formation of the Danau complex (Oga phase). In South Borneo the *Orbitolina*-bearing rocks are folded and intruded by basic and ultrabasic rocks and they are overlain by the Turonio-Senonian (Sakawa phase).

Bajocian fossils were found in Singapore, Aelenian ammonites in the Mae Sot basin, Western Thailand, Bathonian brachiopods of Namyau and Liassic (?) plants of Loian in the Shan plateau, Burma. These fossiliferous formations had been folded together with the older rocks and intruded by granite before the Tertiary basin developed in Central Burma.

The late Mesozoic orogeny was also strong in certain places around the Pacific basin. In western North America, for example, the Diablo and Oregon disturbances correspond approximately to the Oga and Sakawa phases respectively. The Hokonui disturbance in New Zealand is nearly coeval with the Oga orogeny in Japan. The early Oga disturbance is well marked also in the Pamir by the discordance at the base of the Tithonio-Valangian. In Oman, on the other hand, the Middle Cretaceous or pre-Gosau disturbance was strong. The *austrische Phase* in the Alps is nearly contemporaneous with the Sakawa phase in Japan. The bearing of the *austrian* or *subherzynische Phase* on the Alpine tectonics is, however, quite different from that of the Cretaceous orogeny in the Japanese islands, or in Eastern and Southeastern Asia, where the orogenic cycle was completed by the batholithic invasion near the end of the period.

REFERENCES

(1) Chardin, P. Teilhard de, 1940, The Granitization of China, *Bull. Geol. Soc. China*, **19** : 4.

(2) ———, 1943, The Genesis of the Western Hills of Peking. *Geobiologia*, **1**.

(3) Compilation Comm. of Chinese Geol. and Geol. Inst, Acad. Sinica, 1956, Tables of Stratigraphic Sequences in Provinces of China.

(4) Fujimoto, H., 1937, The Nappe-Theory with Reference to the Northeastern Part of the Kwanto Mountainland. *Sci. Rep. Tokyo Bunrika Univ. Ser. C*, No. 6.

(5) Gorai, M., 1956, On the Metamorphic Zones of the Japanese Islands. *Proc. 8th Pacif. Sci. Congr.* 1953, Phil. **2**A.

(6) Huang, T.K., 1952, On the Major Tectonic Forms of China. Peking.

(7) Kimura, T., 1957, The Discovery of a Low Angle Thrust along the Mikabu Line in East Kii Peninsula, Western Japan; Description of Areal Geology and their Sedimentary Rocks. *Jour. Earth Sci. Nagoya Univ.* **2**: (2).

(8) Kobayashi, T., 1941, The Sakawa Orogenic Cycle and its Bearing on the Origin of the Japanese Islands. *Jour. Fac. Sci. Imp. Univ. Tokyo*, Sect. 2, **5**: (7).

(9) ———, 1953, The Mountain Systems on the Western Side of the Pacific Ocean classified from the Standpoint of Genesis. *Proc. 7th Pacif. Sci. Congr. N.Z.* 1949, **2**.

(10) ———, 1956, A Contribution to the Geotectonics of North Korea and South Manchuria. *Jour. Fac. Sci. Univ. Tokyo, Sect.* 2, **10**: (2).

(11) ———, 1956, The Triassic Akiyoshi Orogeny. *Geotek. Symp. zu Ehren von Hans Stille.* Stuttgart.

(12) ———, 1960, The Jurassic of Japan and its Bearing on the Correlation. *Proc. 9th Pacif. Sci. Congr.* Bangkok, 1957, **12**.

(13) ———, Huzita, A. and Kimura, T., 1945, On the Geology of the Central Part of Shikoku, *Japan. Jour. Geol. Geogr.* **20**.

(14) Lee, C.Y., 1948, A Review of Mesozoic Movements in China. *Contr. Inst. Geol. Acad. Sinica*, **8**.

(15) Matsumoto, T., 1947, The Geological, Research of the Aritagawa Valley, Wakayama Pref. *Rep. Geol. Inst. Fac. Sci. Kyushu Univ.* **2**: (2).

(16) ———, 1949, The Late Mesozoic Geologic History in the Nagato Province, Southwest Japan. *Japan. Jour. Geol. Geogr.* **21**.

(17) ———, 1952, A Note on the Cretaceous History of the Circum-Pacific Region. *Japan. Jour. Geol. Geogr.* **22**.

(18) ———, 1956, The Characteristic Features of the Cretaceous System in the Japanese Island. *Proc. 8th Pacif. Sci. Congr.* 1953. Philippines, **2**.

(19) ———, *et al.*, 1954, The Cretaceous System in the Japanese Islands. *Japan Soc. Prom. Sci.* Tokyo.

(20) ———, and Kammera, K., 1949, Contributions to the Tectonic History in the Outer Zone of Southwest Japan. *Mem. Fac. Sci. Kyushu Univ.* Ser. D, **3** : (2).

(21) Minato, M., 1950, Zur Orogenese und zum Vulkanismus im Jüngeren Paläozoikum

des Kitakami-Gebirges, Honshu Japan. *Jour. Fac. Sci. Hokkaido Univ.* Ser. 4, **7**: (3).

(22) Onuki, Y., 1956, Geology of the Kitakami, Mountains. *Explanatory Text to Geol. Map of Iwate Pref.* **2**.

(23) Shiida, I., 1951, Geology of the Kawakami District in the Northeastern Yoshino Mountainland, *Nara Prefecture. Jour. Nara Gakugei Univ.* **1**.

MESOZOIC TECTONICS OF THE NORTHWESTERN CANADIAN CORDILLERA†

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INTRODUCTION

The region under discussion lies within the Cordilleran eugeosynclinal belt (Stille, *26*; Kay, *14*, *15*) and embraces central southern Yukon, south of latitude 63 degrees north, and northwestern British Columbia, north of latitude 58 degrees north.

Interpretation of the stratigraphy of this region reveals that the folded Mesozoic rocks extending southeastwards from Selkirk, Yukon, into northwestern British Columbia probably accumulated in a trough having the same position and extent as the present rather limited distribution of these rocks. This trough—the Whitehorse trough (Wheeler, *29*)—was flanked on the west in late Triassic by a volcanic island arc, which later in Jurassic and early Cretaceous times became a tectonic land with few volcanoes. During the middle Cretaceous the trough was deformed and intruded by granitic rocks.

GEOLOGIC SETTING

An apparently synclinorial belt of folded sedimentary and volcanic rocks of Mesozoic age, intruded by a few granitic bodies, extends southeastwards from Selkirk along Upper Yukon River valley into northwestern British Columbia (Fig. 1). This belt, called the Upper Yukon Mesozoic belt, is separated from a parallel belt of Mesozoic rocks in the St. Elias Mountains to the west by a complex of quartz-rich metamorphic rocks, probably older than Mesozoic (Wheeler, *29*), and granitic plutons of diverse ages. Granitic rocks are most abundant in the southern part of this complex and form the northernmost part of the Coast intrusions (Lord, *20*) extending for 1,100 miles southeastwards along the axis of the Coast Mountains in western British Columbia. The Upper Yukon Mesozoic belt is flanked also on the east by another metamorphic and granitic complex which separates it from a broad belt of Palaeozoic rocks in southeastern Yukon and northern British Columbia (Bostock and Lees, *4*; Mulligan, *25*).

Just north of the Yukon—British Columbia border, part of the Upper Yukon Mesozoic belt is interrupted by a complexly upfaulted block, named here the Atlin horst, composed of late Palaeozoic rocks intruded by granitic plutons (Aitken, *2* Christie, *7*). Ultramafic rocks are particularly well-displayed within and around the margins of this horst. They are found also in the Upper Yukon Mesozoic belt where they apparently intrude rocks as young as Lower Jurassic and in the St. Elias Mountains where they cut Lower Cretaceous rocks (Kindle, *18*).

For the most part flat-lying volcanic rocks of Cretaceous, Tertiary, and Pleistocene age unconformably overlie all older rocks, except in the St. Elias Mountains where Tertiary rocks are overthrust by Permian strata (J.E. Muller, personal communication). Some of the flat-lying Cretaceous volcanic rocks near the head of Yukon River are intruded by granitic plutons.

REGIONAL ENVIRONMENT PRIOR TO THE DEVELOPMENT OF THE TROUGH

Late Permian time was probably one of tectonic quiet, judging from the late Permian assemblage consisting principally of massive limestone, radiolarian ribbon-chert, and greenstone (chiefly flows) all of which appear to have been deposited in seas far from a source for clastic sediments.

The following evidence suggest that the northwestern Canadian Cordillera was uplifted during early and middle Triassic time, perhaps accompanied by volcanism: (1) Lower and Middle Triassic strata are lacking in the region; (2) conglomerate in the lower part of the Upper Triassic succession is widespread in northwestern British Columbia (E.F. Roots, personal communication); (3) Upper Triassic rocks locally overlie Permian formations unconformably (McLearn, *22*; *10*) (4) In eastern Alaska and possibly elsewhere greenstone occurs between Permian and Upper Triassic strata (Martin, *21*).

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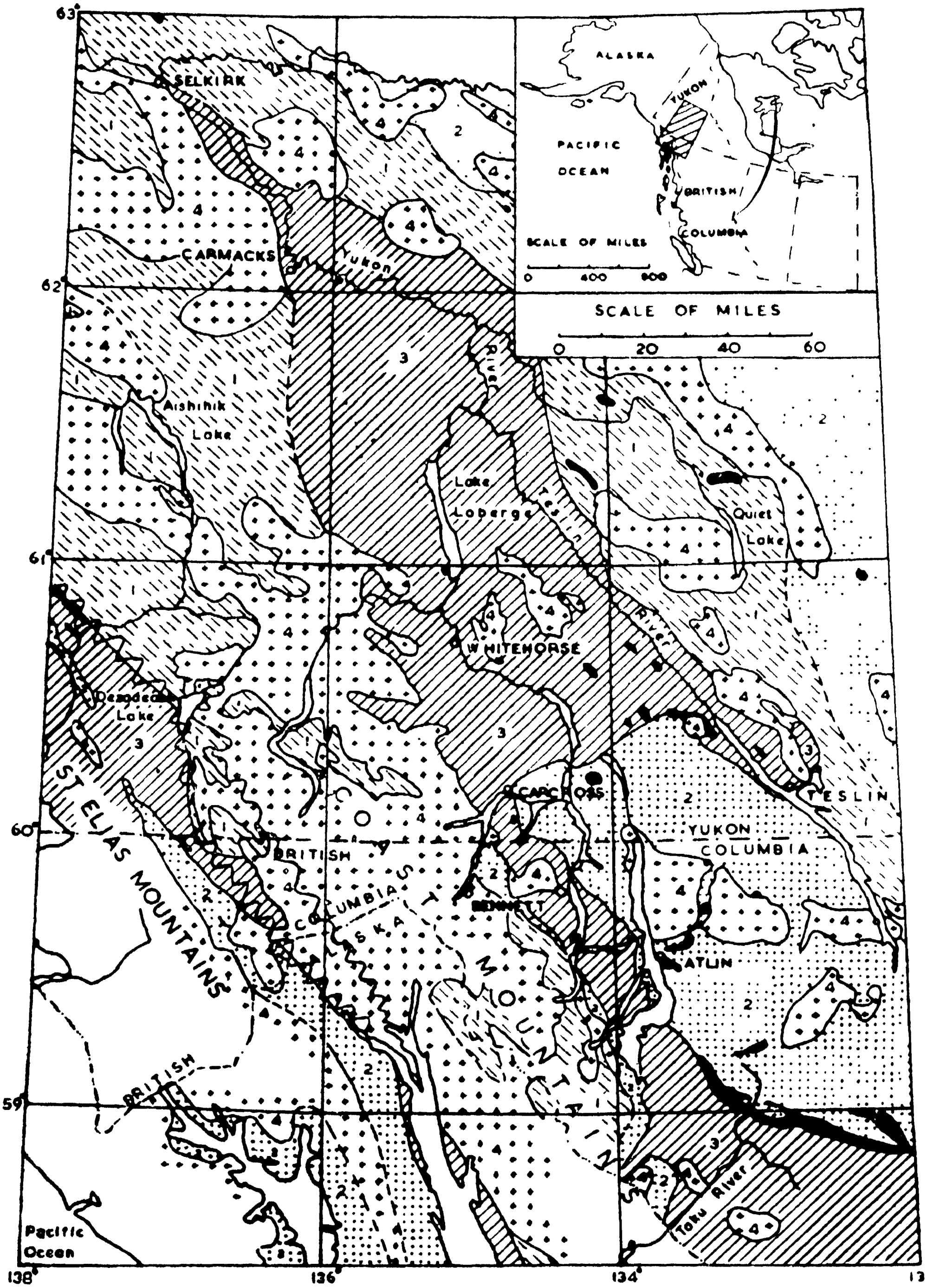

Fig. 1.— Generalized geologic map of part of northwestern Canadian Cordillera excluding undeformed Cretaceous and Cenozoic formations. 1.—Metamorphic rocks, 2.— Palaeozoic rocks, 3.— Mesozoic rocks, 4.— Granitic rocks, black—Ultramafic rocks.

LATE TRIASSIC TECTONICS

Although there is little evidence concerning the events of the early Upper Triassic, it seems clear that by Norian time (late Upper Triassic) an elongate volcanic terrain, probably an island arc (Eardley, *8;* Wilson, *30*; Kay, *15*), lay along the subsequent site of the axis of the Coast Mountains, flanked on the east by a marine trough. Evidence for these features comes from a regional consideration of the distribution, abundance, and character of the Upper Triassic volcanic rocks and in detail from the Norian stratigraphy around Whitehorse, Yukon.

Regionally, the thickest sections of Upper Triassic volcanic rocks and those with the coarsest fragmental materials lie in a linear belt along the flanks of the Coast Mountains, that is, near the western margin of the Upper Yukon Mesozoic belt. Here, volcanic rocks, mainly andesites and basalts, form deposits as thick as 5,000 feet and contain fragmental blocks commonly a foot and locally up to 4 feet across (Kerr, *16, 17;* Wheeler, *29*). Northeastward and eastward Upper Triassic volcanic rocks appear to be less abundant (Tozer, *28*; *10*) and to date have not been found east of the eastern margin of the Upper Yukon Mesozoic belt. Although volcanic rocks occur in the Upper Triassic formations in southeastern Alaska (Buddington and Chapin, *5*) they are absent northwestward along strike in the St. Elias Mountains (Muller, *24*) and in the eastern Alaska Range (Moffit, *23*).

In the Whitehorse area, north of the Atlin horst, coarse Norian volcanic breccias and conglomerates of nearby westerly derivation (Wheeler, *29*) are intercalated with andesitic and basaltic flows along the eastern flank of the Coast Mountains. This assemblage grades eastward over a distance of about 20 miles into a thick succession of greywackes, siltstone, and argillites showing graded bedding. Twenty miles farther east, near the eastern margin of the Upper Yukon Mesozoic belt, equivalent Norian beds are a heterogeneous apparently littoral assemblage of greywackes, agrillites, pea-sized conglomerate, and limestone beds containing corals and abundant fragments of crinoid stems and molluscs. This change in character of Norian beds across the Upper Yukon Mesozoic belt may be interpreted as a section across a sedimentary basin receiving detritus from s volcanic terrain to the west and also perhaps from a rather subdued or remote area to the east.

Since Upper Triassic marine sedimentary rocks also abound in the eastern part of the Mesozoic belt at the southeastern end of the Atlin horst *(10)* and at intervals along the eastern flank of the Coast Mountains (Kerr, *16*; *17*) they probably were deposited in a more or less continuous trough east of the volcanic arc.

By latest Norian, however, the volcanic arc in this region became inactive and limy muds without volcanic materials were deposited right across the trough forming the widespread latest Norian limestone.

EARLY JURASSIC TECTONICS

The quiet period at the end of the Norian was abruptly terminated by the sudden and rapid uplift of the dormant volcanic arc. Coarse debris was supplied to the western margin of the Whitehorse trough and finer detritus was carried farther east to its central part. Some sediments were also derived from east of the trough (Fig. 2). Evidence for the disposition, character, and timing of these uplifts is provided by the Lower Jurassic stratigraphy of the region.

Uplift west of the trough is indicated by the Lower Jurassic conglomerates and erosional unconformities both within the Lower Jurassic succession and between the Upper Triassic and Jurassic formations near the western margin of the Upper Yukon Mesozoic belt. The conglomerates occur as coarse-textured, apparently deltaic lenses up to 4,500 feet in thickness. These lenses, which are of local westerly origin (Wheeler, *29*), pinch out eastward and pass into a marine assemblage of rapidly deposited greywackes, siltstones, and argillites in graded beds occupying the central part of the belt. In the Whitehorse area, the thickness of Upper Triassic rocks removed by erosion before the Lower Jurassic conglomerates were laid down increases westward from the central part of the Upper Yukon Mesozoic belt. For instance, in the central part of the belt the two units may be conformable, but 10 miles west, at least 700 feet of Upper Triassic rocks are missing below the base of the Lower Jurassic conglomerate (Wheeler, *29*). In Taku River area, British Columbia, unconformities within and below the Lower Jurassic formations in the southwestern part of the area are not recognized to the northeast (Kerr, *17*).

The sudden appearance in early Jurassic time of these conglomerates, composed principally of volcanic and granitic debris and containing virtually no metamorphic detritus, indicates that the granitic bodies were emplaced in the volcanic

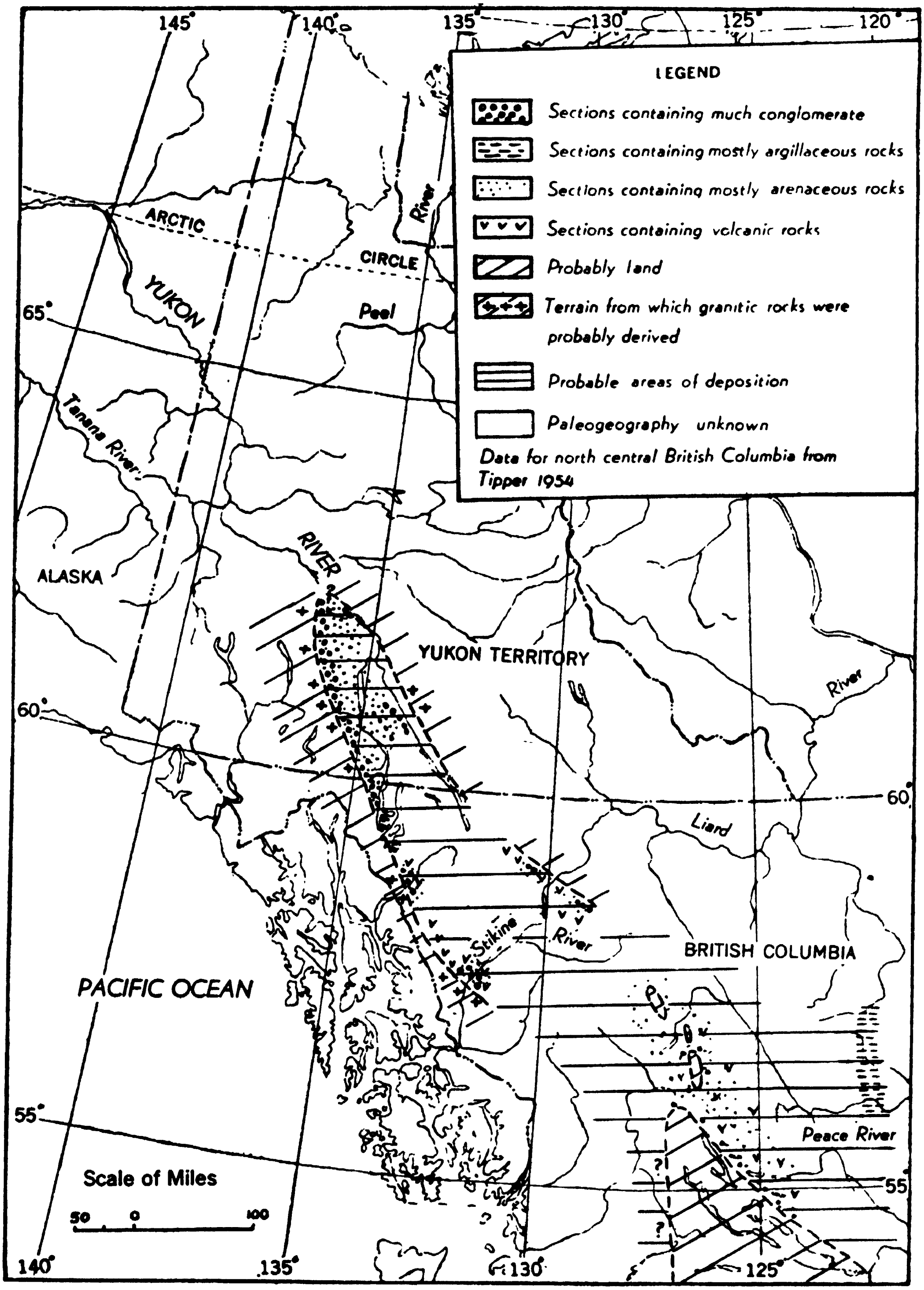

Fig. 2. — Palaeogeographic map of northwestern Canadian Cordillera during the early Jurassic (late Lias).

rocks of the island arc just prior to or during these uplifts. These bodies may have been genuine intrusions or faulted parts of older granitic terrains. Such older terrains have been discovered along the eastern flank of the Coast Mountains beneath Permian (Aitken, *2*) and Upper Triassic *(10)* strata and in southeastern Alaska supplied granitic debris to Silurian and Devonian conglomerates (Buddington and Chapin, *5*).

The conglomerates probably formed in response to rapid uplift which may have been assisted by faulting and was not everywhere synchronous west of the Whitehorse trough. These circumstances are indicated by the coarse conglomerates marking the western margin of the trough (Fig. 2) that appear at different stratigraphic levels at different places.[1]

Conglomerates in the eastern part of the Upper Yukon Mesozoic belt near Whitehorse were probably derived from the east on the following evidence: conglomerates in the eastern part of the belt, forming the basal member of the Jurassic succession, differ from the irregularly distributed, coarse lenses rich in granitic debris in the western part of the belt by containing few granitic fragments and by having a more or less uniform thickness no greater than 600 feet; basal conglomerates near the eastern margin of the belt contain limestone blocks up to 12 feet in size, presumably of local origin; and conglomerates derived from the west pinch out eastward and do not appear to have been deposited in the eastern part of the trough (Wheeler, *29*).

In view of the uncertain relations between the Jurassic and Upper Triassic formations in the eastern part of the Upper Yukon Mesozoic belt little can be said of the tectonics east of the trough other than that land, composed mainly of volcanic and sedimentary rocks and sparingly of granitic rocks, lay in this zone in early Jurassic.

LATER JURASSIC AND EARLY CRETACEOUS TECTONICS

Nowhere in this region has strata of definite Middle Jurassic age or a complete section of the Jurassic been recognized. Middle Jurassic strata may, however, be represented by the siliceous clastic sedimentary rocks lying several hundred feet above late Lower or early Middle Jurassic fossils west of Whitehorse and by similar rocks beneath Upper Jurassic (?) and Lower Cretaceous beds west of Lake Laberge (Cairnes, *6*).

In contrast with the marine and coarse deltaic sediments deposited in the early Jurassic the nonmarine beds laid down in the later Jurassic and early Cretaceous in the Yukon contain coal seams, abundant fragments of quartz, quartzite, chert, and sodic plagioclase, and only a few beds, up to 50 feet thick, of relatively well-sorted conglomerate.

Such a change probably resulted from a combination of factors. One of these may have been the complete destruction of mafic rocks and minerals by increased chemical weathering due to less rapid uplift of the western source under the more humid climate of the later Jurassic and early Cretaceous. Conditions like these are indicated by coal seams up to 10 feet in thickness, numerous plant fragments, and the relative thinness of the conglomerate layers. If the source area had essentially the same composition as before, that is, volcanic terrain containing bodies of granitic rocks bearing potash feldspar, the humid environment would favour the preservation of potash feldspar over plagioclase (Goldich, *11*). In the Upper Jurassic (?) and Lower Cretaceous sediments, however, potash feldspar is absent though sodic plagioclase abounds together with stable quartz, quartzite, and chert. Therefore, another factor, namely a change in composition of the source area to one of a highly siliceous nature may have principally governed the change to siliceous sediments in the later Jurassic and early Cretaceous in the Yukon. Such siliceous source rocks may have been the pre-Mesozoic quartz-rich metamorphic rocks or the Permian and older chert-bearing formations on both sides of the Upper Yukon Mesozoic belt. If these formations were the source rocks, then, west of the Whitehorse trough they may have

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[1] For example, conglomerate underlies beds containing *Arnioceras*? sp. of probable Lower Lias (early Lower Jurassic) age a few miles northwest of Whitehorse. Conglomerates west of Whitehorse form a thick section including beds having Lower Lias *Arnioceras*? sp. near the base and terminating upward just beneath beds holding *Harpoceras* sp. of Upper Lias (late Lower Jurassic) age. Conglomerate lies directly on Lower Lias beds containing *Psiloceras* sp. and *Arnioceras* n. sp. west of Lake Laberge, Yukon (Lees, *19*), a few hundred feet above beds containing Upper Lias Harpoceratids south of Carcross, Yukon, and well above strata holding Lower Lias *Arnioceras* sp. southwest of Atlin, British Columbia (J.D. Aitken, personal communication). Conglomerates also occur above and below late Lower or early Middle Jurassic Hildoceratids near Carmacks, Yukon (Bostock, *3*), and above and below beds containing Upper Lias ammonites about half-way between Bennett and Atlin, British Columbia (R.L. Christie, personal communication). Conglomerates in the Taku River area, British Columbia, are restricted mainly to the lower part of the Lower Jurassic (Frebold, *9*).

been exposed in the uplifted core of the tectonic land which lay west of the zone formerly occupied by a volcanic and granitic highland in early Jurassic time. By the later Jurassic and early Cretaceous the highland was probably worn down and overlapped by nonmarine sediments derived from the siliceous source to the west. This interpretation is supported to some degree southwest of Whitehorse where conglomerate like that in the Upper Jurassic (?) and Lower Cretaceous formation apparently unconformably overlies quartz-rich metamorphic rocks west of the Upper Yukon Mesozoic belt (Wheeler, *29*).

LATE JURASSIC AND EARLY CRETACEOUS PALAEOGEOGRAPHY

In late Jurassic and early Cretaceous the Whitehorse trough appears to have been segmented into a more or less restricted nonmarine basin in the Yukon separated by a land area from a marine environment in northwestern British Columbia. This is suggested by the limitation of nonmarine sediments to an area northwest of the Atlin horst and by the Upper Jurrassic and Lower Cretaceous brackish-marine sediments in northwestern British Columbia which become coarser northward towards a probable source area north of latitude 58 degrees *(10)*.

The western limit of the source area west of the nonmarine basin in the Yukon is delineated by the conglomerate associated with coal seams at the base of the marine Lower Cretaceous succession in the eastern part of the St. Elias Mountains. This conglomerate, however, is missing at the base of the succession a few miles to the west (Kindle, *18*).

DEFORMATION OF THE TROUGH

In mid-Cretaceous time the rocks in the trough were deformed and folded mainly parallel to the northwesterly trend of the trough. In Whitehorse area the structure appears to be a synclinorium (Wheeler, *29*) in which the subsidiary folds on its limbs have axial planes dipping towards its centre. On the west side of the synclinorium at least one northeasterly dipping reverse fault is associated with folds having northeasterly dipping axial planes. The folds were governed markedly by the competence of the rocks. For example, open folds prevail in thick accumulations of competent conglomerate and massive greywacke whereas tight folds occur in incompetent limestone and interbedded greywacke and slate.

The areas bordering the trough, composed of metamorphic and granitic rocks, may also have been involved in this deformation but insufficient work has been done on these rocks to establish this possibility.

The subsequent intrusion of granitic plutons modified the earlier fold-trends in varying degrees. Modification of the structures in Mesozoic rocks was, in general, not pronounced but profound changes were effected in the incompetent late Palaeozoic rocks exposed in the Atlin horst (J.D. Aitken, personal communication)

The Atlin horst was upfaulted relative to the surrounding Mesozoic formations some time after the rocks in the trough had been folded and intruded by granitic plutons. Since the area now occupied by the Atlin horst appears to have been a relatively elevated region in late Jurassic and early Cretaceous time the relative upward movement of this block may have been initiated in the late Jurassic.

TIME AND PLACE OF INTRUSION

ULTRAMAFIC ROCKS

On the basis of the present information the time of intrusion of serpentinized ultramafic rocks exposed within the Upper Yukon Mesozoic belt and in the late Palaeozoic rocks of the Atlin horst is uncertain.

Ultramafic rocks in the Atlin horst are regarded by Aitken *(1; 2)* as having been intruded during the Permian on the basis of their spatial relation to and their intimate and irregular association with Permian greenstone. Those in the Mesozoic belt are elongate bodies, most of which are more or less sheared, occurring near faults or in highly deformed zones in volcanic rocks of uncertain age and apparently into clastic rocks as young as Lower Jurassic (Wheeler, *29*).

According to Hess *(12; 13)* serpentines in an alpine-type mountain system were probably intruded during its first great deformation. Therefore, assuming that Aitken's interpretation of a Permian age for the intrusion of ultramafic rocks is correct, then, the occurrence in the same tectonic belt of sheared ultramafic bodies in highly deformed and faulted zones in Mesozoic rocks may be explained by assuming that they represent Permian intrusions displaced upward as solid intrusions or in fault slices into younger rocks by mid-Cretaceous and, perhaps to some degree, by the earliest Jurassic deformations.

Although ultramafic rocks cut formations as young as Lower Cretaceous in the St. Elias Mountains it is not known when the original intrusion took place because this mountain belt has undergone several disturbances from late Palaeozoic to late Tertiary.

GRANITIC ROCKS

Granitic plutons intrude both rocks deposited in the Whitehorse trough which were deformed in mid-Cretaceous time and a group of flat-lying volcanic rocks unconformably overlying them. The plutons occur as steepwalled bodies in the Upper Yukon Mesozoic belt and in the Atlin horst and as parts of plutonic complexes on each side of them (Fig. 1).

Granitic rocks are most extensive today in zones bordering the Upper Yukon Mesozoic belt where granitic rocks are known to have existed in the early Jurassic, the earliest Upper Triassic, the earliest Permian, and possibly in the Silurian. Whether these older granitic terrains are parts of one or more ancient terrains or whether they represent repeated intrusions which accompanied successive disturbances in the same general zone along the Coast Mountain belt may be answered eventually by age determinations on these granitic rocks.

SUMMARY

In late Triassic the Whitehorse trough was established in central southern Yukon and northwestern British Columbia upon a regionally uplifted zone which followed a period of tectonic quiet at the end of the Permian. This trough lay east of a volcanic arc that probably extended along what is now the axis of the Coast Mountains. The volcanic arc became inactive in latest Triassic. In early Jurassic, parts of the dormant volcanic arc were uplifted spasmodically at irregular intervals to form a tectonic land from which coarse sediments poured into the trough on the east. Some sediment was also derived from the east. Just before or during this period of uplift granitic bodies were emplaced into the volcanic rocks of the island arc either as intrusions or as faulted parts of older terrains. In later Jurassic and early Cretaceous time the trough was segmented by differential subsidence so that in the Yukon it formed a more or less enclosed basin receiving siliceous clastics from the core of the considerably eroded tectonic land to the west and possibly from another siliceous terrain to the east.

In the mid-Cretaceous the life of the trough came to an end and the rocks in it were deformed into a synclinorium. Ultramafic rocks intruded in the Permian may have been displaced at this time. The folded rocks were partly eroded and next overlain unconformably by volcanic rocks. Finally the whole assemblage was intruded by granitic rocks.

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REFERENCES

(1) Aitken, J.D., 1953, Greenstones and associated ultramafic rocks of the Atlin map-area, British Columbia; *Univ. Cal. Los Angeles*, Ph. D. Thesis.

(2) ———, 1955, Atlin, British Columbia: *Geol. Survey Canada* Paper 54-9.

(3) Bostock, H.S., 1936, Carmacks district, Yukon: *Geol. Survey Canada* Mem. **189**.

(4) ———, and Lees, E.J., 1938, Laberge map-area, Yukon: *Geol, Survey Canada* Mem. **217**.

(5) Buddington, A.F. and Chapin, Theodore, 1929, Geology and mineral deposits of southeastern Alaska: *U.S. Geol. Survey* Bull. **800**.

(6) Cairnes, D.D., 1910, Lewes and Nordenskiöld Rivers coal district, Yukon Territory: *Geol. Survey Canada* Mem. **5**.

(7) Christie, R.L., 1957, Skagway map-area, British Columbia; *Geol. Survey Canada* P.S. Map 19-1957.

(8) Eardley, A.J., 1947, Palaeozoic Cordilleran geosyncline and related orogeny: *Jour. Geology*. **55**: 309-342.

(9) Frebold, H., 1953, Correlation of the Jurassic formations of Canada: *Geol. Soc. America Bull.*, **64**: 1229-1246.

(10) Geological Survey of Canada P.S. Map 9-1957. (Stikine River area, British Columbia).

(11) Goldich, S.S., 1938, A study in rock weathering; *Jour. Geology*, **46**: 17-58.

(12) Hess, H.H., 1939, Island arcs, gravity anomalies, and serpentine intrusions. A contribution to the ophiolite problem; *17th Internat. Geol. Congr.* Rept., **2**: 263-282.

(13) ——— , 1955, Serpentines, orogeny, and epeirogeny: in Crust of the Earth, A. Poldervaart (editor), *Geol. Soc. America*, Spec. Paper **62**: 391-407.

(14) Kay, Marshall, 1947, Geosynclinal nomenclature and the craton; *Bull. Am. Assoc. Petrol. Geol.*, **31**: 1289-1293.

(15) ———, 1951, North American geosynclines: *Geol. Soc. America*, Mem. **48**.

(16) Kerr, F.A., 1948a, Lower Stikine and Western Iskut River areas, British Columbia: *Geol. Survey Canada* Mem. **246**.

(17) ———, 1948b, Taku River map-area, British Columbia: *Geol. Survey Canada* Mem. **248**.

(18) Kindle, E.D., 1953, Dezadeash map-area, Yukon Territory: *Geol. Survey Canada* Mem. **268**.

(19) Lees, E.J., 1934, Geology of the Laberge area, Yukon: *Roy. Canadian Institute Trans.*, **20**: (1), 1-48.

(20) Lord, C.S., 1947, The Cordilleran region, part of Chap. VII in geology and economic minerals of Canada, third edition: *Geol. Survey Canada,* Econ. Geol. Ser., **1** : 220-245.

(21) Martin, G.C., 1926, The Mesozoic stratigraphy of Alaska: *U.S. Geol. Survey* Bull. **776**.

(22) McLearn, F.H., 1953, Correlation of the Triassic formations of Canada: *Bull. Geol. Soc. America.*, **64** : 1205-1228.

(23) Moffit, F.H., 1954, Geology of the eastern part of the Alaska Range and adjacent areas: *U.S. Geol. Survey* Bull. **989**-D.

(24) Muller, J.E., 1954, Kluane Lake (west half), Yukon Territory: *Geol. Survey Canada* Paper 53-20.

(25) Mulligan, Robert, 1955, Teslin map-area, Yukon Territory: *Geol. Survey Canada* Paper 54-20.

(26) Stille, H., 1941, Einführung in den Bau Amerikas, Borntraeger, Berlin.

(27) Tipper, H.W., 1954, Revision of the Hazelton and Takla groups of central British Columbia: *State College of Washington*, Ph. D. Thesis.

(28) Tozer, E.T., 1958, Stratigraphy of the Lewes River group (Triassic), central Laberge area, Yukon Territory: *Geol. Survey Canada* Bull. **43**.

(29) Wheeler, J.O., 1956, Evolution and history of the Whitehorse trough as illustrated by the geology of Whitehorse map-area, Yukon: *Columbia Univ., New York*, Ph. D. Thesis.

(30) Wilson, J. Tuzo, 1950, An analysis of the pattern and possible cause of young mountain ranges and island arcs; *Geol. Assoc. Canada* Proc. **3** : 141-166.

NAVADIAN OROGENY IN NORTHERNMOST CHILE†

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INTRODUCTION

In his excellent work "Jurassic Geology of the World," Arkell *(1)* showed that while in North America the Nevadian Orogeny reached its climax, in South America no proved Jurassic folding had been recorded.

Afterwards, Rüegg *(9)* recorded a small outcrop with 52 meters of Tithonian sediments, fortunately preserved lying unconformably over the Dogger "Rio Grande" formation. We propose the name "Jaguay formation" for Rüegg's Tithonian rocks.

Also, according to the same author (Rüegg, 9) the fluvio-lacustrine Aguas Calientes formation of Eastern Perú, assigned tentatively to a Neocomian—Turonian age, rests transgressively over an old Middle-Upper Paleozoic surface, and also over the Jurassic. Rüegg supposed that there was an uplift due to the Nevadian Orogeny, uplift that has been always considered as little probable.

Lately, W. Biese *(2)* described a continuous stratigraphic series in Cerritos Bayos, Antofagasta Province, Chile, which covers from Lower Lias up to the Tithonian. Nevertheless, we must point out that the faunal sequence shown by Biese has repetition of fossils, as *Macrocephalites*, *Cosmoceras*, *Aspidoceras*, etc. and there might be more faults than those shown. Besides, the writers do not see the reasons to assign part of this series to the Portlandian, Tithonian and Bathonian. The same opinion is supported by José Corvalán, paleontologist for "Corporación de Fomento de la Producción," Santiago (personal communication).

About 60 kilometers South of Cerritos Bayos, in the classic locality of Caracoles, H. Harrington *(6)* described Oxfordian, Callovian and Bajocian formations, not showing, however, the presence of Bathonian sediments.

STRATIGRAPHY OF THE COASTAL RANGE BETWEEN IQUIQUE AND ARICA

Three morphological units are present in the Chilean territory between Iquique and Arica. From West to East, they are: The Coastal Range, the Pampa and the Andes Range. The last one has a few active volcanoes, but geological knowledge is still very scarce; here, Galli *(5)* showed the presence of Lias and Upper Carboniferous rocks.

The Pampa (=plain), probably a graben at about 1,000 meters above sea level, has no drainage and is usually covered by a salt crust and in part supports the growth of some tamarugos (carob tree), hence the name Pampa del Tamarugal. North of Zapiga, the drainage is better developed and the Pampa and Coastal Range are cut by a few deep quebradas (=gorges) which resemble the East African Widian. Here the salt crust and the scarce vegetation disappear and the Pampa takes the names of the gorges, as Pampa Tiliviche, Pampa Tana, Pampa Camarones and Pampa Chaca. This last one reaches the sea level by steps in front of Arica.

The Coastal Range reaches a maximum elevation of 1,575 meters at the Atajaña hill. It is made up of rather smooth hills, and narrows and looses elevation to the North. In front of the Pacific Ocean it is cut by an abrupt cliff with a mean elevation of about 500 meters. To the North, the Coastal Range reaches only up to the Arica cliff. The Geology of the Coastal Range is better known due to ENAP's oil prospection during the last year.

A. STRATIGRAPHY OF THE COASTAL AREA SOUTH OF IQUIQUE

Caleta Ligate formation

Type locality: Caleta Ligate, 32 kilometers South of Iquique. The top is the base of Punta

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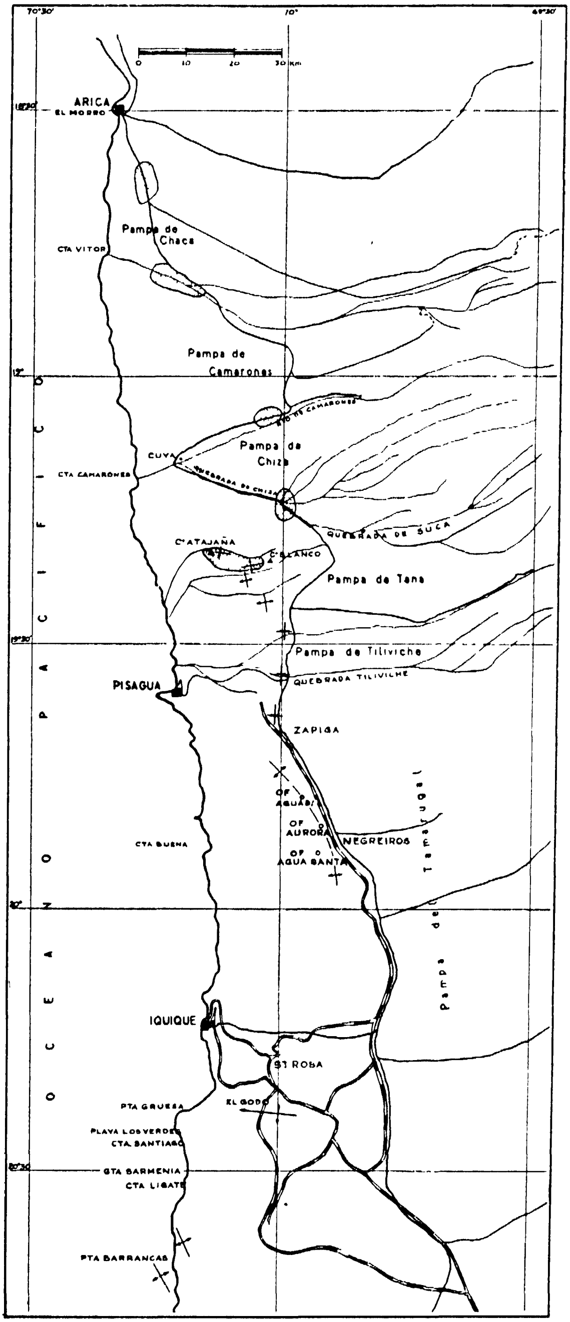

Fig. 1.—Geographical map of Northernmost Chile showing the type localities of Jurassic and Cretaceous formations and their structural trend. The Cretaceous formations are marked by the dotted areas.

Barranco formation; the base is not exposed. Maximum thickness exposed: 320 meters. Lithology: mainly shales and siltstones with rhythmic sedimentation. In the upper part there are about 50 meters of greenish yellow sandstones with nodules, which rest on top of quartzites; at the contact there is a rich fauna and a few conglomeratic lenses. The rhythmic sediments have been drag-folded by several 5-10 meters thick breccia beds from the same formation, which probably slipped down the slope. The texture shows plainly that the breccia moved from East to West as turbidity current. The fauna consists of several specimens of *Terebratula*, *Stephanoceras humphriesianum* (Sow.) and *Cadomites*, which indicate a Middle Bajocian age.

Punta Barranco formation

Type locality: Punta Barranco, 46 kilometers South of Iquique. Top not exposed; the base is the top of Caleta Ligate formation. Thickness: over 1,640 meters. Lithology: mainly microbreccia, with prevalence of breccia towards the base. The breccia fragments are mainly made up of porphyritic rocks, jasper and sandstone. There are some interbedded green to yellow graywackes that grade into breccia and microbreccia and some red to chocolate colored shale beds. A few light to dark colored shale and siltstone beds with syn-sedimentary folds are present near the top and at the contact with the breccias. Towards the base the breccias are well bedded and carry black shale slabs from the underlying formation. A few beds carry shell fragments with *Terebratula*. In two places well rounded river pebbles of acid igneous rocks have been observed, forming lenses within the breccia. It is possible that the Punta Barranco formation correlates with the following formation.

Caleta Sarmenia formation

Type locality: Caleta Sarmenia, 29 kilometers South of Iquique. The top is the base of the Caleta Santiago formation; the base is unknown. Thickness exposed: 1,400 meters. Lithology: breccias of porphyritic rocks and some dark shale fragments, mainly towards the base. Very frequently there is a gradual transition from breccia to yellow or green graywacke, but sometimes the breccia might grade into chocolate to red shale. The upper part presents frequent nodules. No fossils have been found. It is probable that this formation, as well as the Punta Barranco formation, have been sedimented mainly by turbidity currents. The presence of some porphyritic lava flows is suspected, but there are not enough field data to prove it.

Caleta Santiago formation

Type locality: Caleta Santiago, 26 kilometers South of Iquique. The top is the base of the Playa Los Verdes formation. The base is the top of the Sarmenia formation. Thickness: about 600 meters at the type locality. Lithology: black shales with some light colored siltstones, sometimes with rhythmic sedimentation. There are also very well graded silty graywackes with synsedimentary folds. The black shale presents some slump structures with local subaqueous unconformities (discordant hydrodialeima, according to Sanders, 7), which are more frequent towards the top and at the contact with the breccias. Texture and structure point towards sedimentation by turbidity currents. The only fossils found are *Posidonomya*, which might indicate a closed marine environment, low in oxygen and unfavorable for the development of ammonites.

Playa Los Verdes formation

Type locality: Playa Los Verdes, 24 kilometers South of Iquique, Top unknown. The base is the top of the Caleta Santiago formation. Thickness: over 1,500 meters at the type locality. Lithology: porphyritic breccias, with some well bedded sandstones, which present hydrothermal mineralization. There are some beds of microbreccia close to a few meters of dark shale and light siltstone with rhythmic sedimentation which frequently present contemporaneous deformations and dragfolds. Towards the top, the breccias present better bedding; also, there are blocks up to 4 meters in diameter. No fossils have been found.

B. STRATIGRAPHY OF THE COASTAL RANGE SOUTHEAST OF IQUIQUE

El Godo formation

Type locality: El Godo railroad station, South of Santa Rosa. Top: a very thick series of porphyritic breccias. Base: another very thick series of porphyritic breccias and unquestionable porphyritic lava flows. The estimated thickness of El Godo formation is 2,600 meters. Lithology: marine sediments, with thick porphyritic breccias in the central and lower sections. The marine sediments are mainly green to dark rhythmic shales with *Posidonomya*. Few limestone beds are present and they are rarely oölithic. A series of radial faults makes local correlation difficult, but a detailed survey allowed to establish a good stratigraphic column. In the middle portion, ammonites from the *humphriesianum* zone were found *(Cadomites, Stephanoceras)*. H. Fuenzalida, from Santiago's Museo de Historia Natural, found in the upper part one specimen of *Sphaeroceras*, and according to him, it belong to the Upper Bajocian. Towards the base, abundant *Terebratula* were found, similar to those from the Caleta Ligate formation. We may assign them a Middle to Upper Bajocian age to the El Godo formation.

C. STRATIGRAPHY OF THE COASTAL RANGE, NEGREIROS AREA

This area is located to the North of Iquique, between Negreiros and Quebrada Tiliviche.

The sedimentary section is about 3,000 meters thick, and has been subdivided into three formations: Aguada, Negreiros and Agua Santa.

Aguada formation

Type locality: between Oficina (=Nitrate mine) Aurora and Oficina Aguada. The top is the base of the Negreiros formation. The base is not known. Thickness: 830 meters. Lithology: mainly limestones in the middle and upper section exposed; in the basal part and towards the top there are green shales and siltstones. At about 600 meters below the top there is a rich *Macrocephalites* fauna that seems to belong to the Lower Callovian.

This formation cannot be correlated with the formations already described, but the 300 meters of limestone of the lower Chiza formation might belong here.

Negreiros formation

Type locality: between Negreiros and Oficina Aurora. The top is the base of the Agua Santa formation. The base is the top of the Aguada formation. Thickness: 940 meters of hard, gray, calcareous shale, with few limestone beds and some interbedded chocolate colored shale beds towards the middle of the formation. A few sandstone beds are present in the upper part. No ammonites have been found, but its lithology and the age of the boundering formations suggest a correlation with the Caleta Santiago formation South of Iquique, while to the North it might correlate with the upper shaly section of the Chiza formation.

Agua Santa formation

Type locality: West of Negreiros, in the neighbourhood of Oficina Agua Santa. The base is the top of Negreiros formation. The top is unknown. Thickness surveyed: 1,160 meters. Lithology: gray to greenish gray siltstones interbedded with limestone beds and gray and green sandstones. Towards the upper part the green sediments prevail.

Abundant ammonites have been collected in this formation. At a few meters above the base, a bed with *Reineckeia* would incidate the Upper Callovian. 265 meters higher, *Reineckeia* and *Euaspidoceras* are associated showing a probable Lower Oxfordian age, while higher up there are two beds with *Euaspidoceras*, the uppermost carrying also *Ochetoceras* and *Perisphinctes*. This last association shows plainly an Upper Oxfordian age.

It is interesting to mention that in the uppermost part of this formation some anhydrite beds, up to 20 meters thick, are present, which might belong to the "Yeso Principal" (Main Gypsum) from Central Chile and Argentina. The anhydrite beds increase in thickness from West to East.

Towards the North of the type locality, the rocks that are correlated with this formation according to their faunal contents grade into a shalier facies, decreasing the amount of sandstone beds, as it is seen in Pampa Tana. Farther North, in Quebrada Chiza, the upper section of the Chiza formation correlates with the base of the Agua Santa formation, and consists of limestones, siltstones and some sandstone beds. Even farther North, in Quebrada Los Tarros, the shaly Los Tarros formation might represent, according to its fauna, a shalier heteropic facies of the Agua Santa formation.

Towards the South of the type locality, it is quite possible that the sandstone beds grade into the breccias and microbreccias of the Playa Los Verdes fomation, which is thicker and shows faster sedimentation.

D. STRATIGRAPHY OF THE COASTAL RANGE BETWEEN QUEBRADA TILIVICH AND ARICA

In the previous areas, only Jurassic rocks have been found, while North of Tiliviche several marine and continental Cretaceous outcrops have been discovered.

Also, the age of the Andean Diorite intrusions which are quite frequent in the coastal range, may be studied here. The Diorite intrudes the Jurassic rocks which are locally metamorphosed and mineralized. Pebbles of Andean Diorites are found in the continental basal Cretaceous conglomerates. Then the Diorite was intruded after the Upper Oxfordian and before the Tithonian-Neocomian.

In Patagonia, the Andean Diorite belongs to the Upper Cretaceous, after the Sub-Hercynian Orogeny (Cecioni, *4*). In the Northernmost part of Chile, the Diorite was intruded after the Nevadian Phase. The writers cannot state that the Andean Diorite intrusion is gradually younger from North to South in the Chilean Andes, because the necessary data for such statement is fragmentary, and frequently has little paleontological support (Brüggen, *3*).

Porphyritic dikes cut very often the Cretaceous rocks, showing that there were at least three epochs of basic magmatic activity, because the dikes cut two series of very thick porphyritic flows.

Cuya formation

Type locality: In the neighbourhood of Cuya, lower part of Quebrada Chiza. The top is the base of the Chiza formation. The base is not exposed. Lithology: a minimum of 1,270 meters of dark, hard breccia beds, about 5 to 10 meters thick, with some interbedded dark shale and porphyritic flows. These rocks present a variable degree of metamorphism according to the proximity of the Andean Diorite intrusions.

No fossils have been found in this formation. It is older than Callovian.

Chiza formation

Type locality: Quebrada Chiza, 15 kilometers East-Southeast of Cuya. The base is the top of the Cuya formation, with gradual transition between both formations. The top is a small angular unconformity, above which rests the Atajaña formation. Thickness: 940 meters at the type locality. Lithology: marine sediments, that have been subdivided into three members: the lower member, 340 meters thick, is calcareous; the middle member, 470 meters thick, is shaly, and the upper member, 130 meters thick, is a calcareous sandstone. At the base of the lower member several *Reineckeia* were found, which indicate a Callovian age, probably Lower Callovian. In the central part of the middle member *Posidonomya* and one *Parkinsonidae* have been found, which have not been classified as yet.

As it has been already mentioned, it is quite probable that the upper member of this formation correlates with the lower part of the Agua Santa formation; the middle member correlates with the Negreiros formation and the lower member correlates with the upper part of the Aguada formation.

El. Morro formation

Type locality: Arica cliff. The top is the base of a porphyritic complex, with breccia and porphyritic intrusions and flows, not studied in detail. This complex seems to be placed between the El Morro formation and the Los Tarros formation. The base is not exposed. Lithology: three members can be differentiated: the lower member, which crops out at El Morro cliff, consists of 400 meters of pillow lavas with interbedded limestones and green shales; the middle member consists of 250 meters of limestone, and the upper member, at least 210 meters thick consists mainly of chocolate colored shale.

The paleontological contents of the El Morro formation has been studied before: Stehn (*8*, 54 and 150) mentions *Macrocephalites macrocephalus* Schloth.. *Cosmoceras* aff. *ornatum* Schloth., *Reineckeia* sp. and *Posidonomya dalmasi* Dum.. which indicate a Callovian age.

The lithology of the middle member of the El Morro formation is quite similar to the Aguada formation, while the upper member is similar to the Negreiros formation.

Los Tarros formation

Type locality: Quebrada Los Tarros, a little south of Arica. The base is a porphyritic complex, which may be the same found at the top of the El Morro formation. The top is a pronounced angular unconformity below the Atajaña formation. Lithology: 240 meters of dark lamined shale with fossiliferous concretions. The same *Perisphinctes* and *Ochetoceras* sp. from the Agua Santa formation have been found here, showing age correlation, but the lithology suggests deeper shalier facies.

Atajaña formation

Type locality: neighbourhood of Atajaña hill. The top, well exposed at the type locality, is the base of the Blanco formation; the base is not exposed, being covered by a few meters of salt crust. Toward the Northeast of the type locality, in Quebrada Chiza, the conglomerates and sandstones of the Atajaña formation rest on the higher member of the Chiza formation with a small angular unconformity. Lithology: a minimum of 1,400 meters of continental red sandstones, conglomerates and red siltstones, frequently sedimented as lake deposits. They often show suncracks with contemporaneous erosion exhibited somewhere along the line of contact between the fine mud and the coarser upper layer. In some places thin veins of gypsum are present. It is probable that the greater part of these sediments has been deposited in lakes by floods coming from the west.

The thickness of this formation decreases toward the east.

The top is a gradual transition to a siltstone section alternated with marine beds; but there are frequent conglomerate beds with well rounded pebbles and oyster beds at the base of the Blanco formation.

The base of the Atajaña formation is not well exposed at the type locality, but South of Atajaña hill coarse green sandstones of this formation are very close to the Upper Oxfordian shales with *Perisphinctes.* Southeast of Cerro Atajaña (in the middle of Pampa Tana) the same sandstones are very close to the marine limestone with *Parkinsonia*, of a possible Bajocian age. North of Pampa Tana this formation rests on top of the Chiza formation, where abundant *Reineckeia* of Callovian age are present. Also in Quebrada Chiza, shortly below the base of the Atajaña formation, the same faunistic association is found. To the North, in Quebrada Chaca, the Atajaña formation rests on mineralized porphyritic flows (Cuya formation); in Quebrada Los Tarros the same formation rests with angular unconformity over the Upper Oxfordian beds which carry a rich fauna of *Perisphinctes* and *Ochetoceras* (Los Tarros formation).

It is interesting to note that the same beds of the Atajaña formation are found at about the same topographic level resting on very different formations, showing an extensive surface of unconformity at its base. The angularity is exposed in Quebrada Los Tarros and Quebrada Chiza, and is suspected at the type locality. Folds and possible faults must have developed before the deposition of the Atajaña formation.

This formation carries no fossils. The age is younger than Upper Oxfordian and older than the Blanco formation, being closely related to this latter.

The Atajaña formation might be tentatively correlated with the Aguas Calientes formation in Eastern Perú (Rüegg, *9*).

Blanco formation

Type locality: West of Cerro Blanco, at Pampa Tana. The base is the top of the Atajaña formation. The top is not exposed. Thickness: 400 meters exposed at the type locality. Lithology: greenish-gray sandstones with green calcareous sandstone beds and gray and brown laminated shale. The sandstones carry abundant ripple-marks. At the base there are siltstones that grade into the Atajaña formation and well rounded conglomerates with oyster beds.

To the Northeast of the type locality this formation is not present. Here, the Suca formation rests directly on top of the Chiza formation. The relationship between the Blanco and the Suca formations is unknown. The Blanco formation might be older than the Suca formation and might wedge out toward the North, or there might be a lateral change of facies.

One hundred and twenty meters above the base of the Blanco formation, several specimens of *Argentiniceras* have been collected, which indicate a Berriasian (Basal Cretaceous) age.

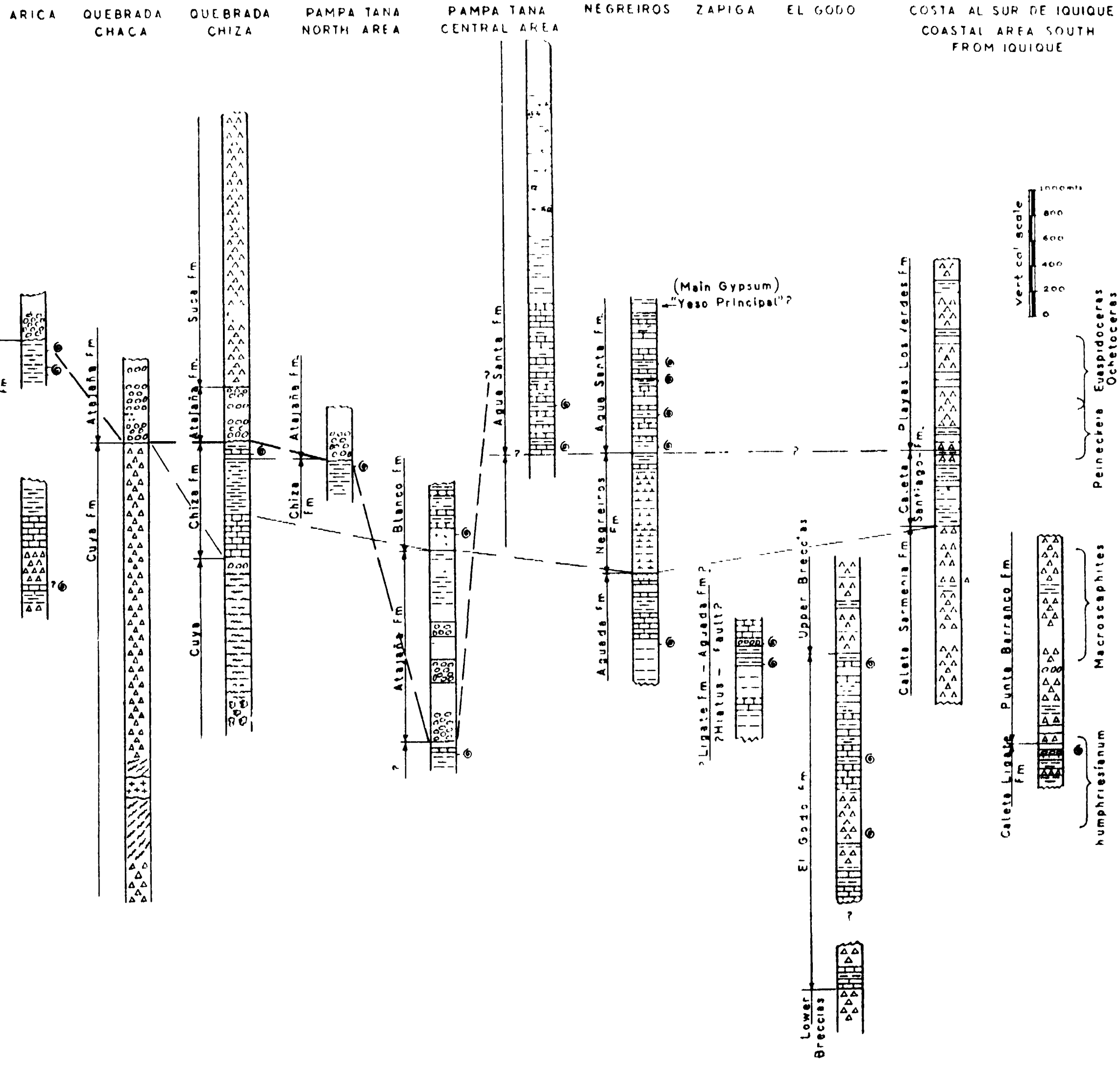

Fig. 2.—Stratigraphic correlation of the Jurassic and Cretaceous formations between Iquique and Arica in the Coastal Range.

Tentatively this formation could correlate with the Jaguay formation of Northern Perú (Rüegg, 9).

Suca formation

Type locality: Quebrada Suca, southeast tributary of Quebrada Chiza. The top is not exposed at the type locality; toward the east it is covered with pronounced angular unconformity by almost flat lying Tertiary rocks. The base at the type locality is the Atajaña formation. Thickness: a minimum of 2,170 meters of porphyritic lava flows 3 to 10 meters thick each, with some thin breccia and red sandstone beds which seem to wedge out toward the West.

The passage from the Atajaña to the Suca formations is gradual, starting with a few lava flows interbedded with the red breccias of the Atajaña formation.

No fossils have been found in this formation.

STRUCTURE

Only a few general statements about structure will be made here.

South of Iquique, by the El Godo railway station, a wide uplift of the Jurassic rocks has been observed, due probably to an Andean Diorite laccolith. The uplift presents a general east-west trend, with many faults of variable displacement, arranged in a conspicuous radial pattern. Diorite is exposed east and south of the uplift.

Farther south, Jurassic rocks are folded with a general NNW-SSE trend.

North of Iquique, these rocks are folded with a N-S trend, but between Zapiga and Agua Santa the fold axes are again NNW-SSE.

It is of interest to mention that the Cretaceous rocks seem to be folded with an E-W trend. There are several E-W faults, and it is possible that differential movements of the basement along these faults originated the gentle E-W folds so different from the main trend of the Jurassic rocks.

CONCLUSIONS

Nobody has ever doubted that there is some kind of unconformity in South America between the Jurassic and the Cretaceous. With a few exceptions, Arkell's idea that "no authentical Jurassic folding can be recorded" in South America, has been generally accepted.

A gentle epeirogenetic uplift, followed by a uniform submergence, might originate a very gentle angular unconformity. The transgressive beds will be deposited more or less on the same formation.

While discussing the stratigraphy, it was pointed out that the Cretaceous Atajaña formation overlaps several Jurassic formations, quite different in age and lithology. Besides, Jurassic and Cretaceous rocks seem to be folded along widely different trends.

The consequence is that between the Upper Oxfordian rocks and the Atajaña formation of a probable Basal Cretaceous age we have a real orogeny, which by definition must be Nevadian. The lack of enough deep gorges that cut the Cretaceous rocks prevent us from seeing the Jurassic folds directly below the Cretaceous.

It is possible that in Northern Chile, as well as in Canada and Alaska, the Nevadian Orogeny has been gentler than in Western United States.

After the Nevadian Orogeny the Andean Diorite was intruded and eroded, forming part of the Cretaceous basal conglomerates. The present writers propose the working hypothesis of a gradually younger age of the Andean Diorite towards the South of the Chilean Andes, because in Patagonia the Andean Diorite was intruded after the Sub-Hercynian Orogeny.

REFERENCES

(1) Arkell, W.J., 1956, Jurassic Geology of the World. Hafner Publ. C. Inc., New York.

(2) Biese, W., 1957, Der Jura von Cerritos Bayos — Calama, Repûblica de Chile, Provincia de Antofagasta. *Geol. Jarb.* **72**, Hannover.

(3) Brüggen, J., 1950, Fundamentos de la Geologia de Chile. *Inst. Geográfico Militar*, Santiago de Chile.

(4) Cecioni, G.O., 1957, Cretaceous Flysch and Molasse in Departamento Ultima Esperanza, Magallanes Province, Chile. *Bull. Am. Assoc. Petrol. Geologists*, **41**: 3, Tulsa.

(5) Galli, C., 1957, Las formaciones geológicas en el borde occidental de la Puna de Atacama, sector de Pica, Tarapacá. "*Minerales*," *Rev. Inst. Ing. de Minas*, año **12** (56), Santiago de Chile.

(6) Harrington, H., 1954, Stratigraphic sections. Unpublished report sent graciously by the author.

(7) Sanders, J.E., 1957, Discontinuities in the stratigraphic record. *Trans. The New York Acad. of Sciences*, Ser. II, **19** (4).

(8) Stehn, E., 1923, Beiträge zur Kenntniss des Bathonian and Callovian in Sudamerika. *Neuen Jahrb. für Min. etc.* Beil-Bd. **49**, Stuttgart.

(9) Rüegg, W., 1956, Geologie zwischen Cañete-San Juan, 13° 00′ - 15° 24′ Süd Peru. *Geol. Rundsch.* **45,** Stuttgart.

(10) ———, 1954, Geología y petróleo en la faja subandina peruana. **XX.** *Congr. Intern., Symposium sobre Yacimientos de Petróleo y Gas*, T. IV, Mexico.

SUB-HERCYNIAN OROGENY IN SOUTHERNMOST CHILE†

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INTRODUCTION

The occurrence of a Mesocretaceous orogeny in Patagonia has been discussed for some time (Steinmann, *8*; Feruglio, *4*; Groeber, *5*; Wenzel *9*; Muñoz Cristi, *7*). Exactly when it took place, however, was not established. Moreover, it was thought that all the conglomerates of the Cretaceous, and even a Tertiary conglomerate, were attributable to one and the same formation and age. They were assigned to the conglomeratic Valdés formation, whose type locality is Puerto Valdés on Isla Dawson in the Strait of Magellan. It has been found, however, that this conglomeratic formation actually belongs to the Senonian and unconformably overlies Turonian sediments, whereas the other conglomerates belong to different stratigraphic horizons, as was pointed out earlier by the writer (Cecioni, *1*). They are not discordant and often represent a regressive phase due to the continued uplifting of the Paleo-Andes, which favored the deposition of younger conglomerates with subrounded elements in the Cretaceous foredeep; it was gradually filled and pushed farther eastward.

The meager data supplied by Feruglio led the writer to believe, moreover, that the presumed unconformity of the Middle Cretaceous at the southern tip of the Argentine Cordillera (Lago Argentino) might actually constitute the northern continuation of the Ultima Esperanza fault, which has been investigated not so long ago near the Chilean-Argentine border due south of the southern finger of Lago Argentino.

Until recently, the evidence of a Mesocretaceous orogeny in Chile consisted almost solely of the unconformity exposed on Isla Dawson. No geological surveys had been made, nor had the fauna been identified where fossils were found.

From 1951 to 1956, the writer was engaged in the task of investigating the more important questions of the Cretaceous in the Magellan trough. After a great deal of field and laboratory work, the stratigraphy was clarified and the principal events that had taken place during the period were determined.

From time to time, progress reports on the investigation were published. Insofar as the sub-Hercynian orogeny in Departamento Ultima Esperanza is concerned, a paper prepared by the writer was pulished in the United States (Cecioni, *3*). It contains the most recent bibliography of the geology of Chilean Patagonia. More specific data on the stratigraphy of the area may be found in the pamphlet "Chile" of the Lexique International de Stratigraphie, now in the process of being printed in Paris.

In Departamento Ultima Esperanza, the Cretaceous presents the following stratigraphic succession, from bottom to top:

Seno Rodriguez formation

Originally considered a series of tuffs, breccias and flows of rhyolite, close investigation of texture and structure revealed it to be a thick glacial deposit. When the glacier receded eastward, the sea advanced from the west. The formation is probably Tithonian.

Southerland formation

Composed of a clayey, sandy marine series 362 meters thick that belongs to the Middle to Upper Tithonian. It is older in the Cordillera zone and younger in the extra-Andean zone toward the east.

Erezcano formation

Consists of a thick series of shales with graywackes, possibly deposited by turbidity currents. All of this formation closely resembles the Black European Flysch. Its age seems to lie between Upper Neocomian and Aptian. Its thickness is estimated at 2,400 meters.

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‡ Stratigrapher for ENAP.

Punta Barrosa formation

Comprises 600 meters of graywackes, possibly originated by turbidity currents—presumably at a time when a cordillera had already been uplifted toward the west. This may for the first time have isolated the Magellan foredeep from the Pacific. The formation is tentatively assigned to the Albian.

Cerro Toro formation

Made up of different members. Toward the bottom are pea-green shales whose facies indicates quiescent sedimentation in closed basins with little oxygen. These are overlain by marls that call to mind the sediments of the Briançonnais facies. The uppermost Cerro Toro formation presents the most typical and best developed characteristics of the orogenic Flysch; *Chondrites* and syn-sedimentary folds are well developed. It is of Cenomanian to Turonian age.

Lago Sofia formation

A thick conglomeratic series ranging in thickness from 940 to 770 meters. Both top and base are exposed. The shape and source of the boulders, the varves at the base and the striae intercalated between the varves and the boulders suggest that these sediments originated in mountain glaciation. They belong to the Upper Turonian.

La Ventana formation

Consists of 590 meters of shales with numerous intercalations of graywackes. This formation, too, presents the orogenic Flysch facies. It is of probable Coniacian age.

Las Chinas formation

Composed of 425 meters of marl presenting the same Briançonnais facies as the marl of the Cerro Toro formation. The marl here encloses the sedimentation of the orogenic Flysch. This formation may also belong to the Coniacian.

Jorge Montt formation

Consists of 1,200 meters of somewhat greenish or bluish shales resembling the peagreen shales of the Cerro Toro formation. This formation presents a Molasse facies and, because of the occurrence of *Baculites ovatus*, is assigned to the Santonian.

Picana formation

Comprises 400 meters of sandstones with Molasse facies. In the northern part of Departamento Ultima Esperanza, however, the sandstone grades locally into shales and graywackes with syn-sedimentary folds and *Chondrites*, indicating a new limited orogenic Flysch facies. Farther north, this facies gives way to sandstones that closely resemble the Tuscan Macigno. These sandstones were originated by turbidity currents and represent a localized type of synorogenic redeposited clastic sediment with the facies of the orogenic Flysch. This formation is in all likelihood of late Santonian or early Campanian age.

Solitario formation

At its type locality, this formation consists of 200 meters of shales with a few thin sandstones. The latter, which present a Molasse facies, occur with more frequency and in greater thickness toward the south. The formation is of probable Campanian age.

La Vega formation

About 800 meters thick, it is composed of near-shore sandstones with a Molasse facies.

Natales formation

Made up of littoral shales up to 1,000 meters thick, with intercalations of siltstones near the top.

Dorotea formation

Consists of littoral sandstones with cross-bedding and lenses that are carboniferous and contain plant remains. The maximum estimated thickness is 2,000 meters, in Cerro Cazador. All of these formations present the Molasse facies. They are of Campanian to Maestrichtian age.

Farther up there are Tertiary Molasse deposits which lack the Lower Tertiary sediments that occur abundantly farther south.

The conclusions which the writer (Cecioni, *3*, 563) had reached with regard to the sub-Hercynian orogeny were as follows: "The initial and final periods of the orogenic Flysch are represented by marly series of considerable thickness, the facies of which is similar to that of the Briançonnais or pre-Alpinian calcareous series. Above and below the orogenic Flysch with *Chondrites*, green shales indicate closed and calm basins developed mainly before the deformation. The orogenic movements reached their paroxysm shortly before the deposition of the Lago Sofia conglomerates. The Paleo-Andes had been uplifted, and mountain glaciations were probably developed upon them, which favored the transportation toward the east of gravel derived from rocks now found at least 150 km away.

"After the deposition of the Lago Sofia conglomerates, the orogenic movements gradually died out in Departamento Ultima Esperanza. The general paroxysm with emergence of the Paleo-Andes developed after the Turonian and before the Senonian, which demonstrates that the orogenic sub-Hercynian phase occurred also in Patagonia. The last epiorogenic Cretaceous uplift took place while the Molasse was being deposited and was responsible for the Macigno. Once these orogenic late and minor uplifts ended, the deposits balanced the subsidence, and the Molasse series locally filled the geosyncline. In the meantime, the Andean diorite gave origin to the laccoliths of Cerro Paine, Cerro Balmaceda, etc., and perhaps to the Andean batholith."

After presentation of the paper on Departamento Ultima Esperanza, the writer completed the geological and paleontological survey in the western part of Isla Dawson, where the Middle Cretaceous unconformity is exposed.

Having been graciously invited to participate in the symposium on "Mesozoic Orogeny in the Pacific Area" at the Ninth Pacific Science Congress in Bangkok, the writer considered it appropriate to report on the latest findings in this paper.

STRATIGRAPHY OF THE SW COAST OF ISLA DAWSON

The geological survey of this part of Isla Dawson was carried out by the writer, assisted by Sr. Renato Reyes B., from March to April, 1954. The time necessary for assembling all the data and compiling the final report was not available until 1957. Surveying the area entailed considerable difficulties; the coast is exposed to violent winds from the west and subject to sudden storms.

Because the sediments of the Cretaceous underwent frequent tectonic disturbances, the thickness of the formations cannot be determined with any degree of accuracy. The formations are exposed either at the top or at the base. Only the Barcarcel formation in Bahía Friend seems to attain a thickness of 870 meters. However, a sizeable portion of these sediments is covered by the alluvia of the Río Friend. From a study of aerial photographs, however, it would appear that the thickness established for this formation at this locality is correct.

The structural map was made on the scale 1:20,000, as were all geologic sections.

Lower Fuentes formation

This is the uppermost Cretaceous formation present in the area mapped. It consists of silty shales with large yellow concretions. The top of this formation is not exposed. Its base constitutes the top of the Rosa formation, as in the type locality of these two formations (southern coast of Seno Skyring). The transition from one to the other is gradual. Approximately 180 meters above the base of the formation, numerous *Baculites inornatus* were found. This species is encountered also at the type locality of the Fuentes formation a few meters above its base. The lower Fuentes formation corresponds lithologically to the younger Natales formation in Ultima Esperanza; in fact, in Departamento Ultima Esperanza *Baculites inornatus* are found in the upper portions of the La Vega formation. Thus, the time line passes from south to north from a shaly to a sandy formation, which indicates that the upper portion of the Rosa (or La Vega) formation is transgressive. In this part of Dawson, Fuentes is exposed to a thickness of 235 meters. It is of Campanian age.

Rosa formation

This formation is composed of hard, massive, green, glauconitic sandstones, sometimes microconglomeratic. At some points of the series, these sandstones exhibit good stratification, particularly toward the bottom. Frequently these sandstones contain calcareous nodules and concretions. In the center portion of this formation, shaly intercalations with thin carboniferous lenses are frequent. In the lower part, some sandstones display evidence of shale shatter, and a few pebbles are observed. Their deposition seems to have been caused either by submarine slumping or by rapid and frequent regressions and transgressions in the shelf itself. This was found to be true also of the sandstones of the La Vega formation, to which the Rosa formation corresponds (Cecioni, 1957, p. 561). The Rosa formation underlies the Fuentes formation and overlies the Barcarcel formation. Both contacts are gradational. The maximum thickness exposed is 1,200 meters. No fossils of significance were found.

Barcarcel formation

In its type locality, the top of this formation constitutes the bottom of the Rosa formation, which was determined by correlating lithology and fossils. The base, however, could not be found. On Isla Dawson, the Barcarcel formation mapped on the basis of lithological and paleontological correlations (Cecioni, *2*)—is exposed with top and base. It underlies the Rosa formation here, too, and overlies the Valdés formation. Both contacts are gradational. In its upper portions, the Barcarcel formation presents many sandstone layers similar to those of the Rosa formation, while at its base a few layers of conglomerates and intraformational breccias are observed. Lithologically, this formation is characterized by the prevalence of shales; but in various levels a notable alternation of graywackes and shales occurs. The upper portions of the graywacke beds exhibit contemporaneous deformations or syn-sedimentary folds. The sandstones are coarse-grained and occasionally contain pebbles and shale shatter. In all probability, these graywackes were originated by turbidity currents and the formation as a whole is generically related to the Flysch, as was already assumed by Kranck *(6)*. In the center portion, limestone beds occur more frequently, and in their vicinity calcareous concretions bent shortly before their complete lithification were formed. Both concretions and limestones are generally rich in fossils, especially *Hamites* and *Baculites.* The maximum thickness of this formation, mapped in Bahía Friend, is 870 meters. The more important fossils found are *Kossmaticeras theobaldianum* (Stol.), *Neograhamites taylori* (Spath), *Hoplites* and *Inoceramus australis* (Wood), indicating that the formation is definitely of Senonian and probably of Campanian age. The same fossils have been found in the Solitario formation, which the writer has correlated with the Barcarcel formation. While related, the two constitute separate formations known by different names; they are not identical lithologically. Both exhibit evidence of disturbances in sedimentation, but the Solitario formation cannot positively be classed with the Flysch facies.

Valdes formation

The type locality was established at the northern tip of Puerto Valdés, between Islotes Rocosos and Peurto San Antonio, where the top of the formation—which constitutes the base of the Barcarcel formation—is exposed. The base of the Valdés formation rests unconformably on an irregular erosion surface. In the lower part of this formation, it was possible to map 560 meters of sediments without a break, and in the upper part, 260 meters. However, it could not be determined whether these two blocks adjoin each other or whether an invisible series due to faulting lies between them, which would increase the thickness of the conglomerates. Lithologically, these are composed of rather angular elements, particularly in the lower center portion. Toward the bottom of the series, these elements become steadily coarser and finally as large as one meter in diameter. Toward the top, the elements are more rounded, more pebbly, and many have the shape of triaxial ellipsoids. The elements are generally composed of dark or red basic rocks, presumably lamprophyres; but especially toward the base, boulders and blocks of Cretaceous shale are observed as well. The writer did not encounter any boulders of Andean diorite, which at the time of deposition of these conglomerates had not been intruded or already exposed by erosion. A number of sandbeds or arenaceous conglomerate beds were observed within the conglomerate series, particularly toward the top. The writer was able to determine that the basic rocks of which some of the elements of the Valdés conglomerate are composed are the same as the ones which make up the numerous dikes that cut the argillaceous sedimentary series underlying the unconformity. However, he was unable to trace the source of the elements composed of red basic rock or to ascertain whether they were of the same dark lamprophyric basic rock, altered and meteorized. This will have to be determined by future petrographic examination of the many samples collected. The animal fossils found directly above these conglomerates indicate that the Valdés formation is of uppermost Santonian or lowermost Campanian age. The conglomerates overlie with angular unconformity the shales of the Cerro Toro formation, which 350 meters below the surface of unconformity—visible 7,500 meters south of Punta Valdés in a small bay exposed to westerly winds—contains *Inoceramus steinmanni* of the Turonian. The unconformity is therefore due to an orogeny and a post-Turonian and pre-Senonian transgression—the sub-Hercynian orogeny by definition.

Lago Sofia formation

As in Departamento Ultima Esperanza, this formation consists of conglomerates whose elements are derived largely from the Seno Rodríguez formation and from the ancient granites of the Cordillera. But on Isla Dawson this formation includes a much higher percentage of elements originating in the lower Cretaceous formations (Cerro Toro, Punta Barrosa and Erezcano), composed primarily of phthanites from the Erezcano formation. The pebbles generally are somewhat more rounded than the ones which make up this formation at its type locality. Limited thicknesses of this formation crop out at Punta Zig Zag. Between Canal Cascada and Caleta Layaza, however, the writer was able to map 1,000 meters of this formation, which overlies the Cerro Toro formation. The top of this formation is not exposed. In its uppermost and sandiest parts, a few meters of varves were observed.

Cerro Toro formation

In this formation, over 1,000 meters of predominantly green shale beds were mapped. They were found of contain *Inoceramus steinmanni* of the Turonian in the upper parts and *Puzosia compressa* of the Cenomanian in the lower parts, where a series of peagreen shales with dark patches—characteristic of the lower portion of this formation at its type locality—was observed. The formation shows evidence of considerable disturbance. It underlies the Lago Sofia formation and overlies the Punta Barrosa formation.

Punta Barrosa formation

Between Canal Gabriel and Bahía Isla (or Canal Cascada), this formation was mapped to a depth of 640 meters. It is composed of graywackes alternating with shales, with graywackes predominating. The graywacke beds are generally well graded, microconglomeratic at the bottom and silty at the top. These sandstones, which resemble the Macigno, may well represent a type of syn-orogenic redeposited clastic sediment, but satisfactory evidence is lacking. As at its type locality (Punta Barrosa, Seno Ultima Esperanza), this formation is overlain by the Cerro Toro formation and underlain by the Erezcano formation. No fossils were found. The formation is tentatively assigned to the Albian.

Erezcano formation

This formation consists of shales that underwent some dynamic metamorphism, with occasional intercalations of light-colored silts with small syn-sedimentary folds, whose facies may be referred to the Black Flysch. The formation was mapped to a depth of 770 meters without reaching the base. Some *Inoceramus* not more closely identifiable were found in places. The age of the formation appears to be between Upper Neocomian and Aptian.

TECTONICS

As may be seen from the attached geologic section, numerous faults disturb the stratigraphic series described above. In many cases, the shift of these faults cannot be determined since the exact thickness of the various formations is unknown.

The general dip of the beds is toward SSW; but still older formations trending in the same direction are present. The faults are therefore thrusts. Such tectonic dislocations are quite frequent in the Cretaceous sediments of Patagonia and Tierra del Fuego, from the town of Puerto Natales as far as Isla Navarino.

The Ultima Esperanza fault should have a shift in the neighbourhood of 2,000 meters. The brecciated belt extends for about 100 meters; in it and in its immediate vicinity, numerous lamprophyric dikes occur.

SUB-HERCYNIAN OROGENY IN SOUTHERNMOST CHILE SUMMARY AND DISCUSSION

It has been found (Cecioni, *3*) that in Departamento Ultima Esperanza the intensity of the sub-Hercynian orogeny reached its peak shortly before the deposition of the conglomerates of the Lago Sofia formation, probably in the Middle Turonian. A short distance north of the town of Puerto Natales in that Department, the sediments of the Cretaceous were not disturbed excessively by this orogenesis, which appears to have affected primarily the older formations (undated schists, granites, Paleozoic, Seno Rodríguez formation), which were uplifted into a cordillera on which mountain glaciation seems to have occurred that favored deposition of the conglomerates of the Lago Sofia formation. After this deposition, orogenic activity gradually died out, and the Molasse series locally filled the foredeep. In the meantime, the Andean diorite gave rise to the laccoliths and perhaps to the batholiths.

In the south of Departamento Ultima Esperanza, in the Strait of Magellan and on Tierra del Fuego, the sub-Hercynian orogeny had a far more profound effect on the Cretaceous sediments. They were uplifted, eroded and then re-covered with a transgressive Senonian conglomerate. The fact that the Lago Sofia conglomerates are folded and faulted below the surface of an angular unconformity would seem to support the theory that the sub-Hercynian orogeny occurred in two successive, separate phases, with the first corresponding to deposition of the Flysch with *Chondrites* beneath the Lago Sofia conglomerates, and the second to deposition of

Fig. 1— Map of part of Patagonia and Tierra del Fuego showing location of detailed mapping (Fig. 2) and the Ultima Esperanza fault.

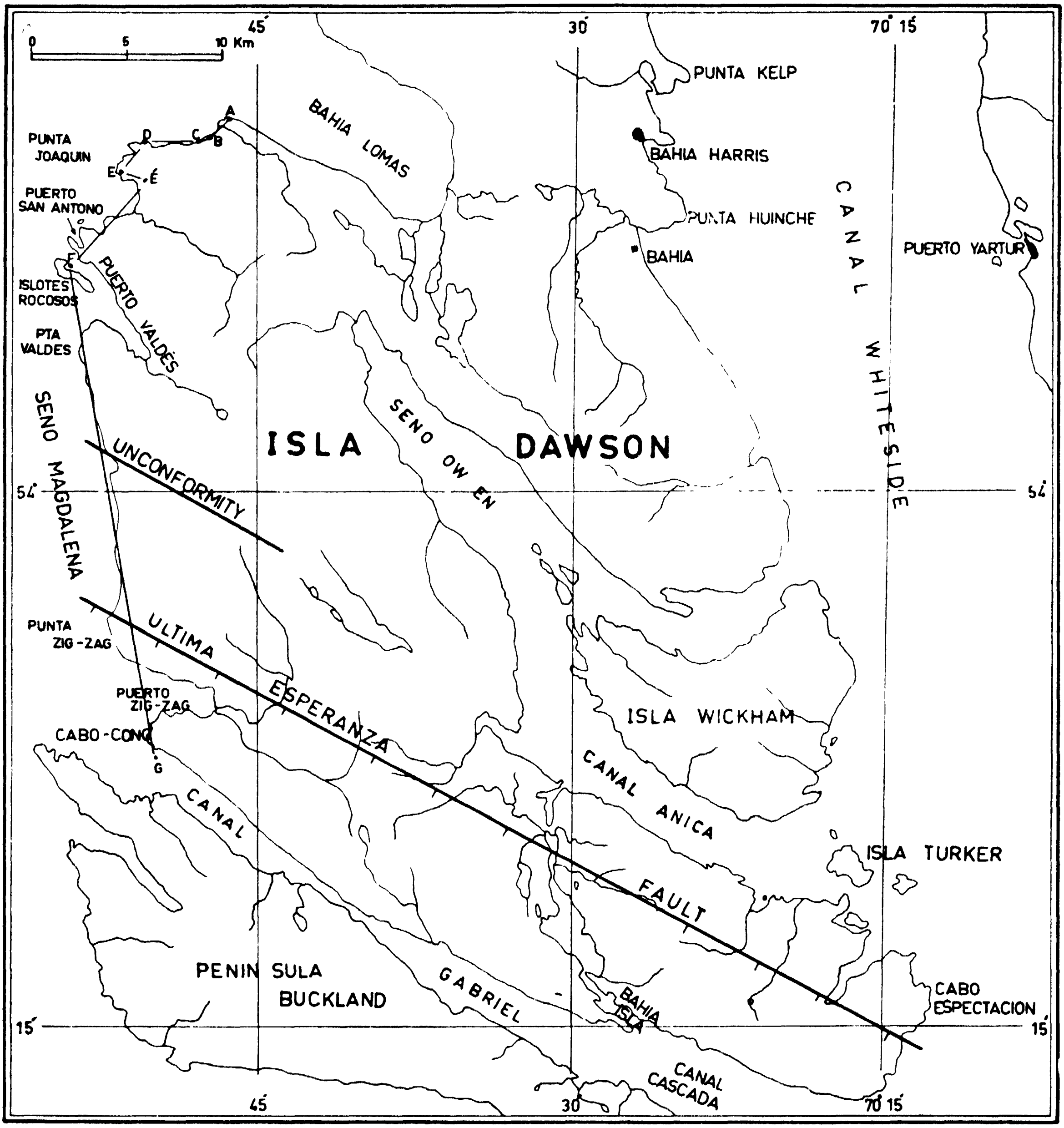

Fig. 2— Map of part of Isla Dawson showing location of the cross section A-B-C-D-E-É-F-G (Fig. 3), the unconformity and the Ultima Esperanza fault.

the Flysch with *Chondrites* on top of these conglomerates.

This theory may be refuted simply by pointing to the fact that the intercalated shale and graywacke members rather than the conglomerates in the deposits of the Lago Sofia formation present the Flysch facies with *Chondrites*. Hence, this formation is made up of synorogenic sediments.

We are now in a position to state the composition of the elements of the Lago Sofia conglomerates as follows: North of Laguna Azul (Cecioni, *3*, Fig. 2) in Departamento Ultima Esperanza, elements composed of Paleozoic rocks are fairly abundant in the conglomerates.

In the center portion of this formation—that is, from Laguna Azul to Peninsula de Brunswick, elements made up of rocks from the Seno Rodríguez formation are frequently encountered. Farther south, elements of the Lower Cretaceous, Neocomian to Aptian are present in remarkable number.

These data do not point to two distinct, separate, successive phases in the sub-Hercynian orogeny; they indicate merely an uneven distribution and intensity of one and the same force which during the sub-Hercynian orogeny deformed younger formations from north to south and moved the western margin of the foredeep still farther. Thus, while in the north the La Ventana and Las Chinas formations with the facies of Flysch with *Chondrites* were being deposited, the peak of intensity of the sub-Hercynian orogeny shifted to the south, with the Paleo-Andes already emerged in part. Then, while the Jorge Montt formation with a Molasse facies was being deposited in the north, a geocratic phase developed in the south, with intense erosion of the sub-Hercynian folds.

Later, a minor orogenic uplift occurred farther north and gave rise to deposition of the El Chinque formation with the facies of Flysch with *Chondrites* and the facies of the Macigno, a type of syn-orogenic redeposited clastic sediment.

In the south, this brief resumption of orogenic activity seems to have occurred after the deposition of the conglomerates of the Valdés formation, that is, while the Barcarcel formation was being deposited, and possibly with some time lag with respect to the disturbances in the north.

On the basis of the foregoing data, the following conclusions representing the final findings of this investigation may be drawn:

(1) The sub-Hercynian orogeny in southernmost Chile deformed still younger formations from north to south and pushed the western margin of the foredeep still farther east.

(2) The sub-Hercynian orogeny—as well as the last brief Senonian upheaval—in southernmost Chile did not occur everywhere all at once and with equal force. Rather, the peak of intensity of the orogenic movements slowly traveled from north to south. Consequently, the Paleo-Andes on Tierra del Fuego are younger than the Paleo-Andes of Patagonia.

REFERENCES

(1) Cecioni, G., 1956, Distribuzione verticale di alcune *Kossmaticeratidae* della Patagonia Cilena. *Boll. Soc. Geol. Ital.*, Roma, **74**.

(2) ——, 1956, Significato della ornamentazione di alcune *Kossmaticeratidae* della Patagonia. *Rivista Ital. di Paleont. e Stratigr.*, Milano, **62**: (1).

(3) ——, 1957, Cretaceous Flysch and Molasse in Departamento Ultima Esperanza, Magallanes Province, Chile, *Bull. Am. Ass. Petr. Geol.*, Tulsa, **41**: (3).

(4) Feruglio, E., 1949-50, Descripción geológica de la Patagonia. *Y.P.F.*, Buenos Aires.

(5) Groeber, P., with A. Stipanicic and A. Mingramm, 1952, Geografía de la República Argentina-Mesozoico, t. II, p. I. *Sociedad Argentina de Estudios Geográficos GAEA*, Buenos Aires.

(6) Kranck, E. H., 1932, Geological Investigations in the Cordillera of Tierra del Fuego. Acta Geogr. *(Bull. Geogr. Soc. of Finland)*, Helsinki, **4**: (2).

(7) Muñoz Cristi, J., 1956, "Chile", from Jenks, W.F.: Handbook of South American Geology. *Geol. Soc. Am.* Mem. **65**, Baltimore.

(8) Steinmann, G., 1930, Geologia del Perú. Heidelberg.

(9) Wenzel, O., 1951, Conocimiento actual sobre la geologia de la Provincia de Magallanesy sus posibilidades petrolíferas. *Anales Inst. de Ingenieros de Chile*, Santiago de Chile, **44**.

Symposium: *The Relation of Volcanoes to Geological Structure.*

Convener: Th. H. F. Klompé (Indonesia; presently Thailand)

MAGMATIC DIAPIRISM AND TECTONIC DEFORMATION

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Concepts on the relation between volcanoes and geological structure depend on the geological theories preferred.

Current theories on the geological evolution can be divided into lateral compression hypothesis and plutonic hypothesis (van Bemmelen, 1954, p. IX and p. 16).

The first group considers the igneous phenomena as the effect of tectonic processes. They speak of tectonic control of igneous activity (Kennedy *et al.* 1954). The second group supposes the reverse relation, viz. an igneous control of tectonic activity (van Bemmelen 1956). These two groups of geological theories might also be characterized as those with a restricted physical and those with a more general physico-chemical line of reasoning (van Bemmelen, 1957).

The study of the physical aspects of the earth was some years ago dedicated to the seismological section of the International Union of Geodesy and Geophysics (I.U.G.G.), which is now called the section of seismology and of the physics of the earth. The study of the physico-chemical aspects of the earth are less satisfactorily fostered by this organisation. This situation has led to a proposal of Rittmann *et al.* (1956) to enlarge the scope of the volcanological section of the I.U.G.G. with the study of the composition of the earth. In their proposal they remark that "on the one hand a number of geological hypotheses does not take into account the results of geophysics and geochemistry. On the other hand, many geophysical calculations are based on premisses which are incompatible with well founded geological and geochemical facts. The laws of physico-chemistry are often ignored by geologist as well as geophysicists".

It is a serious shortcoming of many physical theories (such as the contraction theory, or the theory of thermal convection currents in the substratum) that they take into account only reversible changes of volume and density, which are due to changes of temperature and pressure. Whereas the evolution of our planet is — as a whole — an irreversible process, conform to the main laws of thermodynamics. In other words, the various forms of endogenic energy can be transformed one into the other, but the ensuing chain-reactions are accompanied by an overall loss of free energy and a gain in entropy.

In the past twenty-five years the author has tried to pursue this physico-chemical line of reasoning for the explanation of the relations between magmatic and tectonic events. The basic assumption is that all geological processes are the result of a general strife for equilibrum, and that they are accompanied by readjustments of the distribution of matter with its associated forms of energy (nuclear, chemical, thermal, gravitational). These readjustments can be effected in two ways by means of disperse migrations of atoms and ions, or by means of displacements of matter in bulk.

The *disperse migrations of matter* are the result of gradients of concentration, pressure, temperature and other differences of physico-chemical environment. Short-range as well as long-range migrations may occur. These diffusions influence the chemical composition, causing alterations and transformations of one rock type in the other.

In their turn, such chemical alterations and the heat balance of the associated changes of the chemical bonds influence the physical properties of the matter concerned (density, volume, viscosity, rigidity, elasticity, yield stress).

More or less extensive parts of the earth's silicate mantle (= substratum + crust) become too heavy or too light for the place they occupy in the silicate mantle, and potential energy accumulates in them. This potential energy is ultimately or intermittently released when the yield stresses are surmounted.

The resulting *displacements of matter in bulk* represent the second type of readjustments in the distribution of matter, mentioned above. They tend to restore the gravitatismal equilibrium which has been temporarily disturbed by physico-chemical processes.

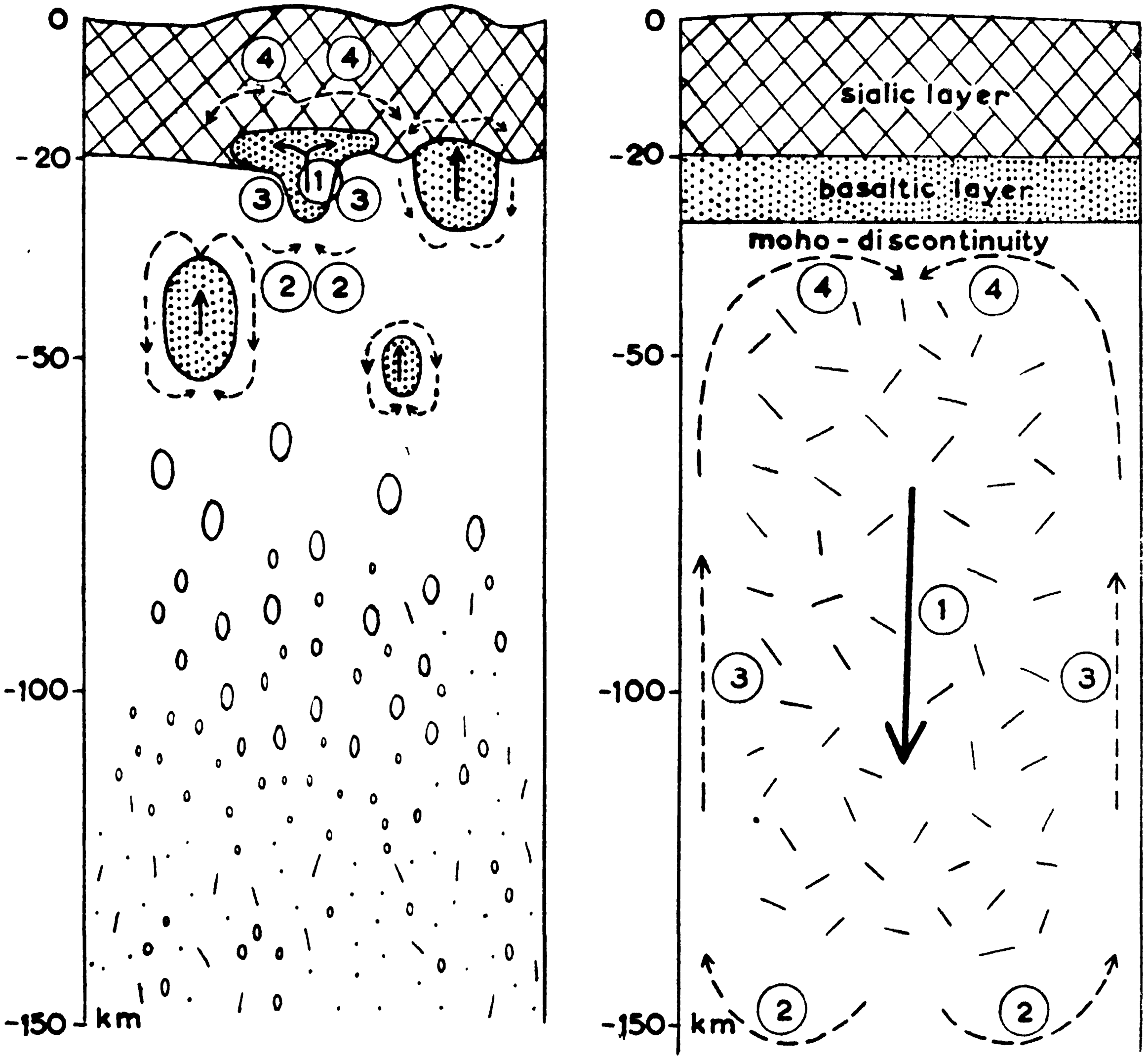
Thus *geochemically generated circuits of matter* will occur in the silicate mantle.

All volcanic and tectonic phenomena observable at the surface are the effect of greater or smaller mass-displacements in depth. Both groups of phenomena are generated by readjustments in the distribution of matter and its associated energy. Thus the general answer to the problem of the relations between volcanoes and geological structure, the theme of this symposium, is that this relation is more fraternal than parental.

Mechanically, two types of mass-circuits in depth can be distinguished, which we call the "buoyant and the "foundering" type.

In the "*buoyant*" *type of mass-circuits* the primary forces are directed upward, trying to push up (according to the law of Archimedes) a body that has become too light for the position

Fig. 1.— *Geochemically generated mass-circuits in the substratum.*



Stage A: Secretion and rise of basaltic fraction from a peridotitic substratum by means of "buoyant" mass-circuits.

Stage B: Subsidence of the peridotitic residue (after the secretion of the basaltic fraction) by means of a "foundering" type of mass-circuit.

EPEIROGENIC MASS – CIRCUITS

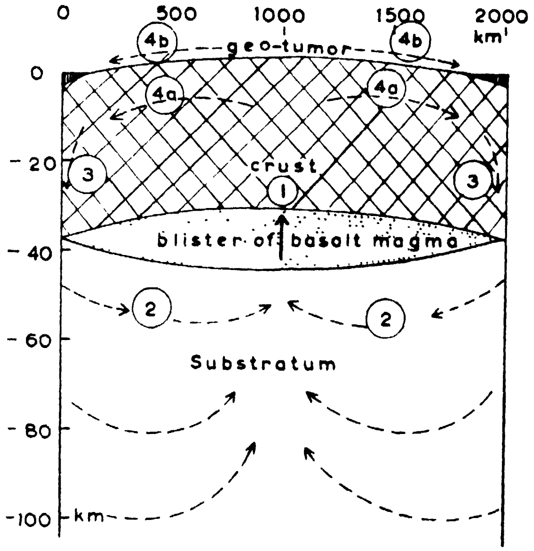


Fig. 2A: Mega-circuit of the "buoyant" type
Formation of a geotumor by a blister of basaltic magma at the base of the crust.

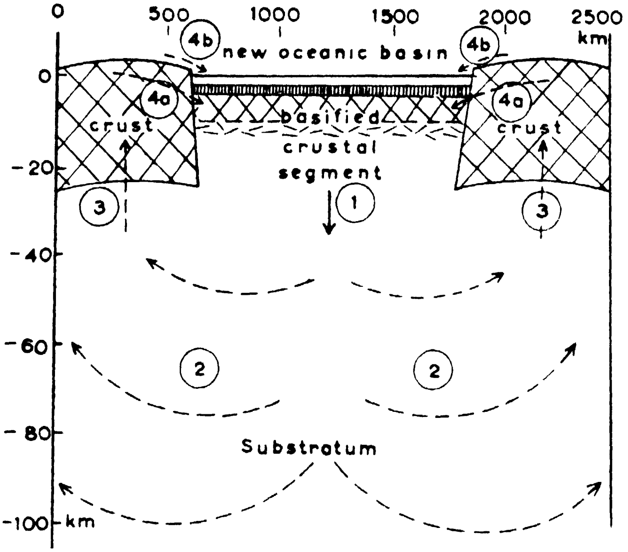


Fig. 2B: Mega-circuit of the "foundering" type
Formation of a new oceanic basin due to the basification of a crustal segment and increase of density of the subjacent part of the substratum (secretion of the basaltic fraction).

OROGENIC MASS – CIRCUITS

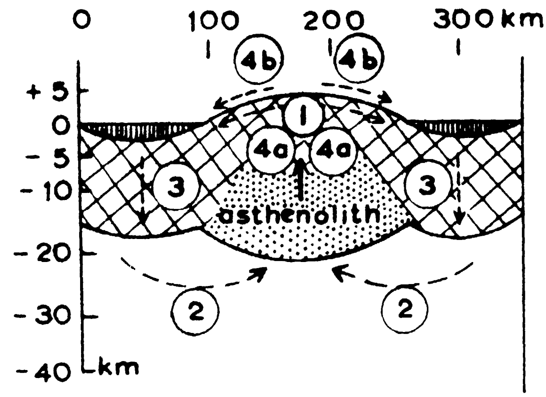


Fig. 3A: Meso-circuit of the "buoyant" type
Uplift of a blister of granitic magma and migma causes a geanticlinal arch of the overlying part of the sialic crust.

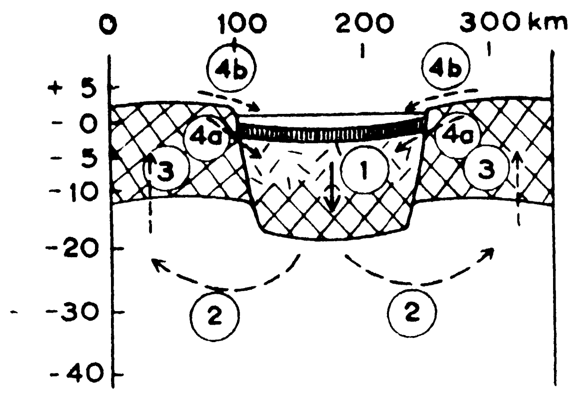


Fig. 3B: Meso-circuit of the "foundering" type
The load of a high-level plate of high-density rocks causes the formation of a cauldron or basin.

it occupies in the silicate mantle.

In the *"foundering" type of mass-circuits* the primary forces are directed downward, because a body that has become too heavy for the place it occupies, pushes downward like the heavy plunger in a hydraulic press-system.

The ensuing mass-circuits are coherent energy-systems in which the gains in potential energy of rising bodies are balanced by losses in potential energy of subsiding bodies.

The loss of potential energy of the pressing parts of the system must be somewhat greater than the gains in the other parts, otherwise the engine would not work. Part of the potential energy will be transformed into heat of internal friction or into seismic shocks, These forms of energy are dissipated and lost for the moving of the mass-circuit concerned.

The primary forces are marked (1) in the figs. 1, 2 and 3. They cause at the base either a centripetal accrue of matter ((2) in figs. 1A, 2A and 3A), or a centrifugal squeezing away ((2) in figs. 1B, 2B and 3B). The surrounding belt subsides in the "buoyant" circuit ((3) in figs. 1A', 2A and 3A) and it rises in the "foundering" type (branch (3) in figs. 1B, 2B, and 3B). The branches (1), (2) and (3) occur simultaneously due to the requirement of volumetric compensation and the negligible compressability of the matter in the silicate mantle under high confining pressure.

The fourth branch, however, which occurs at the boundary with the hydrosphere and atmosphere, is not subjected to the requirement of volumetric compensation. Therefore, it may lag behind in time. This fourth branch closes the circuit, either by means of gravity tectonics (4a) or by means of erosion and sedimentation (4b).

In both types of circuits matter is pushed upward, either directly by "buoyant" forces, or indirectly by an energy-system resembling a "foundering" press.

Now if magmatic material is involved which has a higher mobility (lower viscosity) than the surrounding rocks, it has the tendency to ascent by means of diapirism, forming plutonic and subvolcanic intrusions or volcanic extrusions.

The relation between the location of volcanoes and tectonic structure is such that the "buoyant" circuits show volcanoes on top of the crustal segment that is domed or arched upward, whereas in the "foundering" circuits the volcanic phenomena occur in the belt surrounding the subsiding segments. For instance, the mountain ranges and island-arcs of SE Asia are pushed up by low-density roots and they are crowned by volcanoes whereever magma finds its way to the crest by means of diapiric ascent.

On the other hand, the subsiding block of the Central Banda Basin is accompanied by a revival of the volcanism at the inner side of the Banda Arcs. This diapiric ascent of magma probably is an indirect result of the subsidence of the Central Banda block (see section at the base of fig. 49 in Mountain Building, p. 161, van Bemmelen 1954).

On a smaller scale, the cone sheets of the tertiary centres of igneous activity in Scotland are the result of direct upward pressure of the magma ("buoyant" circuit); whereas the ringdikes are the secondary effect of the sinking down of the central high-density block (van Bemmelen, 1937).

A good example of the fraternal relations between volcanic activity and tectonic structure is the volcano-tectonic history of the Dyngjufjöll Mts with the Askja Caldera in Central Iceland (van Bemmelen & Rutten, 1955). This volcano complex was domed up in late glacial time. The volume of the dome above the surrounding planes was of the order of 100 km^3. During the final stages of the upheaval, basaltic lavas poured out profusely from several fissures in the top area of the Dyngjufjöll dome. The volume of these early syntectonic lava flows is estimated at 10 - 20 km^3. The doming of this complex and the diapiric ascent of magma are apparently two different mechanical solutions of ascent in an "buoyant" mass-circuit, c.q. the hydrostatic overpressure of an uptrusion of basaltic magma.

This uptrusion caused a laccolithic blister of basaltmagma with a domed roof and extrusions of basalt through tension fissures in the roof.

In the next sub-stage of the Dyngjufjöll history a new hydrodynamic situation had developed, viz. a blister of low density magma covered by a roof loaded with consolidated basalts of higher mean density than the corresponding liquid magma of the chamber.

Thus this doming and the outflow of early syntectonic lavas had produced an inversion of the stable density layering. Consequently the cope-stone of the roof quietly subsided more or less vertically into the underlying magma chamber, causing the peripheral outflow of magma along fractures. By this hydraulic mechanism the Askja cauldron on the top of the dome came into existence.

The volume of the late syntectonic peripheral lava outflows, which issued at the time of the collapse of the top part of the Dyngjufjöll dome, was probably somewhat greater (>10 km^3) than the volume of the Askja caldera (with the annex graben of the Ösbjuop 8, 3 km^3). Therefore, these late syntectonic outflows are probably the combined effect of the hydrostatic overpressure in the rising basalt magma (just as the early syntectonic basalt flows) on which a smaller circuit of the "foundering" type was superimposed due to the collapse of the top part of the roof.

After these volcano-tectonic processes had come to a halt, the basalt outflows in the Dyngjufjöll area continued. These post-tectonic lava outflows reached the surface unhampered by way of tension rifts. They were no longer accompanied by tectonic effects.

This picture of the volcano-tectonic evolution of the Dyngjufjöll volcanic complex in Central Iceland is typical for the fraternal relations between magmatic and tectonic phenomena on a larger scale.

REFERENCES

Bemmelen, R.W. van, 1937, The cause and mechanism of igneous intrusion (with some Scottish examples) *Trans. Geol. Soc. Glasgow*, **19** *(3)* : 453-492.

——, 1953, Relations entre le volcanisme et la tectogenèse en Indonésie. *Bull. Volcanologique*, Série **2**, Tome **18** : 57-62.

——, 1954, Mountain Building (a study primarily based on Indonesia, region of the world's most active deformations) Ed. Mart. Nijhoff, the Hague.

——, 1955a, Tectogenèse par gravité. *Bull. Soc. Belge de Géologie*, **64** *(1)* : 95-124.

——, 1955b, L'évolution orogénétique de la Sonde (Indonésie). *Bull. soc. Belge de Géologie*, **64** *(1)* : 124-152.

—— and Rutten, M.G., 1955c, Table Mountains in Northern Iceland, Ed. Brill, Leyden.

——, 1956, The geochemical control of tectonic activity, *Geologie en Mijnbouw*, Nw. Ser., **18** *(4)* : 131-144.

Kennedy, W.Q. *et al.*, 1954, The tectonic control of igneous activity. Inter University Geol. Congr. 1953. Dept. of Geol. University of Leeds.

Rittmann, A. *et al.*, 1956, Newsletter of the Intern. Union of Geodesy and Geophysics, **5** *(14)* : 201.

ON THE ORIGIN OF MOON "CRATERS" AND THE VOLCANISM OF THE OLD SHIELDS

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INTRODUCTION

A discussion of the origin of lunar topography might lead to a better understanding of the inner tectonics of our own globe, particularly if we accept the hypothesis that our satellite was born of a planetary "mitosis" determined by an effect of resonance on the powerful terrestrial tides caused by the sun before the consolidation of the earth's crust.

If the moon is really the result of a colossal rupture of the earth, it is composed—as the most recent astronomical findings tend to prove—essentially of basaltic matter. Because of its small mass (1/81 of the earth), this globe, probably congealed to the very center, does not possess the slightest trace of atmosphere: all the gases and liquids which the lunar "bubble" carried off with it at the time of its birth have long since escaped into interplanetary space, and the same is true of the gases emitted later by volcanic eruptions.

Thus there are, on the surface of our satellite, none of the powerful agents of erosion which have continuously marked the surface of the earth: water, ice, wind . . . Only the drastic changes of temperature between night and day, fluctuating at one and the same point between 100° above and 150° below zero (centigrade), seem to be capable of altering the structure of the rock. But because of the poor conductivity of the rock and of vacuum, the pulverization resulting from this change of temperature is limited to a thin layer at the surface.

Everyone knows that the face of the moon is marked by numerous depressions known as "cirques" or "craters," which seem circular at first sight. Careful examination permits us to distinguish two main categories: on the one hand the vast cirques with horizontal bottom, ranging in diameter from a few dozen km. to 220 km. (Clavius for example); on the other hand, the smaller bowl-shaped craters, ranging from 100 m. to 3 or 4 km. in diameter.

The visible surface of the moon reveals more than 30,000 of these formations and men have long speculated as to their origin.

There are two classical explanations, neither of which seems to take account of the distinction between the immense flat-bottomed depressions and the small hollows with curved bottoms.

THE METEORITIC THEORY

Most astronomers incline toward the meteoritic origin of the craters, which, according to them, results from the extremely violent impact of aeroliths, there being no atmosphere to pulverize them or even to brake their speed. The kinetic energy of these masses moving at a velocity of circa 15.20 km/sec is transformed into extreme heat when they are brought to a sudden stop by the lunar rock. Supposedly the meteorite instantly bursts into a gigantic explosion.

In refutation of this theory it has been argued that no elliptical craters are observed on the moon though the meteorite strikes at an angle inferior to 45° the depression should be increasingly elliptical. The advocates of the meteoritic theory reply that the explosion itself, regardless of the agnle of impact, produces a circular crater, as has been proved too often by artillery bombardments.

THE VOLCANIC THEORY

The other theory is that of volcanic origin; its most qualified proponent is Prof. B.G. Escher.

His two main reasons for prefering a magmatic origin of the lunar cirques is that the meteoritic theory does not explain why:

1) though the size of the meteorites that strike the moon—and consequently the diameter of the craters produced by their impact—depends only on the laws of chance, a crater has *never* been observed to be overlapped by another, larger one: always when one depression overlaps on another, the newer one is the smaller (in exceptional cases two cirques of the same diameter overlap).

2) Certain cirques (Copernicus, Eratosthenes, Archimedes, Arzachel, Tycho) are surrounded by a number of concentric borders, often separated by long, narrow terraces.

A volcanic origin of the craters would account for these characteristics; the succession in time of craters gradually decreasing in size would logically correspond to a diminishing volcanic activity; and the collapse which accompany the formation of a caldera would account reasonably well for the narrow terraces on the edges.

An additional argument in favor of the volcanic theory is that it accounts for certain rectlinear alignments of craters (Hygines, Rheita, the region between Stadius and Copernicus) that may be observed on the moon. These are regarded as equivalent to the volcanic alignments on earth (Laki, Eldgja).

The probability of meteoritic impacts almost continuous and disposed in a straight line is virtually zero.

MAIN WEAKNESSES OF THE CLASSICAL HYPOTHESES

Yet it seems to me that two important factors are constantly neglected in this controversy. The first is the existence of two classes of depressions, differing both in morphology and size: the relatively small *cupules* and the relatively large *cirques.* I believe that the genesis of the craters of the first category may be explained equally well by either theory, that some of the thousands of cupules with a maximum diameter of a few kilometers may be due to the impact of meteorites and others to volcanic eruptions.

But the point on which the two classical theories disagree is precisely not the origin of these small cupules, minor depressions that can be distinguished clearly in powerful enlargements, but the origin of the major depressions which have struck the imagination of observers ever since the invention of the astronomic telescope, and which alone have received names.

Before expounding the third hypothesis—the only one in my opinion which accounts for the formation of the principal cirques of the moon, I should like to call attention to a fact that cannot be reconciled with a meteoritic or even a volcanic origin: the horizontal bottoms of all the depressions. It is difficult to conceive that a crater due to an impact should be bordered by walls *several thousand meters* in height. But above all, one wonders, why, on a satellite without winds and particularly without rains or water courses, should a crater of meteoritic origin or volcano-tectonic collapse origin, not have preserved a trace of its original form, which could only have been that of a funnel in the 1st case and a sink-hole in the second? And none of these vast lunar depressions presents so much as a suggestion of such a shape. How do the "meteorists" or the "volcanists" explain the uniform horizontality of the bottoms?

But there is a still more serious phenomenon, which neither the "meteorists" nor the "volcanists" engaged in the controversy seem to have taken into consideration: the large depressions in the moon *are not circular.* Any good photograph shows this clearly: the large lunar "craters" are *polygonal,* often even *hexagonal,* (figures 1 and 2).

As early as 1908 the French astronomer P. Puiseux wrote: "... The solid crust of the moon was constituted in all its parts by an assemblage of polygonal boxes, juxtaposed and imperfectly welded together."

WASIUTYNSKI'S HYPOTHESIS: CONVECTIVE ORIGIN

In 1946 a Polish astronomer, J. Wasiutynski, published an important paper on the structure of the heavenly bodies, in which he put forward a highly interesting thesis: like the granules of the solar chromosphere or, on an infinitely smaller scale like the polygonal soils of the Arctic, the polygonal "cirques" of the moon are the consequence of the convection cells that stirred the basaltic magma until it definitively congealed.

Convection currents are recognized to be a phenomenon widespread in nature: in any fluid subjected to a thermogravitic imbalance, provided that certain conditions of homogeneity are fulfilled, relatively warm and light currents rise to the higher discontinuity; here they spread out and join with the concentric descending currents of relatively cool, heavy matter. Isolated, such a cell would be cylindrical; but juxtaposed cells, pressed together, are necessarily polygonal, hexagonal when a balance is achieved between them.

As the moon cooled, the original heat of its magma was radiated into interplanetary space. The cooled portions on the surface, made still more dense by the loss of volatile elements, sank, while the inner parts, hotter and less heavy tended to rise.

It is probable that the currents thus engendered were vast at first. Then, as the magma was differentiated in the course of its cooling, it resolved into superimposed layers, not homogeneous and not necessarily concentric, but more or less interlocked in a highly complex way: in the moon of that

Fig. 1.

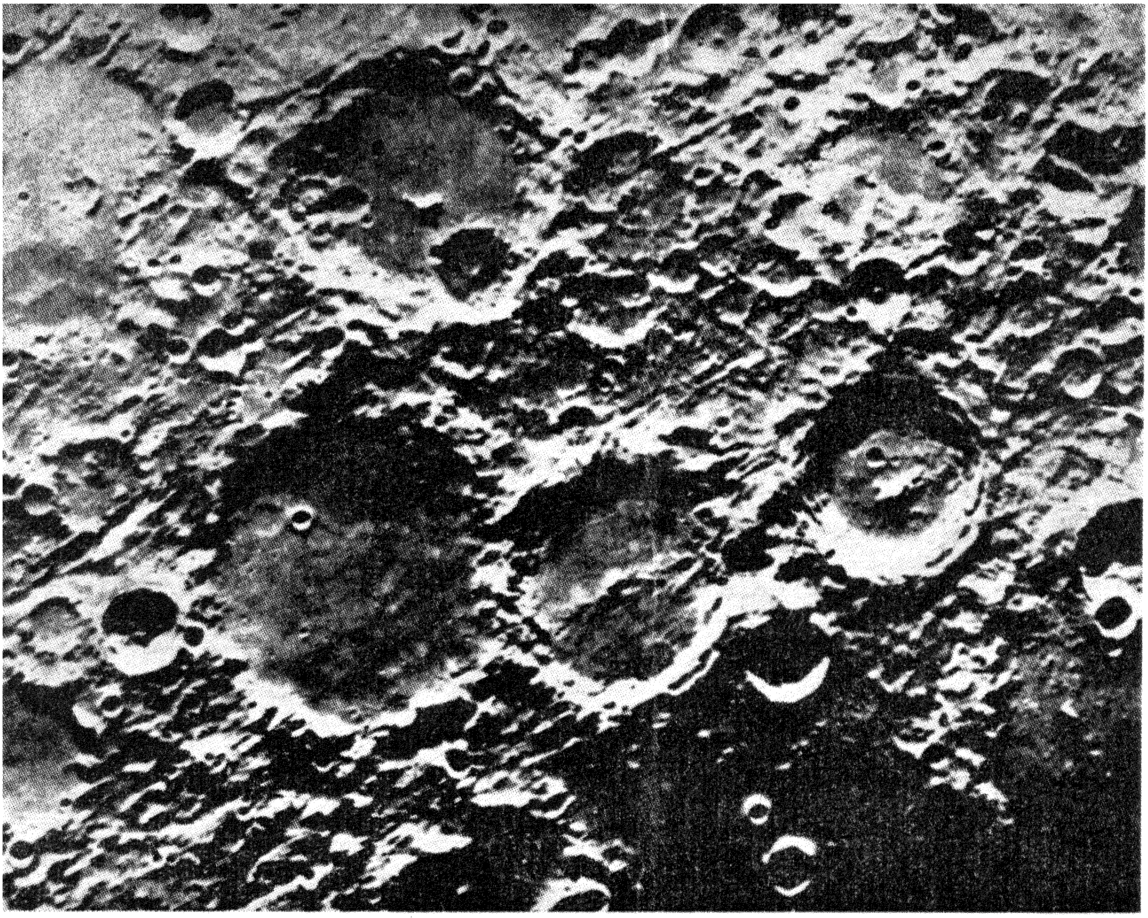

Fig. 2.

time as in the present earth, numerous smaller "pockets" were probably superimposed on certain major discordances. The differences in latitude, gravity, certrifugal force, the chemical variations of the magma, the increasing divergences due to the differentiation of the lunar matter, and doubtless still other factors produced a certain irregularity of physical composition. The convection then became localized in the various stages, strata, and lentils, its characteristics varying with their thickness and viscosity, (which increased as the mass cooled). As the magma became differentiated into superimposed layers, the outer cells of the satellite decreased in size and the prisms thus determined approached the perfect form: the hexagon.

Finally, as the matter became too viscous, the outer cells of the moon were gradually immobilized, the smallest last. This would explain why small hexagons are sometimes overlapping bigger ones, while the converse never occurs.

Thus the lunar craters would only be the outside of the last convection cells to have stirred the lunar magma. Their great mountainous edges would be formed by the piling up of congealed rock which the currents radiating horizontally pushed toward the periphery of the upper surface of the prisms (in accordance with the very same process by which the "polygonal soils" were formed, fig. 3). These rocks, basaltic but no doubt predominantly granitic (the small proportion of granite in the "pre-Pacific crust"), less dense than the molten magma, rose to the surface, and accumulated round the cells, forming increasingly large rectilinear cordilleras.

If we study good photographs of the moon,

Fig. 3—Arctic Polygonal Soils.

we observe that outside of the arenas clearly delimited by these mountainous borders of greater or lesser elevation, there are many others, generally smaller in size, which seem to be merely sketched or half effaced. These should probably be regarded as late cells, operating in a viscous medium already divested of its scoriaceous granitic scum, and which have therefore remained without marginal "foam."

THE "CENTRAL PEAKS"

The theory of the meteoritic origin of the lunar "craters" can scarcely explain the peaks that can be observed near the centers of numerous depressions. The volcanic theory is also baffled: the terrestrial calderas nowhere provide the equivalent of this phenomenon, for the volcanoes within them are generally small in height, rarely single, almost always aligned on fracture zones.

But if we accept Wasiutynski's hypothesis, the existence and central situation of the peaks become comprehensible. It is indeed in the central axis of the cell that are localized the ascending hot currents in which crystallization was last to take place; thus it was here that the last pneumatolytes were concentrated. When this concentration had reached a sufficient degree to overcome the resistance of the surrounding rock, the gases erupted: a real volcanism, of a highly explosive character, was manifested in the center of numerous congealed convection cells, giving rise to those high, conical steep slopes mountains which mark the center of many polygonal cirques.

POSSIBLE TERRESTRIAL CONVECTION CELLS, RIFTS AND KRATOGENIC VOLCANISM

The author is not unaware of the objections that this theory of the moon's structure cannot fail to arouse. But thus far it is the only theory which provides a rational explanation of the polygonal form of the "craters" or, for that matter, which even dares to mention it. Even if we set aside the other inadequacies of the two main hypotheses critisized above, this major lacuna should suffice to discredit them.

Until a different explanation of this polygonal form is offered, we are compelled to assume that cells of thermic convection acted on the lunar magma while it was still in a fluid state.

If we accept the existence of such a phenomenon in the moon, it becomes equally plausible for the earth. The fossil cells of the moon thus support the hypothesis of terrestrial convection currents. In the last 30 years numerous geologists and geopysicist have invoked such currents to explain various aspects of the earth's tectonics, though many others deny their existence.

On first thought it may seem impossible to find polygonal cirques or mountains of the lunar type on the surface of the earth: the granitic crust, fashioned and refashioned over and over again by orogenesis and erosion, doubtless hides the upper surface of the convection prisms beneath a thickness of 20 to 100 kilometers. Nevertheless it might be fruitful to reconsider the main structural lines of our globe in the light of this hypothesis. One of the most interesting regions in this respect might be the Pacific Ocean, and when the topography of its bottom has been ascertained with sufficient precision, when depressions, crests, rifts and volcanic chains have been sufficiently localized, it will doubtless be possible to draw important conclusions concerning the earth's tectonics down to a considerable depth.

This development may not be far off; meanwhile, however, the well-known structure of Africa—vast depressed basins separated by long, narrow ranges — may perhaps, if the granito-sedimentary covering and erosion are taken into account, be regarded as a reflection of terrestrial convection cells.

A schematic map of Africa published by Arthur Holmes in 1944 discloses this structure; the polygonal outline of the borders of many of the basins is evident, fig. 4.

The investigations of these last years seem to point at a phenomenon (cf. F. Dixey, 1956) which startles one at first sight and which classical geology, as far as the author knows, does not mention: these raised and distended vaults between vast subcircular or polygonal basins have been a *constant* feature of Africa since Archaean times. For at least half a billion years, in other words, epirogenesis has affected Africa, forcing these narrow ranges between the immense depressed basins steadily higher. The idea of powerful convection cells, operating since the congealing of the Africa kratogen, would seem to provide a satisfactory explanation of this enduring and astonishingly localized phenomenon. And no other factor seems to account for it.

The graben and rifts that are one of the essential characteristics of African geology are situated along the longitudinal axis of these ranges. The superficial tensions prevailing in the upper few km. of the bulges seem to be the cause of these spectacular clefts. The structure, presumed to be original, of the Red Sea graben confirms the hypothesis that the rifts are determined (at least in the upper part of the earth's crust) by divergent forces and not by convergent ones as is maintained in certain hypotheses. This structure, disclosed in echo soundings undertaken by the first expedition of the Campagnes Océanographiques Françaises, stands out clearly thanks to the absence of sedimentation in this desert sea, the absence of erosion and—at least in two favorable spots—of basaltic emissions. Such a structure, as we know from the laws of mechanics, can

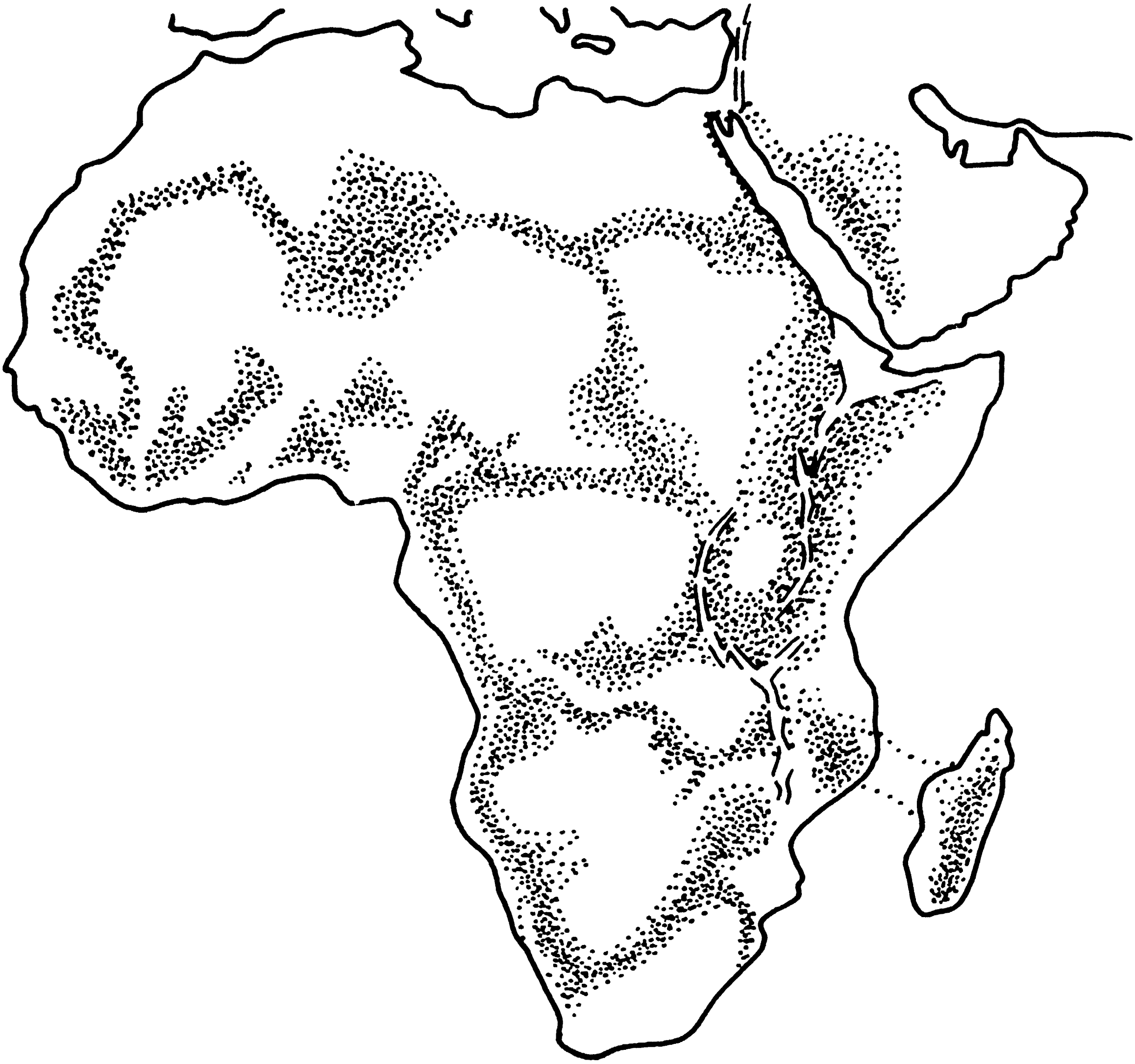

Fig. 4. — Basin and swell structures of Africa, after H. Holmes (1944). Note the well marked polygonal pattern of El-Juf, Chad and Congo basins.

result only from forces of tension to the exclusion of convergent thrusts.

It is readily conceivable that the extensive faults that gave rise to the rift-valleys yielded a passage to the underlying magma, thus engendering the potent volcanism of the Erythreo-African region. And this kratogenic volcanism shows characteristics (rectilinear alignment, basicity of the lavas, eruptive types, presence of permanent basalt or basaltoid lakes.) similar to those of intra-Pacific volcanism (as far as the Andesite line). It would be interesting to explore the geography of the volcanoes of the Pacific Ocean (subaerial as well as submarine and guyots) for a possible polygonal structure.

Dixey looks on these basin and range systems of Africa, the Western U.S.A., Brazil, the Baikal (Cf. Dixey, 1956) as the effect of contraction due to the cooling of the globe.

Perhaps it would be wise, in the light of the lunar structures, to consider this configuration as the superficial aspect of deep and relatively vast convection cells.

REFERENCES

Wasiutynski, G., 1946, Studies in Hydrodynamics and Structure of Stars and Planets. *Astrophysics Norvegica.* **4**, Oslo.

Holmes, A., 1944, Principles of Physical Geology.

Dixey, T., 1956, The East African Rift System. London H.M. Stationery Office.

Cousteau, J.Y. W. Nesteroff and H. Tazieff. Coupes transversales de la Mer Rouge.

Tazieff, H., 1953, Profils en travers du Centre de la Mer Rouge, Contribution á la connaissance des grands effondrements (note préliminaire), in *Congrès Géol. Intern.*-Comptes-Rendus, Section IV, Fasc. IV, Alger.

CRATOGENIC AND OROGENIC VOLCANISM

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(Abstract)

Cratons and orogens are two contrasted tectonic elements of the earth's crust, which are connected by transitions in space and time. The available energy of the magma and the resistance of the crust, which both change continually, determine the birth and the lifetime of a volcano. Displacements between adjacent parts of the crust may be caused by horizontal tension, by horizontal compression, and by the action of vertical forces. Magma will naturally flow toward the place of lowest pressure and volcanic activity will mostly go along with crustal tension and normal faulting, premising that the faults extend downward sufficiently.

In the *cratons* the balance of evidende with regard to the much debated origin of some conspicuous fault troughs accompanied by volcanic activity (e.g., Rhine Valley, East-Africa) is in favour of the predominance of crustal tension in broad swells, uplifted by more or less vertical forces. The location of volcanic activity shows dependence upon the form of the uplifted swell. Strong and long-lasting volcanic activity may be expected in regions of maximal tension.

The more mobile *orogens* show a great variety of types with regard to their tectonic and volcanic evolution. Their history shows successive phases of simultaneous or alternate horizontal and vertical movements. There may be phases of predominant uplift without folding or shortening. In the Andean chains of South America the folding is not very intensive. A principally neritic sedimentation and repeated block-faulting were accompanied by great outpourings of volcanic products and volcanoes occur on the top of the present mountain range. In the Alps a wide composite geosyncline was the site of magma ascent before the orogenic paroxysm. Later strong shortening of the cross-section of the original geosyncline and the thickening of the curst by the superposition of overthrust sheets may have hampered the ascent of magma to the surface and volcanoes do not occur on the top of the present mountain chain. In a number of arcuate orogens there is a striking manifestation of diagonal and transverse volcanic lines, while more or less longitudinal volcanic lines are often prominent in straight orogens. Diagonal volcanic lines are, e.g., found in the northern row of Lesser Sunda Islands near Australia. They are possibly connected with tangential push and relative tension during elongation of the moving island arc. This region affords an example of a relationship between tectonic evolution and extinction of volcanism. Volcanoes are now wanting on the southern or Timor row of islands. On the northern row they are wanting near the place where this row is nearest to the Australian continental shelf. Volcanic action was more prolonged in proportion as the distance between the mobile belt and the Australian craton increases. These examples illustrate the influence of the varying structural evolution upon the carying volcanicity of the mobile belts.

ON THE IMPORTANCE OF SUBMARINE VOLCANIC FORMATIONS INTERCALATED IN THE FOLDED FORMATIONS OF THE GREAT OROGENS

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(Abstract)

Among the volcanic deposits linked up with the final premonitory phases of the folding of a geosynclinal series, the eruption and the discharge of pyroclastics and andesitic or basaltic lavas, mainly under water, and often associated in that case with red argillites and radiolarites, are to be noticed. During the folding proper these volcanic formations are strongly dislocated and accommodated in the upper section of the orogen.

As with all the other geosynclinal deposits, they are subjected to metamorphism, with this peculiarity that, being the last of the formations formed, they will be often in "reduced cover" conditions and will be subjected in general to a phase of weak metamorphism only. Stress conditions and tension may, however, remain intense.

According to the author's view, based on studies and observations in the alpine chain of New Caledonia and Corsica, these volcanic formations would form deposits rich in magnesium, nickel, etc. The metasomatic concentration of these elements would form in a first phase chlorites and serpentines, and in a second phase peridotites and pyroxenes of ultrabasic rocks.[1] We would then have a coherent explanation for the existence of ultrabasic masses of rocks and of the "serpentine belts" which are known in the upper part of the alpine mountain ranges. According to the author, the spilites, dolerites, chlorite-schists, and other associated green rocks, would then represent only the "complementary" products of a real metamorphic differentiation which took place. Moreover some exact observations have shown (cf. J. Avias 1955[2]) that if we calculate the composition of the rock which is supposed to give birth to the metasomatic rocks on one side (containing more magnesium, iron, nickel, etc.) and the associated green rocks on the other side (containing more SiO_2, Na, Ca, etc.), we obtain the composition of a normal oceanic basalt. Apart from the field observations of contact and transitional enclaves, which the author investigated, this theory explains also the fact that "serpentine belts" are developed in recent mountain ranges, such as the alpine chains. In older chains, such as e.g., the hercynian, the corresponding upper part of the orogen has disappeared by denudation and only the root of the orogen, more or less granitized, remains.

The above proposed theory throws a new light on a set of facts which the classical theories were not able to explain, and draws attention to the considerable importance which the geochemical material, represented by the submarine volcanic formations of the pre-orogenic period in the geosynclinal series, had during the later stages in the development of the orogens, particularly in the formation of the ultrabasic rocks in the orogens.

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[1] Under the conditions which correspond with outcrops, these minerals would give birth to classical secondary serpentine.

[2] Colloque International de Pétrographie (Nancy, C.N.R.S. LXVIII): Les échanges de matières au cours de la genèse des roches grenues, (pp. 213-237, 12 figs., 3 tabl, Paris 1955).

THE BLOCK STRUCTURE OF THE CRUST AND ITS BEARING ON ORE DEPOSITS AND VULCANICITY

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THE BLOCK STRUCTURE OF THE CRUST

The existence in the earth's crust of relatively rigid blocks that act as distinct tectonic units is a tenet of many theories of earth structure although these blocks are conceived by different tectonicians to behave in different ways and thus to perform different tectonic functions. The geosynclinal theory, as developed by Deecke, Obrutschev and others from 1910 to 1930 clearly introduced the notion of mobile belts and stable blocks. These latter, although of continental or sub-continental dimensions, were nevertheless, at least in part, subdivisions of existing continents and thus of somewhat smaller dimensions than the continents. The geosynclinal theory itself implied no corollary of a permanent distinctiveness of the rigid blocks, but such a notion had independently been proposed by the recognition of the pre-Cambrian shields and tables, the "coigns" of the continents, about and between which the mobile belts are to be found. By folding and igneous buttressing, old mobile belts of geosynclinal type were conceived to be welded, according to one school of thought, onto the ancient shields.

It followed naturally from such ideas that the folding of geosynclinal deposits should be conceived to have been caused in most instances by a movement together of the rigid blocks on either side — the "jaws of a vise" mechanism, and where, as is so common, the folding is marginal to a continent and facing the ocean, Kober's *Orogentheorie* implied that from a tectonic point of view the ocean floors might be considered as the analogues of these continental blocks, and both continental and oceanic types of rigid masses were united by him as cratogenes (now cratons). Trans-oceanic as well as continental orogens were likewise recognized in Kober's synthesis, but the oceans will not be discussed further in this present account.

To return to the continents, and setting aside for the moment certain alternative hypotheses, advances in knowledge of most shield areas required the further subdivision of these great tectonic units, as more mobile zones especially of Palaeozoic geosynclinal sedimentation and folding were discovered within them. Thus for Bryan, Andrews and Cotton the Australian shield virtually disintegrated into a series of smaller "blocks", and much the same happened with Southeast Asia, Siberia and Africa. In no case, sofar as I am aware, was any structural basis for the existence of these smaller blocks proposed. Their margins were accidents unrelated to structure, and in Bucher's theory, concerning the origin of mobile belts by regional tension due to expansion of the body of the earth, it is clear that the pattern, if any, is a fracture pattern dictated by stress-distribution in a more or less uniform brittle crust, and Wegener's Drift Theory has, I suppose, much the same attribute in relation to the outline and size of the fragements of Pangea, the *Urkontinent*, which are supposed to have drifted in late Mesozoic and Tertiary times to their present positions.

At the same time as this group of theories involving rigid masses was being promulgated, other ideas were also expressed which were fundamentally different. Argand's notion of *plis de fond* and *plis de converture* involves, so far as I can see, no fundamental distinction between rigid blocks and mobile belts, and does not account for the localization of these belts. The theory has, however, not been widely accepted although the assumption of a plastic softening of a crystalline basement has been assumed especially in relation to Saxonian *Bruchfalten*. Theories that postulate crustal downbuckling have, especially of late years, relied largely on convention currents in the mantle to develop tectogenes, and presumably the pattern of tectogenes is therefore related to the outlines of the convection cells. The cells in Arthur Holmes' hypothesis are actually determined by the blanketing effect of pre-existing continental blocks on the escape of radio-genic heat, and the action of the currents is to dismember these blocks. This theory is difficult of application to the origination of pre-Cambrian shields and blocks, and has also not gained much support, nor indeed do Holmes' later writings themselves on topics such as the structure of Africa make reference to it.

This brief review indicates that from one lineage of geological thought, block tectonics emerged from the geosynclinal theory, but did not progress far along this line in relation to the structure of blocks or the pattern of mobile belts. The pattern of folded zones has been a matter that certainly has received much attention in a descriptive way from the time of Suess, but perhaps it might be truly said that the folded belts, however important they may be, have unduly overshadowed the significance and interest of the other lineaments of the globe, to such an extent that workers on lineaments (other than orogens) have been regarded as more than a little unscientific and subject to hallucinations[1]. As one who has frankly been interested in the major lines of a continent that completely lacks mountain chains of the Alpine Revolution, I would venture to say that lineament tectonicians have given greater thought to the precise details of geological lines than have the alpinists; that the Jura arcs are, for instance, better represented as a series of linked lineaments than as flowing curves, and that, broadly speaking, tectonic geology has for many years experienced a serious lacuna due to overemphasis of orogenic-type structures.

Lineament tectonics, which, as we shall see, links with block tectonics at a later stage, virtually commenced with W.H. Hobbs, it has had few notable contributors over several decades, but received a great stimulus from the work of Hans Cloos ever eclectic and global in his thinking, and also from the more detailed analyses of European structures by Sonder. Cloos' theory of basement blocks included an analysis of Alpine tectonics which was the more valuable since others working independently on somewhat similar lines at the same time were more concerned with shield areas. His notion reduces the strategic plan of the Alps to a series of almost accidental tectical exercises, to the slipping and sliding of relatively small basement blocks, in contrast to the broad frontal movement previously envisaged in the action of the *traineau écraseur* by which Africa overrides Europe. According to Cloos, the basement blocks are ancient units, relatively resistant and rigid, between which are weak zones that in places become the sites of geosynclines, and elsewhere are represented as fault or warp zones, very like the lineaments of Hobbs.

Those others who, about this time, were working on related topics each had a slightly different and independent viewpoint. Vening Meinesz on geophysical grounds and considering also the trends of coastlines and oceanic features as corroborative evidence, suggested that many major lineaments are elements of a global network of shears, the pattern of which he calculated (on one assumption) according to a polar shift over 70° of latitude along the meridian of 90° longitude. The actual lineaments included in the study are of a variety of different geological types, some coastal flexures, other great faults, others volcanic lineaments such as the Hawaiian Islands. However, since so many were found to be of pre-Cambrian age, Vening Meinesz concluded that the global shear pattern was formed very early and that later movements have often taken place on the old trends.

A similar conclusions began independently to grow out of work in Africa, chiefly in the Rift Valleys, and in Australia on the Shield, but like so many geological notions, a similar idea has often been expressed by individuals working in every continent, and later work has very largely tended to emphasize that *resurgent tectonics*, as I have termed it, is a geological principle. My own analysis of Australia has led me to recognize the existence of both a systematic network of lineaments including some that are over 1000 miles long, and of resurgent tectonics. It has also indicated that certain lineaments are the boundaries of earth-blocks that have acted as nuclei or core-regions, like Cloos' basement blocks, since late pre-Cambrian time.

Quite recently, Moodie and Hill have made the suggestion that wrench fault tectonics governs many if not all of the main fault lineaments of the world. They have extended their ideas from known wrench faults such as the Great Glen Fault of Scotland, the San Andreas fault, and the Alpine Fault of New Zealand, to other great fault systems where the evidence for lateral displacement is not so certain and where there is likewise very notable vertical displacement. Their work stimulates anew an interest in lineament tectonics, but perhaps enough has been said to indicate some of the major issues involved.

ORE ZONES AND THE INNER STRUCTURE OF BASEMENT BLOCKS

In 1946, I made an analysis of the tectonics of Australia from which it appears that the shield area is itself subdivided, as had been postulated

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[1] See for example the critical remarks of Bucher, in the Crust of the Earth: *Special Paper Geol. Soc. Amer.*, No. 62, 1955, pp. 343-68, "Deformation in Orogenic Belts".

by earlier Australian authors notably Andrews, Cotton and Bryan. My own analysis went further, however, in several ways. Firstly, it indicated that the smaller nuclei within the shield are "framed" by sweeping tectonic lines, some of which represent geosynclines; secondly it suggested that the nuclei or cores themselves possessed a tendency to concentric fold lineaments in the oldest pre-Cambrian; thirdly it indicated continued rejuvenation of the frames or weak zones, and equally continued cratonic characteristics for the nuclei; fourthly it suggested that a network of major fractures, more or less orthogonal, is represented in the Shield, i.e. for at least two thirds of the Australian Continent. These fractures are lower Palaeozoic, but are governed by older pre-Cambrian lineaments. Later, I was able to show that the major structural network for Australia fits that proposed by Vening Meinesz almost precisely—a conclusion that I had previously myself denied. This correspondence is seen particularly in what I have called *megalineaments* and what Sonder calls *linears*—lines that may be traced across the continent for distances of the order of 1,000 miles, and it is of interest to note that, as is also recognized by Sonder in his notion of equidistance of linears, these megalineaments are, indeed, spaced at regular intervals of about 4-500 miles (and, by chance, approximate to the arbitrary lines of shear drawn by V. Meinesz).

PRE-CAMBRIAN NUCLEI AND GEOSYNCLINAL FRAMES

In my first analysis of the Australian shield it was pointed out that the nuclei of the shield are bounded by zones of sweeping geological trends which are structurally weak and correspond in part with younger geosynclines. Since that time it has been demonstrated particularly in researches by the Commonwealth Bureau of Mineral Resources, Geology and Geophysics, as well as by the work of company geologists, that the zones marginal to the Sturtian Nucleus of the Northern Territory correspond with Lower Proterozoic geosynclines. What I have seen of rocks older than Upper Proterozoic in many parts of Australia indicates that the extent and intensity of metamorphism of these old rocks has been greatly over-stated, chiefly because the earlier workers were especially concerned with mining fields such as Broken Hill, where very extensive metamorphism is found. As surveys have been extended into less highly mineralized belts the surprising fact emerges that rocks at least as old as the Lower Proterozoic (of the order of 1250 million years) are very little metamorphosed, excepting locally. It has thus been possible to map belts of sedimentation, to effect stratigraphic correlation within geosynclinal zones, and to provide an astonishingly clear picture of such zones, which, with their *Collenia* reefs and detrital sediments, afford a very clear analogy with younger intracratonic geosynclinal zones. This is now best known from the Pine Creek geosyncline. On the eastern margin of the Sturtian Nucleus the Mount Isa pre-Cambrian belt also exhibits features of geosynclinal deposition especially in the north, but as the belt is traced southwards, increasing metamorphism produces, in places, Archaean-type lithology. At Broken Hill, an analogous gradation from Archaean-type gneisses in the vicinity of the mining centre, to much less strongly metamorphosed rocks a few miles distant has been known for several years, and is confirmed by later mapping. Recent work by Edwards on the amphibolites of Broken Hill shows that certain of these rocks are transformed limestones. Thus the whole regime in this district also begins to suggest geosynclinal deposition, the age being generally regarded as Archaean.

For our present consideration of the relationship of ore deposition to block structures in the crust, it can be said that what is now, I believe, emerging for Australia is a subdivision of the Australian shield into ancient, truly Archaean nuclei, framed with younger geosynclinal zones from the Lower Proterozoic, and, in the Shield, a partial immobilization of these as a result of orogeny, igneous action and ore genesis of pre-Upper Proterozoic date. Within the shield, then, ore zones, especially such as would be commonly regarded as hydrothermal in origin and somewhat closely restricted to the locus of their mobilization, correspond with the framing zones, and likewise with the Lower Proterozoic geosynclines, and perhaps also with older geosynclines still to be mapped. This idea is clearly set out by Noakes in a recent review for the Northern Territory.

The broad picture may be affected by two further considerations. Firstly, ore deposits related genetically to dyke rocks younger than the last geosynclinal phase of ore genesis might exist. This is the case, for instance, with lead ores related to Lower Palaeozoic dyke rocks in the Northampton district, Western Australia. But, so far as is known, dykes of such an age, in the shield area, are limited to rather restricted zones of fracturing near the edge of the shield.

Secondly, highly soluble elements such as uranium and lead may be remobilized by quite small rises of temperature under hydrothermal conditions or even by weathering. Thus such elements may be expected to occur rather widely disseminated and also in quite young rocks. Only rarely, as for example in the case that low concentrations are sufficient to afford a usable ore-deposit, are such effects likely to be economically important, as is true for uranium. The lead deposits in Tertiary limestones along the Red Sea in Egypt do, however, indicate that such effects may be significant for this element also.

The study of the distribution of ore deposits is, in fact, much influenced by the grade of concentration necessary to constitute an ore. This is well shown by the records of gold, which is sought in quantities so low as to be measured in parts per million, and consequently is one of the most widely recorded of minerals.

The Palaeozoic and later hydrothermal ore deposits of Australia are very clearly related to geosynclinal zones, as is almost universally true. What interests us for the moment is, in how far do these young geosynclines lie marginal to pre-Cambrian nuclei, either hidden or exposed, or, on the other hand, in how far do they lie in newly created zones of crustal mobility.

To solve this is not, at present, possible, but at least it is clear that the Australian geosynclines of later date follow in places trends of pre-Cambrian age nearly (e.g. Westralian Geosyncline, Tasman Geosyncline in north-Queensland) and that two dominant orthogonal networks, the one according to Vening Meinesz, the other a bisecting network (the importance of which was also recognized by that author) account for most of the major features, young and old, of Australia.

VULCANICITY

In Australia, Cainozoic vulcanicity is limited to the Eastern Highlands and nearby regions, to the south-west of Western Australia, and to the Fitzroy Valley in the northwest of Western Australia, where a series of remarkable leucite plugs has been discovered by Wade and Prider. The major structural lines of the Eastern Highlands are very clearly fractures—indeed it is a great difficulty in engineering geology to find sites over 100 yards square that are not traversed by faults or shear zones, and "jointing" is ubiquitous. It is in this millieu that the Cainozoic vulcanicity occurs.

A map showing the distribution of the major volcanic centres reveals very clearly a relationship between several of these and known megalineaments, whereby the volcanic centres occur at the intersection of the major fractures. This is particularly notable for the great alkaline complexes of New South Wales, two of which lie on the major boundary fault of the Highlands, where this is intersected by NNW lineaments; a third lies on a NNW lineament projected into the Highlands.

Relationships such as these have so often been described for volcanic phenomena that the interest in relation to Australia is rather local than general, but in another way the results are of interest in that they afford supporting evidence for the existence of the major fractures delineated in Eastern Australia, where the dyke intrusions of Cainozoic age also give clear evidence of strong NW-SE, E-W, and NNE fractures in the Eastern Highlands.

Moreover a further significant point emerges, which is that these Cainozoic dykes are limited in their distribution to a zone that has been geosynclinal since the Cambrian—the Tasman Geosynclinal Zone. Thus, although the vulcanicity represents an effect of fracturing, it is clearly influenced by much more ancient geotectonic structures, and more than that, all Palaeozoic and Mesozoic vulcanicity in Australia, after the Lower Cambrian which is related to Upper Proterozoic tectonics, is likewise strictly limited, and in fact is known only in the mobile belt of the east—the Tasman Geosyncline.

Thus, despite the obvious youthfulness of the highland uplifts, faulting and vulcanicity of Eastern Australia, which suggests that a new fracture pattern is involved, we are forced to recognize that the belt so affected has been mobile throughout Palaeozoic and later time. Such a result—which could equally apply to the Westralian Geosyncline except that this is affected by vulcanicity only to a very minor degree in Cainozoic times only—shows either a persistent structural inhomogeneity that has determined where mobility will be in evidence, or a continuing continent-wide stress and strain pattern that has, in its fundamentals, remained the same since the Upper Proterozoic. The former seems the more probable explanation.

GLOBAL TECTONIC

This is no place to review such a topic on a global scale, but I will venture one or two comments. The great scarp that flanks the Dead Sea Rift on the east is a major fault which appears to have been already in existence in the Cambrian. In this, and in its persistent downthrow on one flank, it resembles the Darling Scarp which flanks the Westralian Geosyncline. The Dead Sea Rift is, of course, only one element of the great rift system of the Africo-Arabian block, and it is now becoming clear that the age of these faults is much greater than was formerly believed; they are known to be at least Jurassic and probably older still, even Pre-Cambrian.

Evidence for the antiquity of major crustal structures is best got in cratonic areas because of their relative geological simplicity. But we know that the European Alpine tectonics can be traced back at least as far as the Middle Carboniferous, a fact which although well known is surely not sufficiently emphasized, for it means that the stress pattern, or at least the strain pattern and dynamics of the Alps are by no means only part of the Alpine Revolution of the Oligocene, but vastly older.

WRENCH FAULT TECTONICS

Like all geological notions the idea of major transcurrent or wrench faulting has its roots far back, but of recent years has come into prominence through the work of Sonder in Europe, Kennedy for the Great Glen Fault, Hill and Dibble for the San Andreas, and many other workers. It is inherent in general theories of folding such as those of H. Cloos. While the notion of basement blocks lends itself readily to lateral displacements, it is true it is much more the physics of the process that is fundamental, for movements of 60, or even 300 miles have been postulated since Jurassic times in New Zealand and in California. A global stress pattern is a *sine qua non* for movements such as this, a pattern not young, and, if not yet known to be entirely old, then at least geologically middle aged.

While there is some evidence for wrench faulting in the megalineaments of Australia it cannot be said that the obvious evidence for great displacements is strong. Moody and Hill's lineaments can account geometrically for all the lines of the world; it will be a major task of geology to prove or disprove their proposition that most if not all lineaments are wrench faults.

That there is still the opportunity, despite a plethora of points of view, for some new way of regarding global tectonics is shown by Brock's work based on Africa. This, however, is so new to me that I must confess I have not yet assimilated the notions in it.

To conclude, we may say that several lines of geological work, on lineament tectonics, geophysics and pre-Cambrian stratigraphy, have begun to converge to reveal the existence of a block structure in the crust—that major geosynclines, igneous action and related or genesis are controlled by such blocks and their framework; and that this is revealed as far back as the Lower Proterozoic. A fundamental issue of a geochemical and practical nature remains. That is, are there major and persistent geochemical differences between the different ore zones, recognizable throughout geological time? Or are such differences as do exist related to the type and intensity or ore-generating processes at any time modified by later erosion to expose the depth zones in different ways?

An answer may be indicated from a mobile belt that has been active at many times since the Cambrian—the Tasman Geosynclinal Zones of eastern Australia. Here the evidence, which has been admirably summarized in a recent work, points clearly to the omnipresence of elements, and to the control of ore-deposition at any time by the geochemistry of the processes of differentiation and ore deposition within a wide range of structural and lithological environments.

CONTINENTAL RIFTING AND IGNEOUS ACTIVITIES IN THE NEOGENE MARGINAL GEOSYNCLINES OF TAIWAN

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INTRODUCTION

The concept of geosynclines, first set forth by Dana in 1873, has been developed into a great unifying principle in geologic science. Geosynclines, as noted, are troughs of long continued subsidence upon accumulation of sediments. Great thickness of sediments, generally considered as one of the important characters of geosynclines, is the result of time as well as rate of depression and deposition. However, the magnitude of subsidence and time limits of a geosyncline are ill defined. Insofar as structure is concerned, a geosyncline is a basin, trough, or furrow whose, base subsided deeply under extensive surficial rocks during their deposition and accumulation.

Based on the form, origin of contained rocks and the associated tectonic environments, the geosynclines are classified by Kay (1947) into orthogeosynclines and geosynclines within the hedreocraton. The orthogeosynclines designated by Stille (1936) are linear or arcuate mobile belt bordering the comparatively stable continents or craton. An ancient craton which had persisting influence on continental development and has close correlation with present structures is a hedreocraton. The orthogeosynclines are subdivided into eugeosynclines and miogeosynclines on a volcanic basis of distinction. An eugeosyncline is a structure that has subsided deeply in a belt having active volcanism, while a miogeosyncline lies in a non-volcanic belt. The area of craton separating the geosynclines are relatively more stable. They commonly have been called geanticlines, uplifts, tectonic lands or platforms.

The concept of geosyncline has been extensively developed and greatly expanded into a geosynclinal theory (Knopf, 1948) through immense number of detailed studies. A remarkable store of facts and interpretations is on hand concerning the geosynclinal sedimentation, the igneous activities during the evolution and revolution of the geosyncline, orogenic phases that comprise the revolution, regional metamorphism and metallogenetic epochs related to intrusives during the successive orogenies. Thus, any site of deposition of any geologic age that deems to be in the nature of a geosyncline can be tested thoroughly with the above phases.

The Neogene stratigraphy in Taiwan shows that there were thick sediments in belts on each side of the Central Mountain. These belts have been depressed into downfolds and are considered to be geosynclines in being linear and in having few volcanic rocks. It is the aim of this paper to examine critically the elements of these geosynclines, with emphasis on the role of igneous activity. The relation of geosyncline to volcanism will be discussed with stresses on the great outpouring of lava in the form of fissure eruption through the process of continental rifting at the initial stage of geosynclinal evolution.

NEOGENE GEOSYNCLINES OF TAIWAN AS MARGINAL GEOSYNCLINES

The origin of the island of Taiwan has been a subject of hypotheses and theories. The hypothesis of a coastal range of the Asiatic continent was expressed by Juan (1956) in contrast to the common modern origin of an island arc. He discussed the problem from various angles such as the structural correlation between continent and the island, the ill comparison with Riukiu arc and Philippine Archipelago, the origin of Formosa Channel, the cause of present simple shore line and the submarine topography around the island, and concluded that the island of Taiwan has long been in existance and is actually a part of the old land of Fukien province.

The Asiatic continent in the Palaeozoic time had an interior platform, the hedreocraton, and the continent was bordered by belts of depression, the miogeosynclines, well shown in the paleogeographical maps prepared by Grabau (1928, pt. II. pl. 10). There have been various interpretations suggested in the past for the paleogeography of continental borders. In the course of his study of the North American continent, Stille preceived the existance of a Pacific pliomagmatic belt and a Rocky Mountain magmatic belt on the continental border of western North America. Kay differentiated these marginal geosynclines as eugeosynclines and miogeosyn-

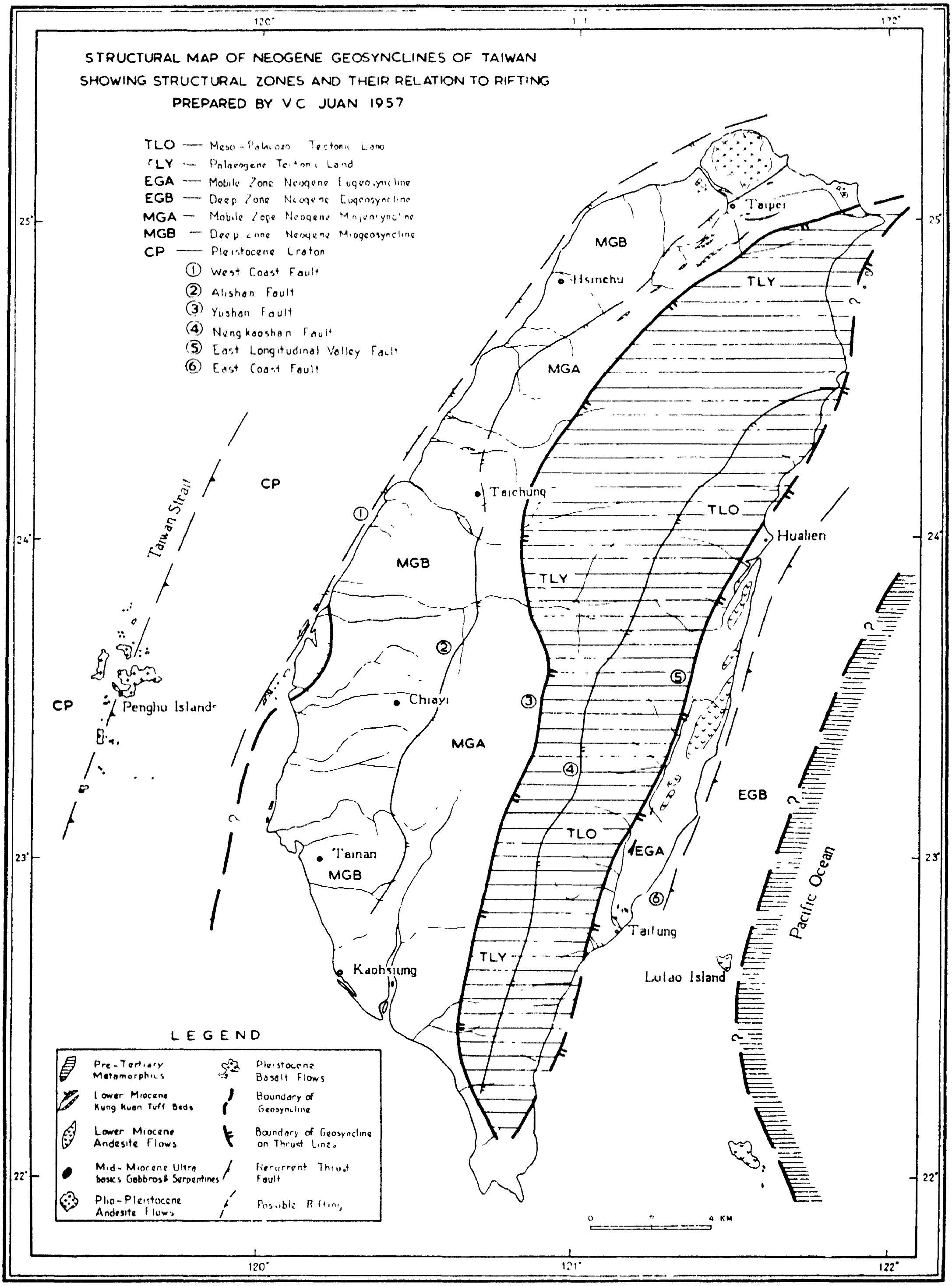
STRUCTURAL MAP OF NEOGENE GEOSYNCLINES OF TAIWAN
SHOWING STRUCTURAL ZONES AND THEIR RELATION TO RIFTING
PREPARED BY V C JUAN 1957
TLO — Meso-Palaeozoic Tectonic Land
TLY — Palaeogene Tectonic Land
EGA — Mobile Zone Neogene Eugeosyncline
EGB — Deep Zone Neogene Eugeosyncline
MGA — Mobile Zone Neogene Miogeosyncline
MGB — Deep Zone Neogene Miogeosyncline
CP — Pleistocene Craton
① West Coast Fault
② Alishan Fault
③ Yushan Fault
④ Nengkaoshan Fault
⑤ East Longitudinal Valley Fault
⑥ East Coast Fault
120°
121°
122°
25°
24°
23°
22°
Taipei
Hsinchu
Taichung
Chiayi
Tainan
Kaohsiung
Hualien
Taitung
Lutao Island
Penghu Islands
Taiwan Strait
Pacific Ocean
MGB
MGA
TLY
TLO
EGA
EGB
CP
LEGEND
Pre-Tertiary Metamorphics
Lower Miocene Kung Kuan Tuff Beds
Lower Miocene Andesite Flows
Mid-Miocene Ultrabasics Gabbros & Serpentines
Plio-Pleistocene Andesite Flows
Pleistocene Basalt Flows
Boundary of Geosyncline
Boundary of Geosyncline on Thrust Lines
Recurrent Thrust Fault
Possible Rifting
0 2 4 KM

Fig. 1.

clines, divisions of compound orthogeosynclines and considered that regions beyond the miogeosyncline were deep-sinking belts of sediments and marine volcanic rocks. These regions are in unit geosynclines lying between and among tectonic swells or grading craton-ward into miogeosynclinal belts.

That the island of Taiwan can not be compared with any existing island arcs is evidenced by the significant fact that no satisfactory account has been given for the reverse direction of the arc which has a convexity facing the continent. No less significant is the fact that Taiwan is not situated on the rim of the continental shelf areas, the rightful locations generally agreed upon for the formation of island arcs. Due to the process of continental rifting, which is very important in connection with marginal geosynclines, continental shelves are absent in this part of the Asiatic landmass.

Viewed as a part of the Asiatic continent, the island has been a belt of marginal geosynclines and that the major structural units constituting the framework of the island are the various components of a composite orthogeosyncline. These involve (1) volcanic Neogene eugeosyncline of the East Coastal Range; (2) a tectonic land forming the Central Mountain in the middle; and (3) non-volcanic Neogene miogeosyncline occupying the western part of the island. In addition, an intracratonal geosyncline—exogeosyncline—at the site of Taiwan Strait is in its embroyic stage of formation.

The geologic history of this orthogeosyncline can be traced back as far as the Palaeozoic. The metamorphic complex (TLO) including schist and gneisses represents the fossil sedimentation in troughs filled up one after another in the periods of the Palaeozoic era. The regional metamorphism that it suffered and the subsequent intrusion of acidic rocks indicate the closing phase of the ancient geosynclinal evolution. A great cordillera was thus formed nearly at the present site of the island, a geologic expression of the so-called Palaeo-Taiwanian revolution.

The late Mesozoic (Upper Jurassic and Cretaceous) and early Tertiary transgressions which invaded the geosynclinal depression broadly downwarped on the flanks of the cordillera were not very extensive, their deposits occupying only limited areas (TLY) west of the Central Mountain. Regional metamorphism of much less degree set in at the end of Eocene, representing the Neo-Taiwanian revolution.

The fossil sedimentations of both the Meso-Palaeozoic and the Paleogene geosynclines appear now as tightly compressed assemblages of a tectonic land in the midst of Neogene geosynclines.

Throughout the period of younger Tertiary, a new ortho-geosyncline was in existance and the island incorporated a new structural unit to its framework. This was the Neogene orthogeosyncline completely surrounded the old tectonic land at the southern tip and occupied both eastern and the western parts of the island, as we see it now. Considered as a marginal geosyncline at the border of the Asiatic continent, it consists of two components, an outer eugeosyncline situated at the present site of the East Coastal Range and an inner mio-geosyncline located west of the Central Mountain. Thus they were separated by a welt of pre-Neogene rocks along the greater part of their length but merged together at the peninsula of Hengchun; and they were not pairs of continuously expanding troughs, but linear arcuate depressions along the border of the continent.

The sediments in the East Coastal Range with and estimated thickness of 6,000 meters (Hsu, 1956) are typically eugeosynclinal. The earliest phase occurring at Lower Miocene time was andesitic lava, which was followed by accumulation of volcanic detritus and fragmental rocks. After the formation of lava agglomerate a transgression set in at the consequence of downwarping and marine environment prevailed and the volcanic materials that formed the argillites were adequately sorted and well stratified Although terrigeneous and volcanic detrital sediments were abundant, great areas were covered with carbonatite, commonly calcitites, of 5 to 25 meters. From this bathymetric extreme, rocks in the eugeosyncline passed on one hand in the northeast to lava, tuff and coarser fragmental rocks and the derivatives of weathered volcanic materials, and on the other in the southwest into terrigeneous sediments eroded from tectonic lands. Thus about 1,400 m. of conglomerate accumulated near Taitung close to the margin of the sea. The presence of metamorphic pebbles suggests vigorous erosion on the exposed old rocks.

In the middle and upper Miocene time, the water depths in the geosyncline tended to increase rapidly, a great sequence of argillite, graywacke and conglomerate reaching a thickness of 2,700 m. were deposited. Since lands were immature, sediments were poorly sorted, graded bedding and slump structures of contemporaneous deformation are generally found. The predominance

DIAGRAMMATIC SKETCH SHOWING THE STRUCTURAL UNITS OF TAIWAN

PL II

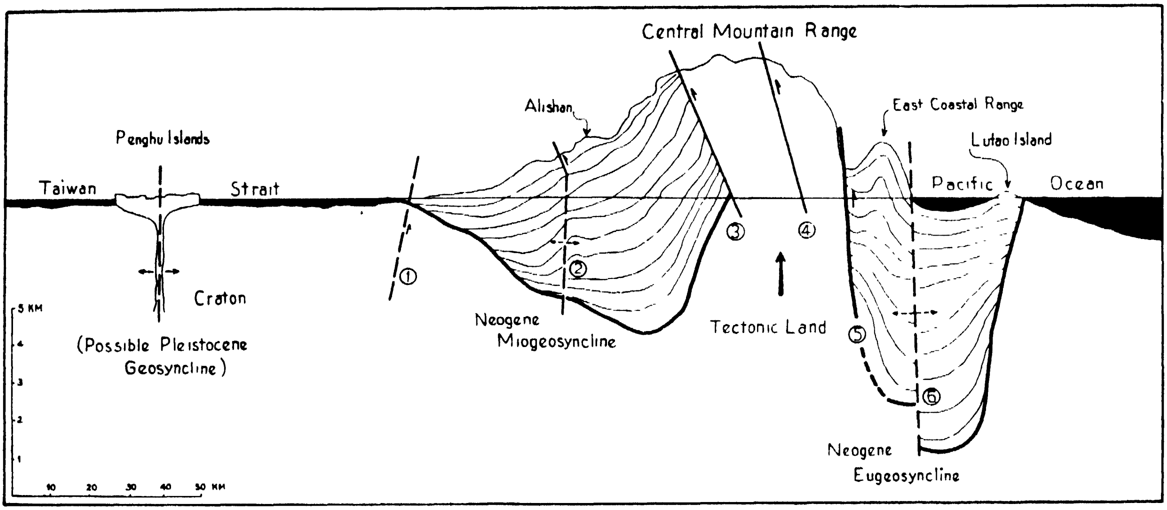

Fig. 2.

of a graywacke suite indicates that tectonic uplift interrupted subsidence, though the sum of movement was downward; and that the belt was commonly quite mobile with steep submarine slopes and high relief land. The absence of orthoquartzite and arkose must be interpreted as reflecting the tectonic mobility that did not permit sorting of rock constituents exposed.

Contemporaneous with the graywacke sequence in the northern part of the geosyncline, sedimentation of massive clayey beds containing exotic blocks of various rocks under condition of mass mud-flow took place in the southwestern part. Such lithologies characterized the deeper part of a physiographic trough with gentle slopes that the mode of transportation of detritus was more of creeping than rolling and promixal to the active recurrent uplifting along the East Longitudinal Fault that dates back as far as the beginning of the Pliocene.

The third cycle of sedimentation in this geosyncline from upper Miocene to Pliocene was typified by alternating beds of graywacke and argillite topped with impure limestone of shallow water origin.

This eugeosyncline extended southward far beyond Taitung and merged into the miogeosyncline of western Taiwan at Hengchun; where spilitic basalt, which is closely related with eugeosynclinal volcanism, has been found (Wang, 1951). The deposits in the eugeosynclinal belt were not continuous into the miogeosynclinal belt. The sediments in the two belts, though not mutually exclusive, are contrasted sharply. These persisting contrast in facies reflects constant differences in sedimentation condition through the periods of Miocene to Pliocene. Curiously, the zone of juncture of the two belts, as invariably verified by Kay (1951) the world over, is one of great deformation; the extensive East Longitudinal Thrust Fault brought the outer eugeosynclinal side as an allochthone over the passage into the inner, miogeosynclinal autochthone.

The sediments in the miogeosyncline of western Taiwan appear in a quite different situation. The intermediate position of miogeosyncline between eugeosyncline and hedreocraton had great influences on deposition which was effected by the peripheral mobile tectonic land and meanwhile received well sorted detritus from relatively stable hedreocraton. Thus argillite and carbonatite, the formation of which were encouraged by more uniform and gradual subsidence, are relatively abundant. Volcanic rocks are rarely present in the northern part and virtually absent in the greater part of the geosyncline. The great sequence of sediments, which has an estimated thickness of more than 7,000 meters, represent also three cycles of sedimentation. Such rhythmic deposition began with weak volcanism as evidenced by the Kungkuan pyroclastics in the first cycle of Lower Miocene age and succeeded with a long period of accumulation of argillite and low grade graywacke (Wang, 1954) and sandstones belonging to the orthoquartzite clan and followed by organic deposition of coal and carbonatite. This has been termed as foreland facies (Pettijohn, 1957, p. 633-636) in opposition to the geosynclinal facies which is typical in the eugeosyncline. Although the distinction of facies depends primarily on the stability of source areas and the availability of transport to the sedimentation trough, the foreland facies, a product of accumulation of shallow seas, has its greatest thickness and volume in the miogeosyncline. However, locally coarse rudites have been found in the late cycle of sedimentation of the Late Miocene to Pliocene, but owing to the shifting of direction of trangression in different cycles of sedimentation and the orogenic movement recurrent before the time of Pliocene, distinctions between distal, axial, and proximal facies can not clearly be made, though a foreland facies has been noted in association with a geosynclinal facies in the same geosyncline at different times and places.

IGNEOUS ACTIVITIES IN THE MARGINAL GEOSYNCLINES

Daly (1912) was the first one who had the idea that the geosynclinal evolution and the orogenic revolution controlled by it are marked by a definite cycle of igneous activity. This hypothesis was later elaborated and extended by both Kossmat (1921) and Scheumann (1924) into prototectonic, syntectonic and apotectonic stages characterized by submarine basalts and associated "ophiolites"; granitic intrusions; and stocks and batholiths of massive granite respectively. These ideas had become a full-fledged theory by 1932 (Knopf, p. 568) when they were applied to explain the igneous activity during the Variscan period in Saxony and thus offered a possibility of shedding some light on a major problem of geology in other regions.

In the eugeosyncline of the East Coastal Range, several series of igneous rocks have been noted. Volcanism was active at the begining of the evolution of the geosyncline early in Miocene time. 800 meters of andesites were erupted in the earliest time, but later 1,500 m. of andesitic pyroclastics were deposited. As the deepening of the sedimentary trough continued as a consequence of the subsequent accumulation of nearly 1,400 meters of sediments, the Middle Miocene Lichi formation (Hsu, 1956), plutonic intrusions of the type of serpentinized peridotite and gabbro came in during the first great deformation that folded the sediments in the geosyncline. Somewhat later several chonoliths of dolerite and basaltic glassy rocks (Juan et al, 1953) intruded probably at the height of the tectonic revolution between Middle and Upper Miocene time. However, true "geosynclinal basalts" have not been found, a small submarine body of spilite (albite basalt) was extruded before the geosyncline was extinguished at the end of the Pliocene.

In the miogeosyncline of western Taiwan, corresponding igneous activities in the different stages of evolution of the geosyncline have also been found, though somewhat different in petrography and strikingly contrast in magnitude and intensity. The earliest phase was the volcanism of early Miocene, well represented by the Kungkuan tuff beds in the northern part of the island. The thickest accumulation is reported about 230 meters, where four beds of tuff have been observed. Except for the lowest bed which is represented by volcanic agglomerate and breccia, the upper three beds are well bedded tuff intercalated with marine shale and siliceous limestone. When the floor of the geosyncline, upon receiving thick accumulation of cyclic depositions of marine strata and coal beds brought about by alternate transgressions and regressions, sank into considerable depth at the end of Middle Miocene, igneous activity of the second phase appeared as intrusions of alkaline basalt, analcite dolerite and basanite (Yen, 1949 a & b). The unstable nature of the floor of the deepening geosyncline, as indicated by the greatly differing rate of subsidence, more rapid in the southern portion, perhaps made possible the rise of the molten magma. However, the problem is much more complex petrographically, for it involves a change of nature of magma from subalkalic to alkalic between Lower Miocene to Middle Miocene. The last phase of igneous activity with a corresponding age of Pliocene was formerly held as nonexistant in this province. But careful structural research seems to have validated the thought that the Tatun volcanism of mainly andesite flows may be taken to account for this epitectonic stage. Structurally, the group of Tatun volcanoes, though situated at the northern tip of the island, lies well within the boundary of the province of the miogeosyncline. The volcanoes are evidently localized on open spots along faults and their eruptions were not vigorous nor explosive but characterized by a slow escape of emanations, thus resulting in hydrothermal concentration of ore-forming solutions. Sulphur deposits occur within the andesites and gold-copper ores in the dacite bodies.

From the evidences for the Neogene geosynclines in Taiwan that have been briefly sketched here, it can be seen that a series of happenings seem to have only partially confirmed to the systematic cycle of igneous activity outlines by Kossmat. According to Kossmat, the submarine eruption of basalts and other ophiolites began when the geosyncline was nearly filled. In the Neogene miogeosynclines of Taiwan, like the Appalachian geosyncline of Palaeozoic age south of New York, no extrusion of basalt has been found, but basalt pyroclastics were erupted and in the eugeosyncline, the highly differentiated lavas of andesite, similar to the Tasman geosyncline of Queensland (Sussmilch, 1935) were extruded at the inception of the geosyncline early in Miocene time. Thus true geosynclinal basalts witnessed by Tyrrell (1937) in the Caledonian geosyncline are not present here at the stage of geosynclinal sedimentation. Basaltic rocks such as gabbro, serpentinized peridotite, dolerite and basalitc glassy rocks occurred in the eugeosyncline at a time when the geosyncline was almost filled. However, since these rocks have suffered no metamorphism and thereby become altered into well known green rocks collectively called "ophiolites', they are not considered to be the prototectonic phase but concomitant with the folding at the syntectonic phase of the crustal revolution as illustrated by Hess (1940) in his study on the Appalachian peridotite belt.

In the Neogene geosynclines of Taiwan, no granite is known to have been emplaced during the syntectonic stages. It is doubtful whether such granite intrusions have ever occurred in depth. For the ultrabasic and basic, the latter ones have been named Taiwanite by Juan (1953) as representing a kind of parental magma type, occurred instead. This fact invalidates the theory that the granite magma was generated at the stage of folding by disolving the sialic roots of the folds that had subsided deeply into the sima in restoring equilibrium, and that the Intrusion of granite is a mark of isostatic subsidence. It seems that the intrusions of the basic rocks at this stage were guided rather by rifting that initiated the growth of the geosyncline near the contact of the Asiatic continent and the Pacific Ocean.

In the apotectonic phase, the situation of the Neogene geosynclines was quite similar to what has been outlined by Kossmat. The crust, which became greatly stiffened and rigidified by folding and by the masses of basic rocks intruded into it, was no longer foldable. Further tectonic disturbances appeared in the form of faulting. The geosynclines were pinched in between fault slices of an imbricate thrust system at the end of Pliocene. It is remarkable to note that this diastrophic pulse thus regarded as paroxysmal was accompanied by the eruption of andesitic lavas representing a definite concentration of the erupted material around open spots, thus individual volcanoes were built up. This concentration itself is the final stage in the history of the eruption which started as fissure eruption at the stage of the nascency of the geosynclines.

In summerizing the above, it is clear that the Neogene marginal geosynclines began their formation as a result of volcanism and the history of the geosynclines is definitely marked by eruption of submarine andesitic or basaltic pyroclastics at the initial stage or prototectonic stage, intrusions of ultrabasic rocks at the syntectonic stage or stage of folding and eruption of andesitic lavas in the form of volcanoes accompanied by hydrothermal concentration of ore-forming solutions at the epitectonic stage.

CONTINENTAL RIFTING AND GROWTH OF THE CONTINENT

The geosynclinal belts have long been recognized as tectonically mobile and magmatically active. The destruction of geosynclines by compressional deformation has been analysed by Rich (1951) to appear in a consistant cycle of events comprising (1) upwarping caused by the rising of magma, (2) thrusting and crumpling at the geosynclinal margins, (3) overriding and folding of sedimentary rocks near the upwarp, (4) the repeated thrusting from the same direction after a period of halts, (5) development of tension in the upwarped area after thrusting has ceased, and (6) final sinking of the upwarped area accompanied by outpouring of lava.

The sequence of events in the life cycle of the orthogeosyncline of Taiwan, though not conform in detail to the above, is essentially the same as outlined. The tectonic land within the Neogene orthogeosyncline consists of two parts, the Meso-Palaeozoic (TLO) and the Paleogene (TLY) tectonic land, representing probably the ancient marginal geosynclines. The Meso-Palaeozoic tectonic land is occupied by granite gneisses and amphibolites and crystalline schists of Palaeozoic age injected by pegmatite and quartz dykes of possibly Cretaceous age. This mountain range forming the nucleus of the cordillera has thus been in existence since the Mesozoic era. The Paleogene tectonic land was a geosynclinal depression broadly downwarped on the flanks of the cordillera during the Paleogene, and was regionally metamorphosed into slates and phyllite formations by the Neo-Taiwanian revolution at the end of the Eocene and also dislocated at the close of Oligocene. It is the writer's conviction that the dislocations like the Alishan fault and the East Coast fault among other recurrent faults originated far back during this period in the nature of rifts, initiated in the Neogene geosynclines on both flanks of the cordillera. When the orogenic deformations occurred in the Neogene geosynclines are traced in detail, we realize that the events of development of tension and final sinking of the upwarped areas accompanied by outpouring of lavas enumerated by Rich were actually continental rifting of the foreland areas of the ancient geosynclines at least in this particular region.

Geologists have been cognizant of the fact that the island of Taiwan is situated at the intersection of two mighty island arcs, the Riukiu islands and the Philippines and that it has a curvature looped in a reverse direction instead of being the same as its neighbours which show convex fronts facing the Pacific Ocean. It is also generally held that the mechanism responsible for the formation of island arcs is mainly of underthrusting of a simatic layer of the crust under the ocean and its counterpart overthrusting and overriding the sial layer from the direction of the broad epicontinental seas behind the arc. Thus repeated low-angle thrusting dipping landward occurred in all arc structures. When we examine the directions of compression in the neighbouring arcs which are about N 35°-50°W in the Riukiu arc and about N 60°-75°E in the Philippine arc, it is not surprising to find that the resultant tension should be in the direction of N 5°-20°E and it should be manifested best at Taiwan, the location of intersection. This explains well the fact why continental riftings of the above mentioned direction were developed in this particular region where, owing to lack of epicontinental seas between the Asiatic continent and the marginal geosynclines, the repeated thrustings in the cycle of compressional deformation came all from the southeast and were dipping oceanward, and final sinking of the foreland area of the Paleogene geosyncline accompanied by fissure eruption became the new site of a Neogene geosyncline. This working hypothesis seems to fit the requirements of the Neogene geosynclines and to explain logically also the fissure eruption displayed at the beginning of the Pleistocene in the Taiwan Strait, the foreland area of the Neogene miogeosyncline; and the fact that a new geosyncline has started and is still in its stage of geosynclinal sedimentation.

There are different views about the origin of the islands in the western Pacific. The old idea of continental fragmentation is generally regarded as untenable. For the advances in knowledge of the nature of continents and ocean beds have gravely raised a question whether a continent would under any condition break up and sink. Theory has also been advanced that the islands bordering the continent are formal marginal orthogeosynclinal belts and that the original continent was a small craton that grew as orogenies consolidated such marginal geosynclinal belts (Lawson, 1932; Stille, 1934). The growth of a continent must be considered from two aspects, the present physical constitution and the past geologic record of the earth. Thus the history of the island of Taiwan is significant in these considerations.

Responding to the isostatical adjustment caused by the denudation of the Asiatic continent, the island of Taiwan has been a marginal geosynclinal belt since Palaeozoic time. With the invasion of sialic materials at the end of the Mesozoic, as represented by pegmatite bodies in the Central Mountain area, the belt was consolidated and a coastal range was added to the continent at the expense of simatic ocean basins. By the same process, an eugeosynclinal belt was formed as a new subsiding area outside the range at Neogene time. The geologic history of the island thus strongly suggests that the continent has been expanding and all evidences point toward a theory of continental accretion.

However, the process of continental accretion exerted by the Neogene eugeosyncline has been incompletely executed, for the latter was immaturely extinguished when viewed from the fact that batholithic intrusions, as required in the normal geosynclinal cycle of events, were lacking. It is the writer's belief that the growth of this marginal geosyncline must have been interrupted by recurrent continental rifting, an inevitable result consequent to the wave of powerful compression affected by the inflow of heavy subcrustal materials toward the neighbouring island arcs, as already stated before. Since the continental rifting is held as the initial mechanism of development of an eugeosyncline, the continent must have been expended more rapidly through the frequent occurrence of vast outpouring of lava in the form of fissure eruption than through an intermediate "island arc" stage. It is therefore reasonable to assume on the strength of the above considerations, that where continental rifting is absent, the growth of the continent has reached a limit, and paraliageosynclines without adjoining volcanic belts will be developed along the border of the continent.

REFERENCES

Daly, R.A., 1912, Geology of the North American Cordillera at thè Forty-Ninth Parallel. *Canada Geol. Surv.* Mem. **38**: *(481)*, 489-490.

Dana, J.D., 1873, On the Origin of Mountains. *Am. Jour. Sci.*, **5**: 347-350.

Grabau, A.W., 1928, Stratigraphy of China. Pt. II, Mesozoic, *Geol. Surv. China*, Peking, pp. 744.

Hess, H.H., 1940, Appalachian Peridotite Belt; its Significance in Sequence of Events in Mountain Building. *Geol. Soc. Am. Bull.* **57**: 1996.

Hsu, T.L., 1956, Geology of Coastal Range, Eastern Taiwan. *Bull. Geol. Surv.* Taiwan, **8**: 39-63.

Juan, V.C. et al, 1953, Taiwanite, a New Basaltic glassy Rock of East Coastal Range, Taiwan, and its Bearing on the Parental Magma-type. *Acta Geol. Taiwanica*, **5**: 1-25.

Juan, V.C., 1956, Physiography and Geology of Taiwan. *Proc. 8th Pacific Sci. Congress.* **2**: 281-312.

Kay, Marshall, 1947, Geosynclinal Nomenclature and the Craton. *Am. Assoc. Petrol Geol. Bull.*, **31**: 1289-1293.

Kay, Marshall, 1951, North American Geosynclines. *Am. Geol. Soc.* Mem. **48**: 143.

Knopf, Adolph, 1948, The Geosynclinal Theory. *Am. Geol. Soc. Bull.* **59**: 649-670.

Kossmat, F., 1921, Die Mediterranen Kettengebirge in Ihre Beziehung zum Gleichgewichtzustande der Erdrinde. *Sächsischen Akad. Wiss.*, Math-phys. Kl. **38**: *(2)*, 46-48. As quoted by A. Knopf.

Lawson, A.C., 1932, Insular Arcs, Foredeeps, and Geosynclinal Seas of the Asiatic Coast, *Bull. Geol. Soc. Am.* **43**: 353-382.

Pettijohn, F.J., 1957, Sedimentary Rocks. 2nd ed., Harper & Brothers, New York, p. 633-636.

Rich, J.L., 1951, Origin of Compressional Mountains and Associated Phenomena. *Bull. Geol. Soc. Am.* **62**: (10), 1179-1222.

Scheumann, K.H., 1924, Präyariskische Glieder der Sächisch-Fichtelgebirgischen Kristallinen I, Die Magmatische Orogenetische Stellung der Fronkenberger Gneisgesteine. *Sächsischen Akad. Wiss.*, Math-Nat. Kl. Abh., **37**: 7-61, 1927. As quoted by A. Knopf.

Stille, Hans, 1934, The Growth and Decay of Continents. *Research and Progress.* **1**: 91-14. As quoted by A. Knopf.

Stille, Hans, 1936, Die Entwicklung des Amerikanischen Kordillerensystems in Zeit und Raum. *Preuss. Akad. Wiss.* Phys.-Math. Kl. Sitzungsber. **15**: 134-155. As quoted by a Knopf.

Süssmilch, C.A., 1935, The Carboniferous Period in Eastern Australia. Austr. & New Zealand Assoc. Adv. Sci. **22**: 83-118.

Tyrrell, G.W., 1937, Flood Basalts and Fissure Eruption. *Bull. Volcanologique*, **1**:90-91.

Wang, Y., 1951, A Preliminary Study on the so-called Dolerite of Chienshan, Hengchun, Taiwan. *The Formosan Science*, **5**: 1-2, 39-51.

Wang, Y., 1954, Graywacke from Nankangshan and its Vicinity East of Taipei City. *Acta Geol. Taiwanica*, **6**: 125-131.

Yen, T.P., 1949a, Analcite Dolerite and Analcite Basanite in Taiwan. *Bull. Geol. Surv. Taiwan*, **2**: 25-50.

Yen, T.P., 1949b, A Preliminary Study on the Alkaline Basalt of Tsaolingshan, Tachi, Sinchu, Taiwan. *Bull. Geol. Surv. Taiwan*, **2**: 1-23.

TECTONICS AND VULCANISM IN NORTHEASTERN MELANESIA

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(Abstract)

Several oceanographic traverses in the Fiji-Tonga region of the South-West Pacific by Expedition CAPRICORN of the Scripps Institution of Oceanography, on research vessels *Spencer F. Baird* and *Horizon* provided some geomorphic data for an interpretation of the submarine geology. Combined with this information, careful contouring of other bathymetric data from existing charts (admittedly rather meagre and imperfect) permit some indication of a tectonic pattern.

Possible short echelon ridges (WSW-ENE) crossing the Hunter Island Ridge, S.W. of Fiji, seem to confirm the theory of Hess that a dextral transcurrent fault (right lateral strike-slip) bisects the northeast part of Melanesia. A similar but more pronounced belt of little horst and graben type ridges en echelon (WNW-ESE) marks the E-W northern border of Melanesia, suggesting a second dextral transcurrent line. Here the northern Melanesian border slopes gently down to the Central Pacific Basin.

In contrast, the eastern Melanesian border is marked by a double island "arc" with a volcanic inner row in the Falcon Ridge and a non-volcanic outer row, the Tonga Ridge (NNE-SSW). These are separated from the South Pacific Basin by the very deep Tonga Trench. This feature is non-arcuate but rectilinear, and may also represent a dextral transcurrent fault extending to New Zealand. Mechanically, this spoke-like arrangement of strike-slips offers no ready explanation, but great lateral displacements of the order of hundreds of miles seem improbable.

In the whole regions, active vulcanicity is limited to the Falcon Ridge and vicinity. Isolated plugs of late Tertiary age occur on or near the Hunter and North Melanesian echelon fracture zones, while the central mass of Fiji, standing like a keystone in the center, is composed mainly of older Tertiary (and even Cretaceous) volcanics. All are dominated by the andesite series, with basalts playing a quite subsidiary role. No typical "continental" sediments or granite-type rocks are known in the entire area.

The character of the sea floor of the Efate Basin and the Fiji Basin suggests a great complexity of block faulting and small volcanic cones (but no large seamounts; the latter are found only east of the "Andesite Line"). Numerous truncated platforms throughout the area suggest planed-off andesite complexes locally surmounted by coral reefs. In some cases, the reefs have been drowned completely, and in others they are elevated, indicating continued tectonism in the region.

Deep focus earthquakes are restricted to the Tonga trend. Shallow seismicity is common around Fiji. Crustal structure south of Fiji is indicated by CAPRICORN'S seismic refraction surveys (Raitt) to be intermediate in character between typical oceanic and typical continental. Gravity surveys by submarine (*HMS. Telemachus*) are still under study by Worzel, who (personal communication) indicates a similar picture.

The writer interprets N.E. Melanesia as a semi-continental segment of the earth's crust, in the process of incorporation into the continental mass of Australasia, but still in part foundering back into unsupported crustal areas "regeneration". This picture does not conform in any way to the standard pattern of a circum-continental orthogeosyncline or an epicontinental parageosyncline; on the contrary, it may provide an insight into the evolutions of a differentiated crust in the earliest history of a well-established continent. However, in this case, the history of volcanicity and differentiation began possibly no earlier than the Cretaceous.

ON THE RELATIONS BETWEEN SEISMIC AND VOLCANIC PHENOMENA AND THE ENERGY BALANCE OF THE BEZYMIANNY VOLCANO ERUPTION

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On the 22nd of October 1955, for the first time in history, an eruption of the Bezymianny Volcano on Kamchatka began, which lasted for over a year and proved to be very interesting.

The eruption can be divided into five stages:

I. Pre-eruption stage from the first volcanic earthquake to the first gas-explosion of the volcano, from September 29 to October 22, 1955.

II. Stage of strong ash eruptions of a volcanian type: from October 22 to the end of November 1955.

III. Stage of a moderate activity, from December 1955 to March 1956.

IV. Gigantic paroxysmal explosion on March 30, 1956.

V. Growth and development of the extrusive dome in the newly formed crater: from April to the end of 1956.

I. PRE-ERUPTION STAGE

The eruption was preceded by numerous earthquakes, the total number before the eruption being 1285. The first shock of this swarm of earthquakes was recorded on September 29, 1955; the displacement at the Volcanological Station in Klyuchi (45 km from the volcano) reached II μ. The number of shocks and their energy increased every day. From October 9, the earthquakes were already counted in one-two hundred per 24 hours.

On October 11th, the ground displacement in Klyuchi exceeded 100 μ; for the first time the epicentre (the region of the Bezymianny) and the focal depth were determined. From October 18 shocks were registered with amplitudes of 1000 μ and more. The nature of this earthquake swarm enabled us to be very confident of an eruption to follow soon and indeed the eruption point was determined quite correctly.

II. STAGE OF STRONG ASH ERUPTIONS

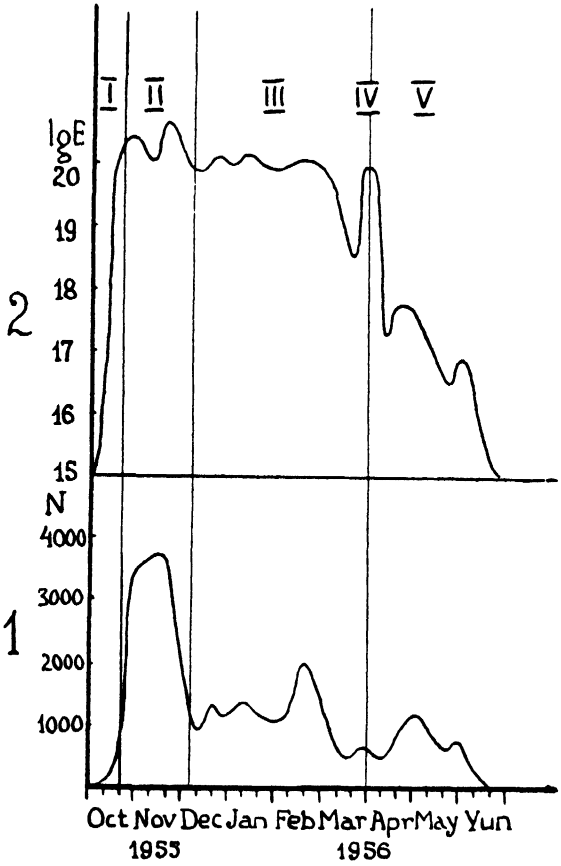

Fig. 1.—Diagram showing changes in number (1) and energy of earthquakes (2) in the course of the eruption. Roman figures indicate periods of eruption.

The eruption began at about 6.30 a.m. on the 22nd of October. During the first days the eruption was moderate, an ash-gas cloud not exceeding 1 or 2 km. rose above the crater. However, the energy of the explosions grew daily. From October 26 on, ever-growing ash-falls were taking place in a radius of 40-60 km. from the volcano. Judging from the starting points of the ash streams the diameter of the new crater did not exceed 250 m.

On November 7, the activity increased considerably. On the night of November 13 the ash cloud reached a height of 5 km. above the crater. All night long giant bright lightnings flashed in the eruptive clouds, the ash cloud moved to the East, reached the Pacific Coast, and moved further into the open ocean. On November 14 the ash column reached a height of 7.5 km. above the crater (10.5 km. above sea level). Violent ash falls passed in Klyuchi on November 16-20. On the 17th of November twylight reigned all day long, light was lit in houses and streets, automobiles moved with switched-on headlights. All street work was stopped. Sometimes the ash-fall intensified to such an extent that no lit windows and street lanterns were seen at a distance of 150-200 m.

In 24 hours the ash layer accumulated to 11.5 mm or 7.5 kg/m^2, reaching about 25 mm or 16 kg/m^2 by the end of November in Klyuchi. During November strong ash-falls occurred within a radius of 250 km. from the volcano. The explosions expanded the crater, its diameter became 700-800 m.

III. STAGE OF MODERATE ACTIVITY

From early December 1955 ash eruptions became weaker and rare. On January 25, 1956 the crater was thoroughly inspected by aircraft. The depth turned to be small with a bottom in the form of a sloping convex shield covered with pyroclastics. Evidently the November explosions expanded the crater and a dome began to grow. In February frequent, but weak, explosions were observed which gave rise to small incandescent avalanches. Comparing the earlier and late photographs it was found that the SW part of the volcano had risen. The height of the rise was established to be 100 m. Such a considerable rise suggests an extremely powerful magmatic pressure which could not have discharged itself by pressing up but one dome inside the crater.

IV. PAROXYSMAL EXPLOSION

Indeed, on March 30, 1956 the eruption reached its culmination. An enormous explosion occurred on that day and destroyed the top of the volcano and changed not only its shape but also the surrounding relief completely. This explosion and the accompanying phenomena are treated in a separate report ("Kamchatka Valley of Ten Thousand Smokes").

V. FINAL STAGE OF THE ERUPTION

Following the explosion on March 30 was the upheaval of an extrusive (endogenous) dome in the new crater. The growth of the dome was as usual followed by weak and moderate explosions and the formation of incandescent avalanches. At the end of July 1956 the formation of the dome was completed, its height reaching 320 m. above the crater bottom.

In late autumn 1956, the eruption ended entirely and in December, the dome, except the very summit, was already covered with snow.

EARTHQUAKES RELATED TO THE ERUPTION

The Bezymianny eruption was preceded and followed by numerous earthquakes. Their registration was made at the Klyuchi Volcanological Station, 45 km. from the volcano, with Kirnos seismographs with equal magnification 500 and intervals from 0.2 to 10 sec., as well as with Kharin seismographs with "peak" characteristics (magnification 10,000 at the period of 0.2 sec.). In both cases the registration was galvanometric on photographic paper.

The total number of shocks in Klyuchi for 9 months (from October 1955 to June 1956) was 33,150. The number of earthquakes and their energy are graphically expressed in fig. 1. The lower curve gives the summary figure of earthquakes for each decade in months, the upper the logarithm of seismic energy expressed in ergs for the same periods of time. As can be seen from the graph the number of earthquakes and their energy do not coincide. In the course of the eruption the number of earthquakes drastically changed, its energy being approximately on the same level for a long period of time.

In the pre-eruption stage the number of earthquakes and their energy rapidly increased and; by the end of that period the earthquake energy reached a constant value of the order of 10^{19} ergs per 24 hours whereas the number of earthquakes did not yet reached the maximum, being 200-220 shocks per 24 hours at the end of the period.

At the beginning of the eruptive stage the number of earthquakes rapidly reached maximum values of 350-400 per 24 hours. The drastic rise in number of earthquakes during that period was mainly due to very weak shocks which had practically no reflections on the energy balance. Corresponding computations showed that the drastic increase in the number of earthquakes could be stipulated by intensity rise of the explosions. By the end of the stage of intense ash eruptions a decrease of explosions occurred simultaneously with no less rapid lessening of the number of shocks. On November 24, 303 shocks were registered, while next day the number was down to 100 per 24 hours.

Later, such high values as in the middle of November were no longer observed.

Despite the fact that in December 1955 and January 1956 the number of earthquakes drastically dropped and the visible volcanic activity decreased considerably, the energy of earthquakes retained its former level and a further eruption progress was expected.

In February 1956 a certain rise in the number of shocks took place which is likely to be related to movements of the dome and explosions giving rise to incandescent avalanches.

From the end of February there was a steady decrease of earthquake energy. It seemed that the eruption had been exhausted and came to an end. But precisely at the moment of seismic energy drop a giant explosion took place on March 30 which produced a sharp "peak" on the energy curve. Following this "peak" the seismic energy dropped down to 10^{14} ergs per 24 hours by late June 1956.

Despite a general drop of seismic energy during the growing phase of the dome the number of shocks in April and May 1956 noticeably increased reaching 300 per 24 hours on some days of April. This rise of shocks was likely to be related to the processes of the dome growth. By the end of June 1956 the number of earthquakes lowered down to 1 per 24 hours. By this time the dome was already mainly shaped. Extremely weak seismic activity continued gradually decreasing till the end of 1956.

All earthquakes connected with the eruption of the Bezymianny Volcano differ much from the usual local tectonic and volcano-tectonic earthquakes by their large period (2.5 to 3.0 sec. instead of 0.2) and peculiar maximum phase after the arrival of S waves. All more or less large earthquakes were analogous in every detail and had the same source and cause; they had an increased depth (about 50 km.) and were likely to occur in the zone of a volcanic hearth or in the lower part of the volcanic chimney.

The number of earthquakes and partly their intensity are directly related to the course of the eruption but as has been mentioned already, the curve of the earthquake number and their energy did not coincided. The reason for this discrepancy is that in the computation of shocks all oscillations are taken into consideration including very weak earthquakes connected with volcanic explosions and other separate surface phenomena. As to the energetic characteristics it primarily depended on stronger shocks which all without exception had an enhanced depth and were caused by deeper volcanic processes determining the general variation of the eruption. Thus, a thorough analysis of the variations of seismic phenomena can not only help in predicting time and place of the forthcoming eruption but also helps to a certain extent to forecast the variations of the eruption underway.

ENERGETIC BALANCE OF THE ERUPTION

The energy of several separate earthquakes was computed from Galitzin-and-Jeffreys formulae and so far as the record nature and periods of all the shocks were completely analogous, the basis was assumed to deduce the empirical energy formula for that group of earthquakes by the seismographs of the Klyuchi Station:

$$\lg E = \lg A^2 + 13.45,$$

where E is the earthquake energy in ergs, A-ground displacements in microns. From that formula the energy of all the earthquakes was determined. The summary energy of all the earthquakes proved to be $E_1 = 2.3 \times 10^{21}$ ergs.

So far as during earthquakes in the form of seismic oscillations about 1/300 of the total energy is spent, the total tectonic energy released during the Bezymianny eruption is equal to approximately 7×10^{23} ergs.

Proceeding from the volume (ab. 3 km.^{3}) and mass (5.5×10^9 grams) of the agglomerate flow, from the thermal capacity of rocks (1.1×10^7 ergs) and original temperature of the eruptive substance (minimum of 600°), the thermal energy of the eruption is determined to be 3.6×10^{25} ergs.

Thus, the tectonic energy of the eruption makes for no more than 2 per cent of the thermal energy. Hence it follows that magmatic energy should be considered as the primary factor, and the seismic effects as the secondary factor of the eruptions.

The energy of the explosion on March 30, 1956 can be estimated in several ways:

1. Calculations were made of the energy of the earthquakes connected with the explosion. The mean energy from data of five seismic stations in

the Far East was found to be $E = 10^{20}$ ergs. Counting that about 0.1 percent of the total energy of the eruption is emitted as seismic oscillations, it was determined to be 10^{23} ergs.

2. The explosion energy can be estimated by the air wave of the explosion (Taylor's formula)

$$E = \frac{2\pi\ RH \sin\gamma}{{}^{s}\rho_{o}V} \int P_{o}{}^{2}dt$$

where R is the Earth's radius, H - the height of a homogeneous layer of the atmosphere (13,000 m.), v - sound velocity, ρ_o - air density at the Earth's surface, γ - distance from the explosion source in degrees, P_o - pressure, t - time.

The average value of the air wave from records of eight meteorological stations located at a distance of 45-780 km. from the volcano made for 3×10^{22} ergs. During the volcanic explosions about 10 per cent of the total energy transforms into the air waves. Hence the explosion energy is about 3×10^{23} ergs.

3. The explosion energy can be also determined by the mass and velocity of the material ejected by the explosion.

$$E = \frac{mv^2}{2},$$

The mass of the material ejected by the explosion is estimated to be 1.2×10^9 tons, the average initial velocity of the explosion is equally 360m/sec. Hence kinetic energy of the explosion is about 8×10^{23} ergs.

The mean value of the explosive energy on March 30 is equal to 4×10^{23} ergs. Thus, the explosion energy makes for only one per cent from the total thermal energy of the eruption. As it can be seen the share of gaseous energy is more than modest. From this point of view the known state by F. Perret: "gas is the active agent and the magma is vehicle" is not correct. It is evident that the main active force of the eruption is thermal energy of the magma while gas is only a transformer of that energy into an explosive one and the efficiency of a volcano as a heat engine is very low.

VOLCANIC ZONE OF THE KURILE ISLANDS

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The volcanic zone of the Kurile Islands was until recent one of the least studied volcanic zones of the Globe. The first information on some volcanoes was brought to Moscow by Cossack Kozyrevsky in 1713. A thorough description of several volcanoes was compiled in 1769 by I. Cherny. These data were published in German by P.S. Pallas in 1783 and have become widely known. After the transfer of the islands to Japan special volcanological investigations were conducted by J. Milne in 1878 and 1885. All further summaries repeated the data obtained by I. Cherny and J. Milne. The latter author reports 52 volcanoes from the Kurile Islands, of which 17 are active.

Japanese scientists (Tanakadate, etc.) published new data in European languages but only for the Taketomi crater, an adventive crater of the Alaïd Volcano, which originated in 1934. Our own investigations started in 1946 and were continued in 1951-1954. These investigations embrace, to a certain extent, all the islands of the archipelago, and permitted to get a general idea of nearly all active and of several extinct volcanoes of the Kurile Island arc. At least 89 volcanoes, including 39 active ones, were found.

The Kurile arc, like some other island arcs, is a double one. The outer arc forms the Small Kurile Ridge, the greater part of which is hidden under the ocean waters forming a submarine ridge, called the Paleokuriles in 1947 by the author, and thoroughly investigated by the Institute of Oceanology of the USSR Academy of Sciences in 1950-1951, with the expeditionary ship "Vityaz". The internal arc forms the Big Kurile Ridge, the place of concentration of recent volcanic activity.

The islands of the outer arc are composed of Cretaceous and Lower Tertiary sedimentary and volcano-sedimentary rocks with intrusions of gabbro-diorites.

The foundation of the internal arc is composed of sedimento-volcanogeneous rocks and intrusions of leucocratic plagio-granites and granodiorites of Upper Tertiary.

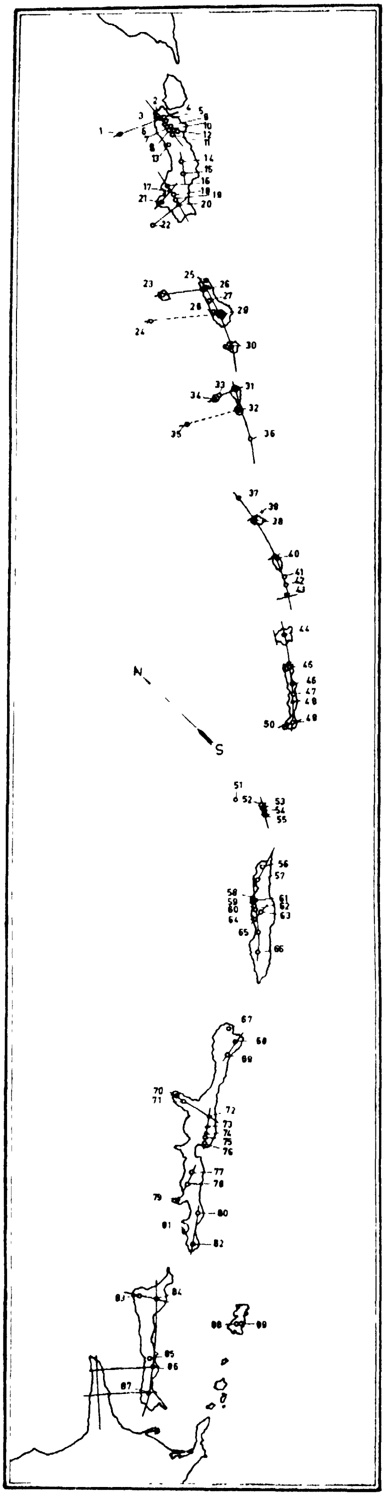
The map shows the location of active and extinct volcanoes. The numbers of the volcanoes are corresponding to those in table I. First of all, the eye is caught by a linear arrangement of the majority of the volcanoes along definite lines following in general the trend of the arc with, a NE direction. Nevertheless, the rows of volcanoes do not follow exactly the direction of the arc but intersect it somewhat obliquely forming comparatively short echelon sections, deviating northwards from the general trend of the arc. Especially distinct is the echelon structure of the volcanic rows in the northern part of the arc; in the larger southern islands, where much space is occupied by Tertiary rocks, the echelons are only expressed vaguely. It is interesting to note that the chains of Tertiary volcanoes have different directions, deviating form the trend of the Quaternary volcanoes eastwards by approximately 20°.

Besides the volcanic chains longitudinal to the trend of the arc, there are also transversal rows in north-western direction. There are reasons to believe that the transversal rows are younger that the longitudinal ones.

The most active recent volcanoes are usually situated in the transversal rows, especially at the intersection of longitudinal and transversal rows. In addition the "intersections" are the locations of the longest active volcanoes, from Early Quaternary, sometimes from the Late Tertiary epoch till Recent.

Table I gives the list of volcanoes of the Kurile Arc, geographical position and altitude, short characteristics of each volcano and date of the last eruption. The active volcanoes are underlined. Further investigations may lead to the discovery of more extinct volcanoes on the large islands of the arc, but the number of active volcanoes will hardly be changed.

From the table we see that form and structure of the volcanoes are very different. Stratovolcanoes are predominating, pure lava volcanoes are rare. The role of endogeneous (extrusive) domes is very significant. The prevailing form of the volcanoes is the Somma-Vesuvius-type, sometimes developed in such an excellent form as the Krenitsyn Peak or Tyatya; occasionally this type is complicated by erosion or tectonic disturbances.



Ideal single cones (Alaid, Prevost Peak, etc.) and well-developed calderas (Karpinsky, Lvinaya Past, etc) occur frequently. Caldera-walls are usually incomplete. Many active volcanoes have crater lakes (Ebeko, Pallas, etc).

The type of the latest eruptions is rather different. The prevailing type is Volcanian (Ebeko, Cherny, etc.), or Strombolian (Alaid, Chikurachki, Nemo Peak, etc.). Also violent eruptions of the Plinian type (Severgin, Raikoke, etc.) occur. Outpourings of extensive lava flows occur less frequently (Goryashchaya Sopka in 1881, Snow, Menshoy Brat in the Medvezhi Caldera). Widely spread are upheavals of endogeneous domes (Sinarka in 1878, Goryashchaya Sopka in 1883, etc.). Very often destructive incandescent avalanches come down along the slopes of volcanoes (Sinarka, Sarychev Peak, etc.).

Three big eruptions occurred since 1945: the Sarychev Peak erupted on Matua Is. in 1946, the eruption was characterized by strong incandescent avalanches the deposition of which changed the contours of the coastal line. In 1952 Krenitsyn Peak, the central cone of the big Caldera Tao-Rusyr on Onekotan Is., became active; at first a lateral explosive crater originated, then at the foot of the cone—a submarine one was formed in which an endogeneous dome developed. In 1957 an eruption took place in the crater lake of Zavaritsky Caldera on Simushir Is., which resulted in considerable changes of the contours of the northern part of the lake.

The petrographical and chemical composition of recent lavas is rather different. The dominant part of it belongs to pyroxenic andesites with rhombic and monoclinal pyroxene. Biotitic andesites can be encountered on Fuss Peak. Many volcanoes, especially those with pumiceous pyroclastics, produce acid hornblende andesites which are often transformed into dacites. Among lavas and slags frequently occur andesite-basalts and even basalts. Table II gives a few analyses of recent lavas.

The geological history of the Kurile arc before the Upper Mesozoic is not known. The Lower Cretaceous was accompanied by folding movements with intensive volcanic activity. The Upper Cretaceous was characterized by sea transgression and decrease of volcanism. In Late Mesozoic and Early Cenozoic orogenic movements, accompanied by basic intrusions took place, at the same time the Little Kurile arc was completed. In the Tertiary the area of the Big Kurile arc was a region of shoal water and intensive submarine and subareal volcanic activity. Between Miocene and Pliocene folding and intrusions of granite occurred, followed by a general upheaval and intensive erosion. During the Late Tertiary volcanism renewed its activity and continued till recent times. In the Quaternary upheaval and depression of land formed a number of submarine and subareal terraces. At present the region of the Big Kurile Ridge is lifted up, while the Little Kurile Ridge—is submerging.

At the beginning of the glacial period all modern calderas and sommas of complex volcanoes were formed. Two stages of congelation with weak volcanic activity during the interglacial were known on the northern islands. In post-glacial, and partly in interglacial time, modern central cones of the complex volcanoes and some simple volcanoes (Alaid, Fuss Peak, tentatively also Chirinkotan) originated. The Recent volcanic activity is but a weak remainder of that during the early part of the Quaternary.

Table 1
List of Volcanoes
on the Kurile Islands[1]

Name of volcano	*Geographic position*		*Height*
ALAID IS.			
1. *Alaid*	50°51′5	155°34′	2339
Isolated cone with adventive cones. Top eruption-1894, lateral-1934.			
PARAMUSHIR IS.			
2. Vetrovoy	50°43′	156°03′	1088
Much destroyed, pre-glacial.			
3. *Ebeko (Jo Ruko)*	50°41′	156°01′	1138
The pre-glacial somma destroyed, central cone with 3 craters, in one of which there is a warm lake. Eruptions in 1934/35.			
4. Neozhidanny. (Fusikei)	50°40′8	156°01′7	1066
Post-glacial cone with lava-flows.			
5. Slag cone.	50°40′5	156°01′3	900
The same.			
6. Nasedkin.	50°39′	156°00′	1152
Pre-glacial, destroyed.			
7. Bogdanovich.	50°37′	155°59′5	1056
Maar with a fresh lake.			
8. Kozyrevsky.	50°36′	156°00′	1161
Post-glacial cone with lava bocca.			
9. Krasheninnikov.	50°36′	156°00′5	950
Post-glacial cone with a large lava-flow.			
10. Bilibin	50°33′5	155°58′	1080
The same.			
11. Vernadsky. (Taise)	50°33′	155°57′5	1184
Destroyed volcano with traces of post-glacial activity.			
12. Levashov. (Mitsuga)	50°31′	156°04′	857
Pre-glacial, partly destroyed.			
13. Fersman. (Aragava)	50°30′5	155°50′	1052
Pre-glacial cone in a caldera.			
14. Arseniev. (Takahiza)	50°23′	155°48′	894
Tertiary caldera-volcano, destroyed.			
15. Levinson-Lessing. (Komaga)	50°17′	155°41′5	818
Tertiary, much destroyed.			
16. *Chikurachki*	50°19′5	155°27′5	1817
Post-glacial cone, on the edge of an ancient volcano. Erupted in 1853/59.			
17. *Tatarinov. (Oruka)*	50°18′5	155°26′5	1593
Pre-glacial caldera-volcano. Explosions in the post-glacial time. Solfatara activity.			
18. Lomonosov. *(Kamuri)*	50°15′	155°26′	1682
Complex volcano with post-glacial flows and domes.			
19. Arkhangelsky.	50°13′	155°25′	1463
Destroyed, pre-glacial.			
20. *Karpinsky. (Hakuen)*	50°09′	155°22′	1377
Pre-glacial caldera, with post-glacial effusion and explosions. Solfatara activity.			
21. *Fuss Peak.*	50°16′	155°15′	1772
Single cone. Erupted in 1854.			
SHIRINKA IS.			
22. Shirinka.	50°12′	154°59′	748
Isolated strato-volcano.			
MAKANRUSHI IS.			
23. Makanrushi.	49°47′	154°26′	1169
Destroyed caldera-volcano.			
AVOS ROCK			
24. Avos.	49°43′	154°06′5	34
Top of the ancient submarine volcano.			
ONEKOTAN IS.			

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[1] Active Volcanoes are italicized; notes refer to last eruption; height in meters.

Name of volcano	Geographic position		Height	
25. *Asyrmintar.*	49°36′	154°54′	570	Single strato-volcano. Erupted in 1938.
26. *Nemo Peak.*	49°34′	154°48′5	1019	Central cone in a large destroyed caldera Amka-Usy. Erupted in 1906.
27. Shestakov. (Encio)	49°28′5	154°44′	708	Ancient destroyed massive.
28. Kryzhanovsky.	49°25′	154°42′	551	Ancient caldera-volcano.
29. *Krenitsyn Peak.*	49°21′5	154°42′5	1325	Central cone in the form of an island in the caldera lake of the Tao-Rusyr Caldera. Erupted in 1952.
KHARIMKOTAN IS.				
30. *Severgin.*	49°07′	154°31′	1145	Low cone plugged up by the dome in a destroyed E somma. Erupted in 1933.
SHIASHKOTAN IS.				
31. *Sinarka.*	48°52′5	154°10′5	934	The somma destroyed by sector trough faults. A dome in the crater of the central cone. Erupted in 1878.
32. *Kuntomintar.*	48°45′5	154°01′	828	Semi-caldera with a small central cone. Erupted in 1872.
ECARMA IS.				
33. Eastern Ecarma.	48°57′	153°58′	796	Destroyed volcano.
34. *Ecarma.*	48°57′	153°56′5	1171	Single strato-volcano. Erupted in the 1760-ies.
CHIRINKOTAN IS.				
35. *Chirinkotan.*	48°59′	153°29′	742	Post-glacial caldera-volcano. Erupted in the 1880-ies.
LOVUSHKI ROCKS				
36. Stone Lovushki.	48°32′	153°51′	42	Top of an ancient submarine volcano.
RAIKOKE IS.				
37. *Raikoke.*	48°15′	153°15′	551	Single cone. Erupted in 1924.
MATUA IS.				
38. *Sarychev Peak.*	48°05′5	153°12′	1498	Central cone with destroyed somma. Erupted in 1946.
39. *Submarine.*	48°05′	153°20′		Two submarine eruptions in 1924.
RASSHUA IS.				
40. *Rasshua.*	47°46′	153°01′	956	Destroyed somma with 4 cones. Erupted in 1846.
SREDNY STRAIT				
41. Karlic. (Dwarf)	47°39′	152°57′	1	Summit of a submarine volcano.
SREDNY ISLETS				
42. Sredny.	47°35′	152°52′	27	Summit of an ancient submarine volcano.
USHISHIR ISLES				
43. *Ushishir.*	47°31′	152°49′	401	Somma divided into two small isles, a crater bay with residues of the central cone and domes-in a caldera. Phreatic eruption in 1884. Solfataras.
KETOY IS.				
44. *Pallace Peak.*	47°21′	152°28′5	993	Excentric cone with a hot lake in the crater on the edge of the Ketoy Caldera (1172 m). Erupted in 1924.
SIMUSHIR IS.				
45. Uratman.	47°07′5	152°14′	679	Partly destroyed cone in a caldera occupied by a crater bay down to 266 m in depth.
46. *Prevost Peak.*	47°01′	152°07′	1361	Isolated cone, Erupted early in the XIX century.
47. Ikanmikot.	46°58′	152°04′	645	Destroyed cone.
48. *Zavaritsky. (Midori-Ko)*	46°55′5	151°57′	625	Two inside caldera-volcanoes. In the inner caldera a lake with slag cone and two domes. Erupted in 1957.
49. Milne.	46°49′	151° 47′	1539	Somma destroyed from SE, the central cone plugged up with a dome.
50. *Goryashchaya Sopka. (Glowing Mountain)*	46°50′	151°45′	890	Strongly destroyed somma, the central cone crater plugged up with a dome; large lava-flows. Erupted in 1944.
BROUGTON IS.				
51. Brougton.	46°43′	150°44′	800	Destroyed stratovolcano.

Name of volcano	Geographic position		Height	
BLACK BROTHERS ISLES				
52. Chirpoi. (Daiho)	46°32′	150°52′5	691	Destroyed double strato-volcano.
53. *Cherny (Io-san)*	46°31′5	150°52′5	624	Single cone with adventive craterlets. Erupted in 1857.
54. *Snow.*	46°31′	150°52′5	400	Single lava cone with abundant lava-flows. Erupted in 1879.
55. *Chirpoev Brat.*	46°28′	150°48′5	752	Much destroyed somma with a central cone. Fumarolic activity in the XVIII century.
URUP IS.				
56. Desantny. (Daisanto)	46°11′	150°23′	866	Tertiary volcanic massive.
57. Antipin. (Zurigane)	46°09′	150°14′	1222	Cone destroyed from the south.
58. *Trezubets. (Trident)*	46°04′	150°07′	1018	Somma destroyed in N (1222 m.). The central cone a dome with an explosive crater. Erupted in 1845/46.
59. *Berg.*	46°04′	150°05′	900	Somma in N destroyed (1108). The central cone a dome with small flows. Erupted in 1951/52.
60. Caldera.	46°04′	150°03′	1100	Ancient caldera with NW destruction.
61. *Kolokol. (Bell)*	46°03′	150°03′5	1326	Single cone with a destroyed crater. Erupted in 1894(?).
62. Borzov.	46°03′	150°03′	1120	Destroyed single cone.
63. Kavraisky.	45°57′5	150°03′5	842	Tertiary cone.
64. Tri Sestry. (Three Sisters)	45°55′5	149°54′	999	Much destroyed volcano with traces of recent fumarolic activity.
65. Rudakov. (Daiba)	45°52′	149°49′	543	Single cone with a freshwater lake.
66. Ivao.	54°44′	149°40′	1426	Complex volcano with a lake in the destroyed crater. Post-glacial lava flows.
ITURUP IS.				
67. Kamui.	45°31′	148°49′	1323	Ancient caldera-volcano, destroyed from NE.
68. *Medvezhiy.*	45°23′	148°48′	1125	Partly destroyed somma. Three central cones: Kudryavy (988), erupted in 1883; Menshoi Brat (563 m) violent lava-flows.
69. Caldera.	45°21′	148°47′	854	Ancient, nearly completely closed.
70. *Chirip.*	45°23′	147°55′	1564	Single cone on the ancient caldera edge. Erupted in 1860.
71. Bogdan Khmelnitsky	45°20′	147°55′	1589	Partly destroyed strato-volcano.
72. *Baransky. (Jiusu)*	45°06′	148°02′	1126	Single cone with a lava plug in the crater. Erupted in 1951.
73. *Tebenkov. (Kotamoi)*	45°01′	047°55′	1212	Extinct central cone, with a large explosive crater Machekha with fumarolic activity on the somma slope.
74. *Ivan Grozny. (Sio)*	45°00′5	147°52′	1158	Very complex volcano, much destroyed somma. At the summit of the central cone three domes. In the atrio endogeneous and exogeneous domes. Solfataras.
75. Motonopuri.	44°59′5	147°50′	953	Ancient strato-volcano.
76. Rebunshiri.	44°58′5	147°48′	782	Ancient strato-volcano.
77. Burevestnik. (Onneto)	44°52′5	147°27′5	1427	Ancient destroyed volcano.
78. Stokap.	44°50′	147°20′	1566	Ancient strato-volcano with traces of post-glacial activity.
79. *Atsonupugri.*	24°49′5	147°07′5	1205	Isolated cone with residues of somma on its slope. Erupted in 1932.
80. Urbich.	44°38′	147°12′	907	Ancient caldera-volcano with a lake.
81. Lvinaya Past. (Moikesi)	44°37′	147°00′	403	Ancient caldera-volcano with a bay down to 460 m in depth.
82. *Berutarube.*	44°28′	146°56′	1222	Destroyed shield volcano with post-glacial flows. Solfataras.

Name of volcano	*Geographic position*		*Height*
KUNASHIR IS.			
83. Rurui.	44°27′	146°08′	1486
Single strato-volcano with a destroyed crater.			
84. *Tyatya.*	44°21′	146°15′	1822
Somma with well-preserved fine caldera. A small central cone with lava flows into the caldera mouth. Erupted in 1812.			
85. Otdelny.	44°02′	145°46′5	476
Destroyed volcano.			
86. *Mendeleev.* *(Rausu)*	43°59′	145°42′	890
Somma and central cone partly destroyed. A dome in the crater, destroyed lateral craterlets on the slopes. Erupted in 1880.			
87. *Golovnin.* *(Tomari)*	43°53′	145°32′	547
Caldera-volcano with a deep freshwater lake. Two domes and explosive craters in the caldera, a hot lake in one crater. Erupted in the XIX cent.			
SHIKOTAN IS.			
88. Notoro.	43°46′5	146°41′	358
Ancient destroyed cone.			
89. Tomari.	43°46′	146°44′	356
Ancient destroyed cone.			

Table 2.
Chemical Analysis of Lavas of the Kurile Volcanoes.

Samples	1	2	3	4	5	6	7
SiO_2	50.29	51.75	53.33	54.80	58.07	61.91	65.30
TiO_2	1.28	1.20	0.95	0.73	0.68	0.75	1.22
Al_2O_3	18.96	17.20	18.60	18.84	17.21	16.89	15.84
Fe_2O_3	3.44	3.95	4.21	5.79	3.61	3.14	3.08
FeO	6.75	7.58	4.63	2.30	4.23	3.89	2.40
MnO	0.33	0.22	0.18	0.16	0.16	0.21	0.14
MgO	4.14	4.02	4.00	3.70	3.04	2.20	1.70
CaO	10.25	10.32	9.34	8.60	7.41	5.96	5.12
Na_2O	2.85	2.12	3.38	2.67	3.19	3.21	3.70
K_2O	1.25	0.96	1.09	2.22	2.02	1.01	1.65
H_2O	0.20		0.21	0.10	0.10	0.32	0.13
H_2O	0.09	0.51	——	0.30	0.28	0.62	0.11
P_2O_5	0.40	0.50	n.d.	0.05	0.02	n.d.	0.09
S	0.02	n.d.	n.d.	0.06	0.05	n.d.	n.d.
Total	**100.25**	**100.33**	**99.92**	**100.32**	**100.07**	**99.75**	**100.48**

No. 1 — Andesite-basalt, Volc. Alaid, Crater Taketomi, eruption 1934. Coll. Tanakadate, anal. Jap. Geol. Survey.

No. 2 — Andesite-basalt, Volc. Tiatia, eruption 1812? Coll. Zhelubovsky.

No. 3 — Andesite-basalt, Peak Sarychev, eruption 1946, Coll. Gorshkov, anal. Tovarova.

No. 4 — Biotite-andesite, Peak Fuss, coll. Gorshkov, anal. Posnikova.

No. 5 — Andesite, bread-crust bomb, Volc. Ebeko, eruption 1935. Coll. Gorshkov, anal. Tovarova.

No. 6 — Andesite, Peak Krenitsyn, ash, eruption 1952. Coll. Piip, anal. Tovarova.

No. 7 — Dacite, dome, volc. Mendeleev, coll. Gorshkov, anal. Tovarova.

REFERENCES

Gorshkov, G.S., Catalogue of the active volcanoes of the World, Part VII Kurile Islands. Int. Volc. Ass. Napoli (in press).

Kuno, H., 1935, Petrology of Alaid volcano. *Jap. Journ. Geol. Geogr.* **12** : (3-4), Tokyo.

Milne, J., 1886, The volcanoes of Japan. *Trans. Seism. Soc. Japan*, **9**, (2), Yokohama.

Tatarinov, M., 1783, Neue Beschreibung der Kurilischen Inseln. Neue Nordische Beiträge, Bd. **4**. SPb.

TO THE QUESTION OF CAINOZOIC VOLCANISM IN SOUTHERN SAKHALIN

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(Abstract)

In the thick section of Tertiary deposits of Southern Sakhalin a substantial place is occupied by volcanic rocks. Their presence is associated with manifestations of three independent phases of effusive volcanism on the island. The main manifestations of the first phase relate to Lower Miocene; of the second, to Middle Miocene and the third, to the second half of Pliocene.

Intrusive manifestations were associated with all three phases of volcanic activity. On a limited part of Southern Sakhalin without an apparent relation to effusive volcanism an injection of basic magmas of an increased alkalinity into the subsurface parts of the crust took place with a formation of hypabyssal bodies. The age of the subalkaline intrusions is approximately Lower Pliocene. Manifestations of volcanicity on Southern Sakhalin took place on the background of its geosynclinal development during the Tertiary period.

From the chemical point of view the products of all phases of effusive volcanism form a normal calcareous-alkaline series, while the products of independent hypabyssal injections form a subalkaline series.

A PRELIMINARY ACCOUNT OF CRETACEOUS TO RECENT VOLCANIC ACTIVITY IN RELATION TO THE GEOLOGICAL STRUCTURE OF BRITISH BORNEO

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INTRODUCTION

This preliminary account summarizes information gained to-date from the systematic regional geological survey of British Borneo now in progress under the direction of F.W.Roe, Director, Geological Survey Department. Information on the volcanic rocks of east Sarawak is mainly from surveys by the author; work published on other parts of British Borneo which has been referred to is given in the list of references. A more comprehensive account, including further work on the volcanic rocks of North Borneo, will be given when the writer has completed his regional study of the igneous rocks of British Borneo, and regional surveys now in progress have been completed.

British Borneo is built mostly of Upper Mesozoic and Cainozoic sedimentary rocks laid down during the development of the Cretaceous to Recent geosyncline, and most fully developed in the central and northern region. The main events in the history of the geosyncline are summarized in table 1, and figure 1 shows the distribution of volcanic rocks in relation to the Cretaceous and Tertiary sediments. The Palaeozoic and Mesozoic rocks of west Sarawak, west of the Lupar Valley, belong to the stable block of the Sunda Shelf which extends over much of western Kalimantan, the South China Sea, and the Malayan Peninsula. Extensive subsidence during Cretaceous times in the central and northern area initiated the development of the geosyncline when it was marked by the deposition of great thicknesses of Cretaceous and Lower tertiary sediments in the resulting, wide, trough-shaped depression. These sediments, the Rajang Group, which are at least 45,000 feet thick in southern Sarawak, were strongly folded and uplifted during Upper Eocene times in Sarawak, and in the Lower Eocene and Oligocene times in North Borneo. They form a zone of highly folded sedimentary rocks which is one of the main structural features of the region. The thick Upper Tertiary and later sediments have accumulated in basins along the margins of the uplifted older sediments.

VOLCANIC ROCKS

Two main periods of volcanic activity, associated with the structural development of the geosyncline, have occurred as follows:

(i) *Basalt-spilite association* consisting of pretectonic extrusive occurrences of basalt and spilite, interbedded with the Cretaceous and Eocene sediments of the first, and main, phase of sedimentation. A little rhyolite also occurs but is relatively rare.

(ii) *Basalt-andesite-dacite association* formed during widespread eruptions of volcanic rocks during Upper Tertiary and Quaternary times which took place from volcanic centres situated on the areas of folded Cretaceous and Lower Tertiary sedimentary rocks.

BASALT-SPILITE ASSOCIATION IN SARAWAK

In the Lupar Valley, in southwestern Sarawak, an outcrop of Danau Formation, about ten miles wide, comprising mainly shale, chert, marl and limestone, with associated basalt and spilitic lavas and pyroclastic rocks, extends westwards from the Lakes (lake = Danau in Malay and this is the type locality for the Danau formation) area of Kalimantan. The formation which has been dated by foraminifera to be mainly Cretaceous and partly Paleocene and Lower Eocene, is contemporaneous with the lower part of the thick geosynclinal facies of the Rajang Group lying to the northeast of the Danau Formation outcrop. West of the Lupar Valley, sediments of similar age are restricted to the Kuching-Bau area where a relatively thin sequence of Cretaceous sediments of calcareous shelf-facies occurs. It therefore appears that the volcanic activity in the Lupar area occurred at the southwestern

Table 1
Igneous Activity associated with the British Borneo Geosyncline

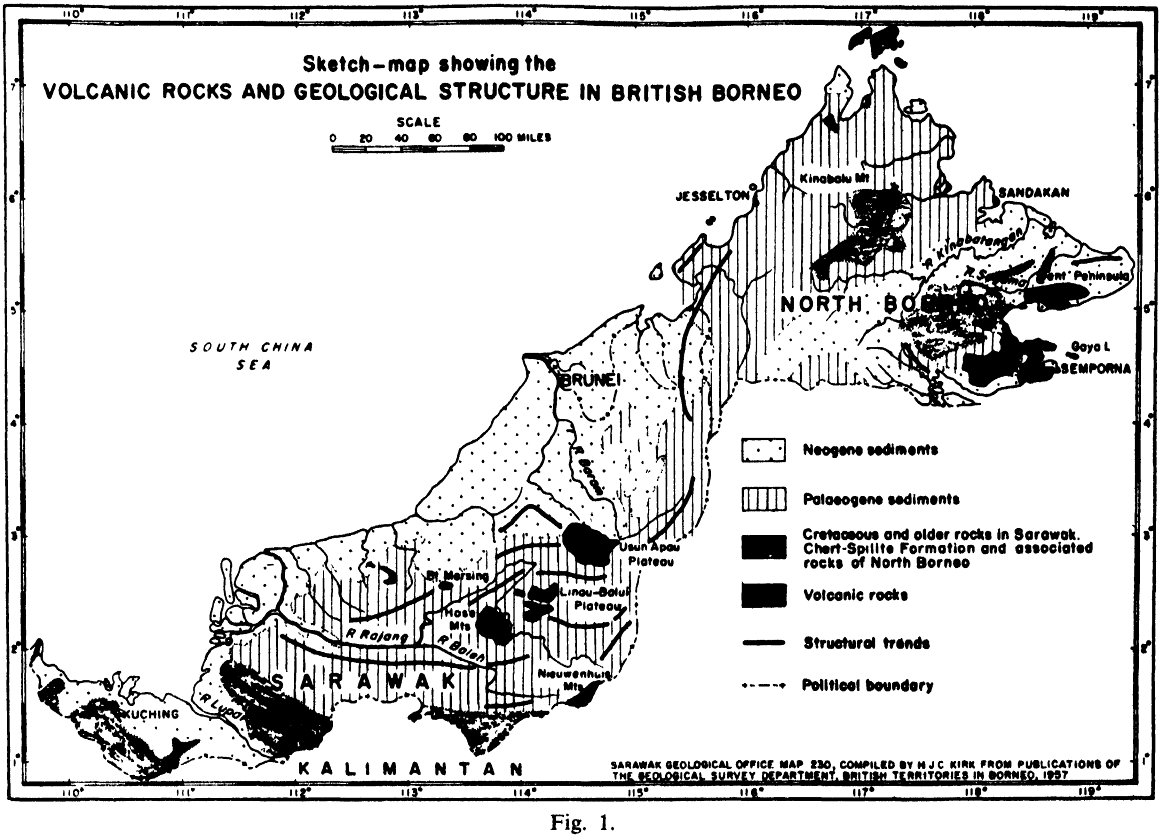
	Sarawak – Brunei				North Borneo			
	Earth Movements	*Main Sediments*	*Volcanic Rocks*	*Intrusive Rocks*	*Earth Movements*	*Main Sediments*	*Volcanic Rocks*	*Intrusive Rocks*
QUATERNARY	*Uplift and Orogeny in N Sarawak-Brunei*	*Alluvium and coastal deposits*	*Basalt lavas of Usun Apau and Linau areas Dacitic tuff in the Usun Apau*	*Dacite porphyry intrusions in the Usun Apau*		*Alluvium and coastal deposits*	*Basalt, andesite, dacite and rhyolite tuff in Semporna and Segama area*	
PLIOCENE		*Thick clastic sediments of N Sarawak and Brunei*	*About 3,000 feet of andesite and basalt in the Nieuwenhuis Mountains* *About 5,000 feet of dacitic rocks in the Hose Mountains*	*Tonalite porphyry of Bukit Kalulong* *Basalt, andesite, and lamprophyre, and adamellite minor intrusions of the upper Rajang* *Gabbro, diorite, and minor granitic intrusions of the Kuching area*	*Orogeny ?*			
MIOCENE	*Uplift and Orogeny*	*Over 16,000 feet of clastic Sediments in central and N Sarawak (Setap and Belait Group)*			*Orogeny in east*	*About 20,000 feet of clay, shale, sandstone, and limestone in south, northeast and north N Borneo (Bongaya Formation)* *Over 10,000 feet of sandstone and shale in central N Borneo (Tongod Formation)*	*Andesite lava and tuff of eastern N Borneo*	
OLIGOCENE		*Over 6,000 feet of clastic sediments in central Sarawak (Buan Group)*			*Major Orogeny and uplift in west*			*Granodiorite of Kinabalu*
EOCENE	*Uplift and Orogeny* *Probable Orogeny*	*Over 45,000 feet of Cretaceous-Eocene Graywacke, shale, slate and phyllite forming Rajang Group of E and S Sarawak*	*Thin rhyolites in central Sarawak* *Over 5,000 feet of basalt and spilitic rocks in central Sarawak*	*Microgranodiorite, dacite microtonalite, and quartz andesite intrusions of Kuching area* *Large intrusions of granite and granodiorite in west Sarawak*	*Orogeny in west*	*Over 10,000 feet of shale with sandstone in the Kalabakang area* *Thick sandstone and shale of the Crocker Range* *Thick sandstone, chert, shale, and limestone of Chert-Spilite Formation of Segama Labuk and Kudat areas*	*Basalt, spilite, and tuff associated with the Chert-Spilite Formation*	*Extensive peridotite dunite gabbro, and banded diorites of east, central and N Borneo* *Minor intrusions of basalt and spilite in the Chert-Spilite Formation*
CRETACEOUS		*Thick shale, sandstone, chert, and limestone of the Danau formation in Lupar and Usun Apau areas*	*Basalt and spilite of Lupar and Usun Apau areas*	*Dolerite sills in the Lupar area*				

edge of the geosyncline. The regional strike of the volcanic rocks is west-northwest and this marginal volcanic zone may extend as far as the Natuna Islands where basic volcanic and intrusive rocks associated with radiolarian cherts occur (van Bemmelen, 1949. p. 303). In the Northern Usun Apau area a narrow faulted outcrop of Cretaceous rocks of Danau Formation facies, containing flows of basalt and spilite, is present along the northern edge of the steeply folded belt of the Rajang Group. These volcanic rocks appear to occupy an analogous position on the northern side of the Cretaceous to Eocene belt of geosynclinal sedimentation, to those on the southern side in the Lupar area.

At Bukit Mersing, in central Sarawak, basic volcanic rocks, mainly basalt lavas, some showing pillow structure and spilitic composition, and thick beds of tuff and agglomerate, form a lens with a maximum thickness of over 5,000 feet. The volcanic rocks are intercalated in steeply dipping Upper Eocene sediments on the northern margin of the geosynclinal facies of the Rajang Group, and were evidently extruded from a volcano of central type situated on the northern margin of the geosyncline in the closing phases of this period of sedimentation, before the strong folding movements in the Upper Eocene occurred. Thin flows of rhyolite are intercalated in later Eocene sediments of the Arip Valley and were deposited after the main orogeny.

BASALT-ANDESITE-DACITE ASSOCIATION IN SARAWAK

Eruptions of basalt-andesite-dacite, and rhyolite have occurred from widespread volcanic centres active from the Miocene to the Quaternary. The main volcanic districts (see fig. 1) are in the Hose Mountains, Nieuwenhuis Mountains, Linau-Balui and Usun Apau areas of eastern Sarawak, and in numerous localities in central and southern Kalimantan. The distribution of the volcanic activity in British Borneo shows a close relationship to the structural history of the geosyncline; without exception the volcanic centres lie on,

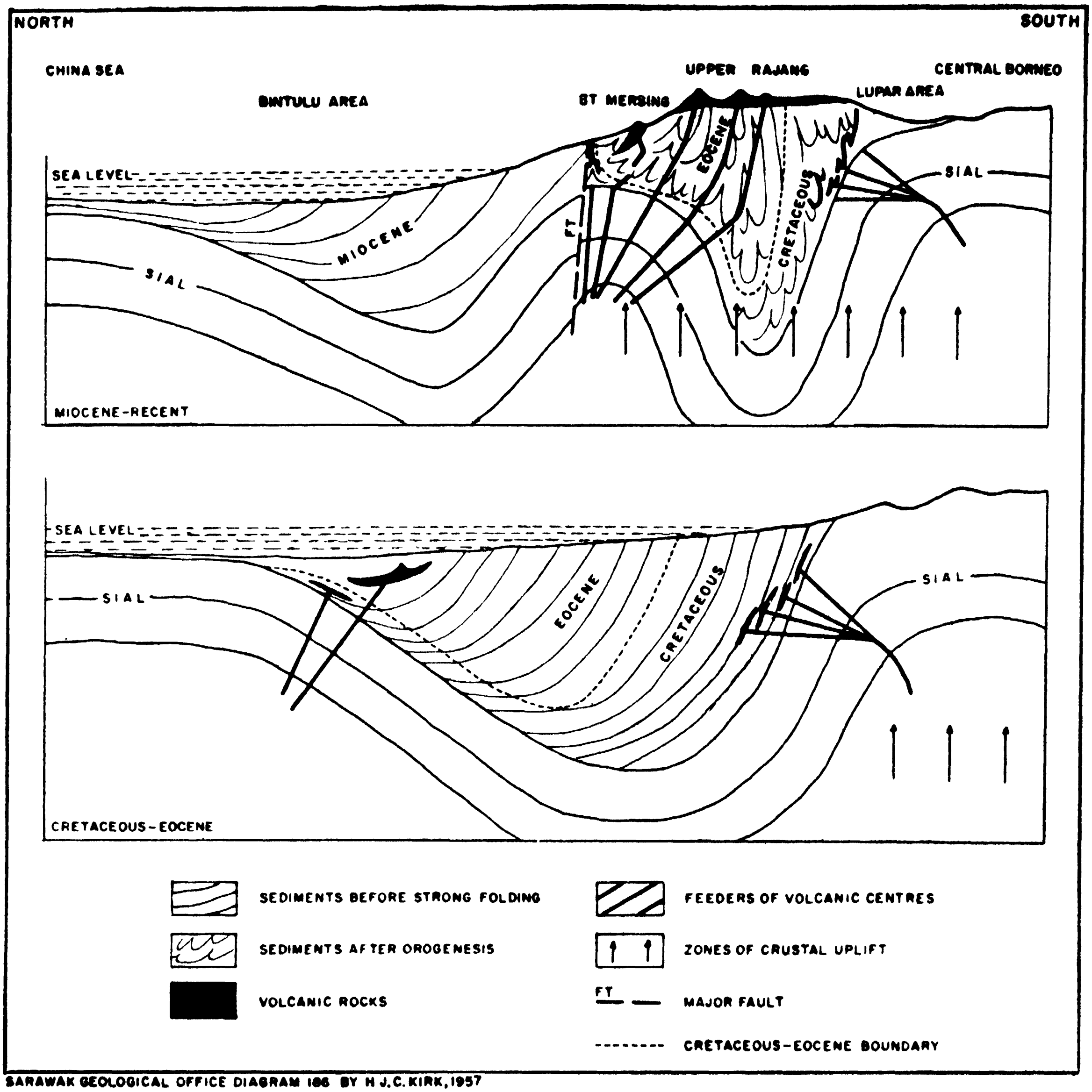


SARAWAK GEOLOGICAL OFFICE MAP 230, COMPILED BY H J C KIRK FROM PUBLICATIONS OF THE GEOLOGICAL SURVEY DEPARTMENT, BRITISH TERRITORIES IN BORNEO, 1957

Fig. 1.

or near, uplifted areas of folded Cretaceous and Lower Tertiary sediments, around which the sedimentation basins, of the Upper Tertiary and Quaternary rocks were formed. The volcanic belt is a continuation of the Tertiary to Recent volcanic arcs of the Philippines, the vulcanicity in eastern North Borneo being an extension to the chain of young volcanic centres along the Sulu arc.

In the upper Rajang Valley of eastern Sarawak eruption of great thicknesses of mainly pyroclastic dacitic and andesitic volcanic rocks occurred during the Pliocene, and continued until Quaternary times in the Usun Apau area. In the closing stages of the volcanicity basalt lava of late Pliocene and Quaternary age was erupted from several centres in the Usun Apau and Linau-Balui areas. In the Usun Apau, Linau-



SARAWAK GEOLOGICAL OFFICE DIAGRAM 186 BY H J.C. KIRK, 1957

Fig. 2.

Balui area, and the Nieuwenhuis Mountains, the positions of the volcanic centres show possible relationships to the structure of the steeply folded underlying sedimentary rocks; they are located in areas where marked changes occur in the regional strike (see fig. 2). From the Usun Apau vents it is estimated that about 50 cubic miles of dacitic pyroclastic rocks were erupted. These vents are situated where the regional strike of the underlying sediments changes from west-northwest to east-northeast and northeast; in addition, to the north and east of the vents there are marked local changes in strike of the sediments. The basalt lavas of the Linau-Balui area lie across the hinge region of a change in regional strike of the isoclinally folded Eocene sediments; on the western side of the basalt outcrop the regional strike is to the northeast, whereas on the eastern side the strike has changed to east-southeast. The volcanic centres of the Nieuwenhuis Mountains are situated where the regional strike of the underlying folded Cretaceous sediments changes from east-northeast in the upper Baleh Valley, to between northeast and north-northeast to the north of the areas.

TECTONIC EVOLUTION AND VOLCANICITY IN SARAWAK

Figure 2 illustrates the tectonic evolution and mode of occurrence of volcanic rocks associated with the geosyncline in Sarawak. Early in Cretaceous times an uplift of the stable block of Mesozoic and older rocks forming western Borneo, and a subsidence of the sialic layer adjoining its northern margin, started the development of a tectogene in which over 45,000 feet of Cretaceous and Eocene sediments were deposited. The deposits were thickest along the steep southern limb of the tectogene, nearest the main source of sediment, and thinned towards the northern side of the geosyncline. Intense distortion of the sialic crust occurred at the northern margin of the thick sialic layer of the Sunda Shelf area of western Borneo, where it joined the sialic layer forming the southern limb of the tectogene, and, to a lesser extent, in the zone of bending of the sial in the incipient geanticline on the northern limb of the tectogene. Crustal flexures in these areas formed zones along which the magma could move and gave rise to the Cretaceous and Eocene volcanic activity of the basalt-spilite association in the Lupar, northern Usun Apau, and Bukit Mersing areas.

During the Upper Eocene period of orogenesis Eocene and Cretaceous sediments were strongly folded and thereafter behaved as an extension to the core of older Sunda Shelf rocks. During the orogenesis, a new downfold of the crust was created north of the belt of folded Cretaceous and Palaeogene sediments, and became the subsiding basin in which the Miocene sediments accumulated. The sialic crust, thickened immensely by the layer of Cretaceous and Eocene sediment, became the site of isostatic uplift, causing major faulting south of the Miocene basin (in the Usun Apau and Belaga area) along lines of weakness at the crest of the now fully developed geanticline. During the Upper Tertiary orogeny, the southerly directed compressional movements strongly folded the Miocene rocks, and forced large quantities of basalt, andesite, and dacite magma through the weakened portion of the crust to cause the widespread Miocene-Quaternary volcanic activity.

VOLCANIC ACTIVITY IN NORTH BORNEO

In North Borneo, Cretaceous to Eocene volcanic activity which led to the formation of the basalt-spilite association was more widespread than in Sarawak. It may be inferred that this is a basement formation on which the younger Tertiary formations were deposited. Large and scattered outcrops of these Cretaceous and Lower Eocene deposits containing volcanic rocks occur in eastern North Borneo, the Labuk area, Kudat Peninsula, and on Banggi Island (see fig. 1). Unlike Sarawak, the volcanic activity of the basalt-spilite association appears to have been along a broad belt occupying the major part of the geosyncline in which the rocks of the Chert-Spilite Formation were deposited. The volcanic rocks appear to be associated with a peridotite-gabbro-diorite association of Lower Tertiary plutonic rocks which occur abundantly in eastern North Borneo.

Upper Tertiary and Quaternary volcanic rocks occurring in the Semporna and Dent Peninsula area have been described by Reinhard and Wenk (1951, pp. 31-47) and Fitch (1955, pp. 50-54) who considered the volcanic centres to be a continuation of the chain of young volcanoes along the Sulu arc. At the beginning of the Lower Miocene, small volcanic eruptions produced andesitic tuffite and agglomerate, interbedded among marine Aquitanian sediments, exposed in the lower River Segama, and in an outlier of Aquitanian rocks west of Darvel Bay. More extensive volcanic activity occurred in Quaternary times in the Segama Valley and on Semporna Peninsula where olivine basalt, basalt, andesite, dacite and rhyolite lavas and pyroclastic rocks were extruded in subaerial eruptions to form widely distributed plateaux, terrace features and valley infillings. Gaya Island east of the Semporna Peninsula, is a partially eroded volcano built of andesitic pyroclastic material, probably ejected in Quaternary times.

REFERENCES

Campbell, C.J., 1956, Geology of the Usun Apau area. *Brit. Borneo Geol. Survey Ann. Rept.*, 86-120.

van Bemmelen, R.W., 1949, The Geology of Indonesia, Government Printing Office, The Hague.

Fitch, F.H., 1955, The Geology and Mineral Resources of part of the Segama Valley and Darvel Bay area, North Borneo. *Brit. Borneo Geol. Survey Mem.* **4**, Government Printing Office, Kuching, Sarawak.

Haile, N.S., 1954, The Geology and Mineral Resources of the Strap and Sadong valleys, West Sarawak, including the Klingkang Range coal. *Brit. Borneo Geol. Survey Mem.* **1**, Government Printing Office, Kuching, Sarawak.

Reinhard, M. and Wenk E., 1951, The Geology of the Colony of North Borneo. *Brit. Borneo Geol. Survey* Bull. **1**, (H.M.S.O., London).

Roe, F.W., 1954, An outline of the geology of British Borneo. *Brit. Borneo Geol. Survey Ann. Rept.*, 6-22.

Stephens, E.A., 1956, The geology and mineral resources of the Kota Belud and Kudat area, North Borneo: *Brit. Borneo Geol. Survey Mem.* **5**, Government Printing Office, Kuching, Sarawak.

Wilford, G.E., 1955, The geology and mineral resources of the Kuching-Lundu area, West Sarawak, including the Bau mining district: *Brit. Borneo Geol. Survey Mem.* **3**, Government Printing Office, Kuching, Sarawak.

LATE TERTIARY AND QUATERNARY VOLCANICITY AND STRUCTURE IN NEW ZEALAND

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(Abstract)

In New Zealand, two regions of upper Tertiary and Quaternary volcanism are separated by a non-volcanic region. The volcanic regions are comparatively stable and characterised by high-angle normal faulting. The non-volcanic region is more mobile and characterised by steep clockwise transcurrent faulting.

One volcanic region occupies the north-west half of North Island, and is divided into three petrographic and structural belts striking north-west, and a fourth striking north-east. In the north-west a central basalt province is bordered by andesite and andesite-rhyolite provinces. The western province, ranging from hypersthene to hornblende andesite, reached a maximum in the Miocene and became extinct in the Pliocene. The central basalt province began in the Miocene, culminated in the Pliocene with immense sheets and central-volcanoes of flood basalt, and is still active around Auckland city with young volcanoes of picritic and basanitic olivine-basalt. The eastern province was continuously active through the Miocene and Pliocene, passing through, probably at least two andesite-dacite rhyolite cycles, culminating in great sheets of ignimbrite and rhyolite.

In the late Pliocene or early Quaternary, the north-east volcanic belt became active across the centre of the island, overlapping slightly the southeast ends of the earlier north-west belts. Activity has been continuous with further ignimbrite eruptions, rhyolite, dacite and central andesite-volcanoes. North-east trending graben structures formed between Lake Taupo and the Bay of Plenty by subsidence along innumerable active faults. These grabens have since filled with pumice flows and pumiceous sediments. Three andesite and one rhyolite volcano are still active, thermal springs abound, and catastrophic pumice eruptions have occurred up until modern times.

The north-west volcanic belts are now tectonically and seismically stable and align with an older trend joining New Zealand to New Caledonia. The north-east volcanic belt aligns with the Kermadec-Tonga volcanic arc and parallels major tectonic features developing since the Miocene. It is bordered on the south-east by a major negative gravity anomaly and coincides with a zone of intermediate-focus earthquakes, the near-vertical boundary of the deep seismicity coinciding with the western boundary of the active volcanism. Tensional-transcurrent faulting and post-Oligocene basins of thick marine sedimentation characterise the negative-gravity belt. To the south-east a wide belt of compressional-transcurrent faulting includes most of the young mountain ranges of New Zealand. In the South Island, the volcanicity ranges from late Miocene to early Quaternary and lies east of the high mountains in the stable coastal area. The volcanoes are basaltic with trachytes and phonolites. In Foveaux Strait, the Solander Islands are hornblende-andesite volcanic remnants and lie close to the edge of the compressional belt in a zone of moderate seismicity.

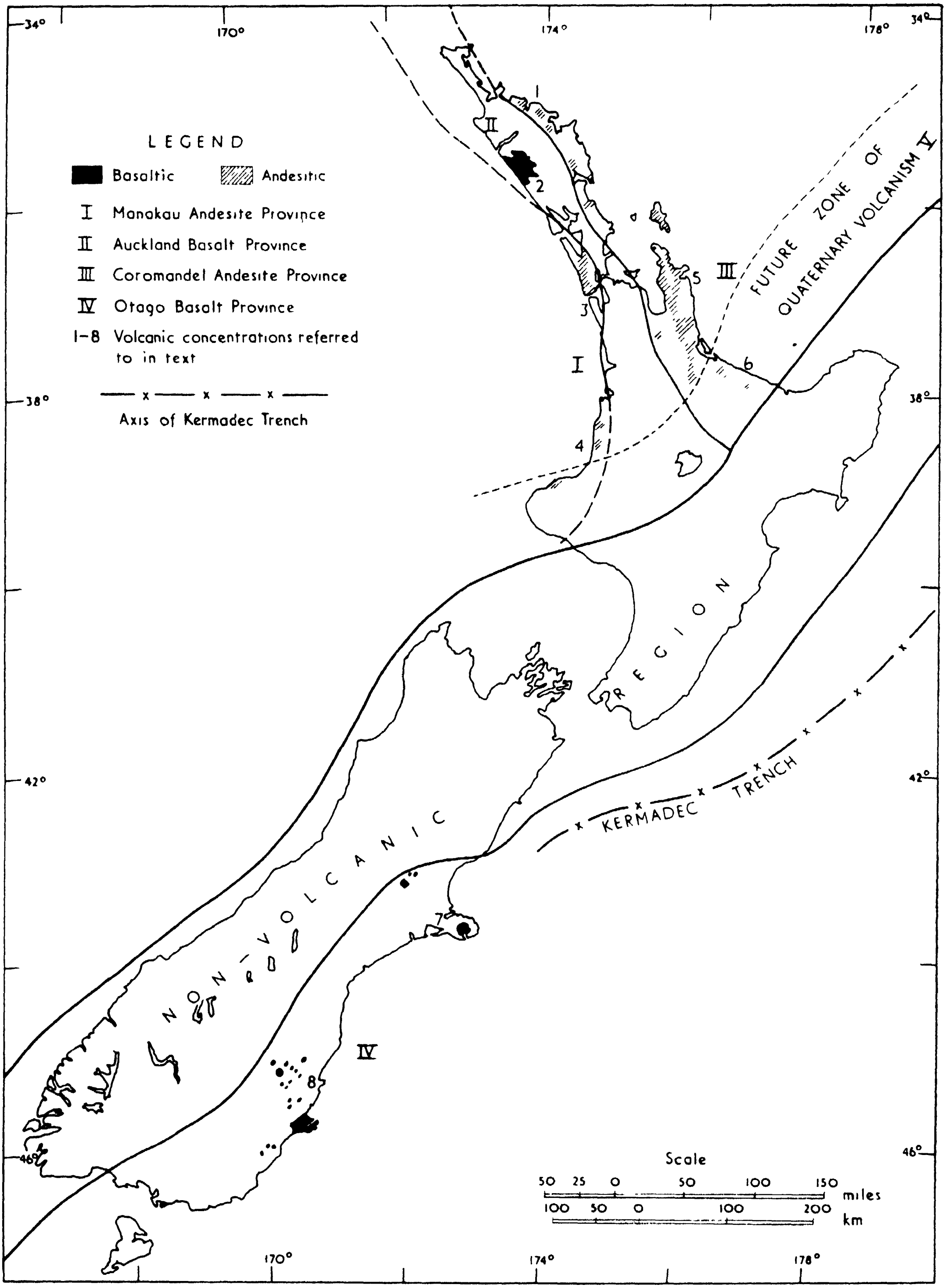

Fig. 2. — Quaternary volcanics.

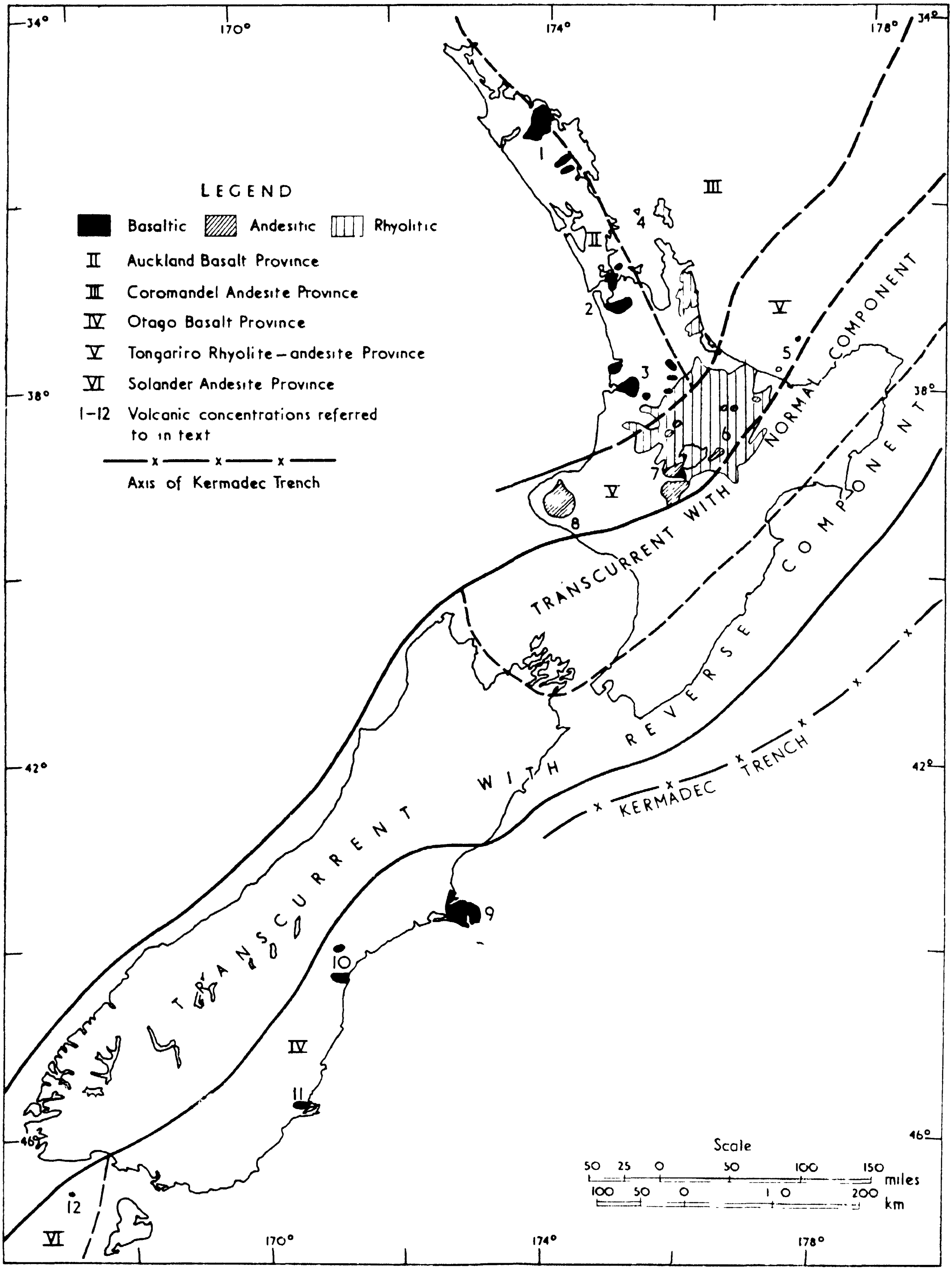

Fig. 1. — Upper Tertiary volcanics.

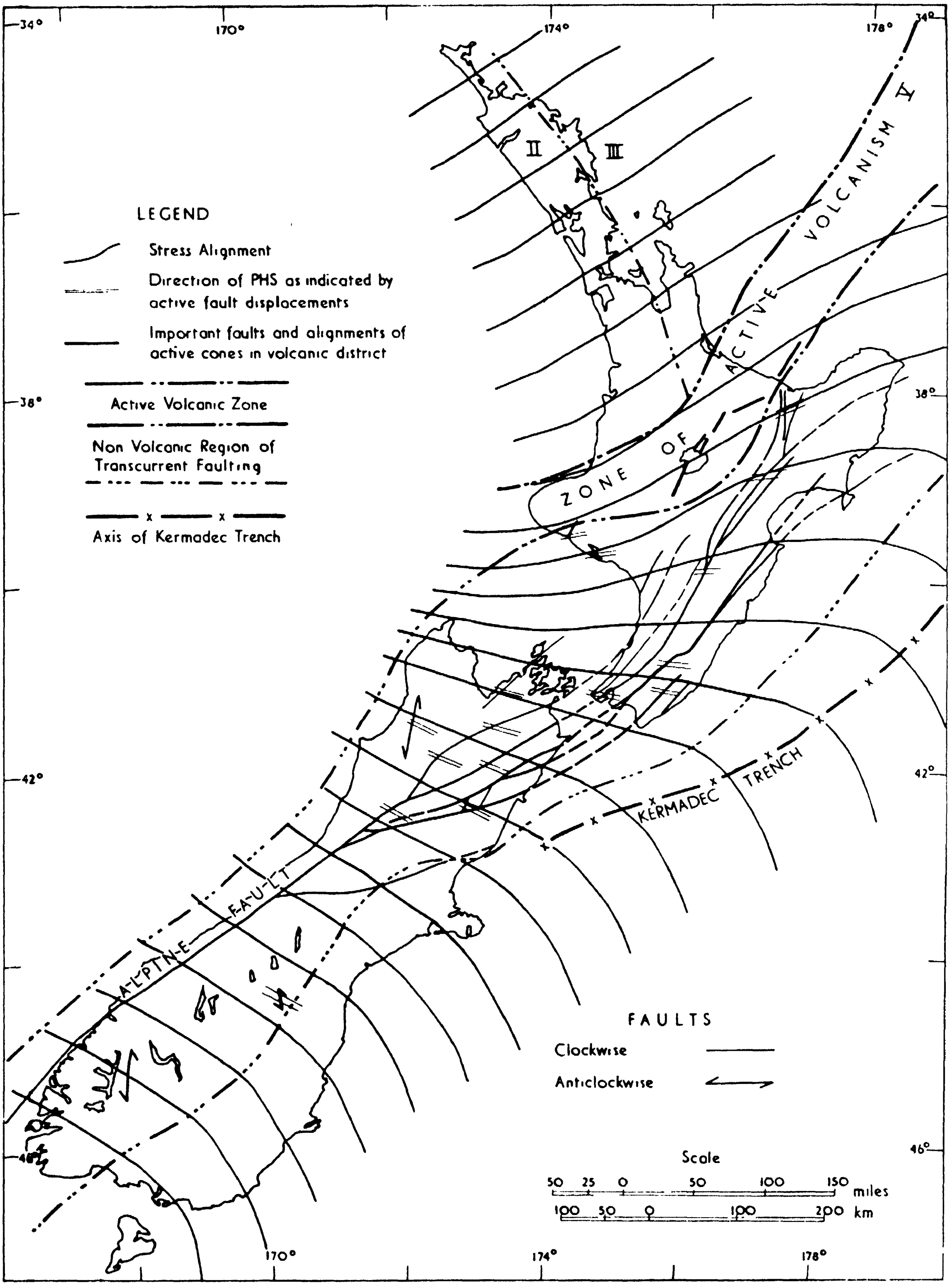

Fig. 3. — Principle horizontal stress near ground surface at present day and quaternary transcurrent faults.

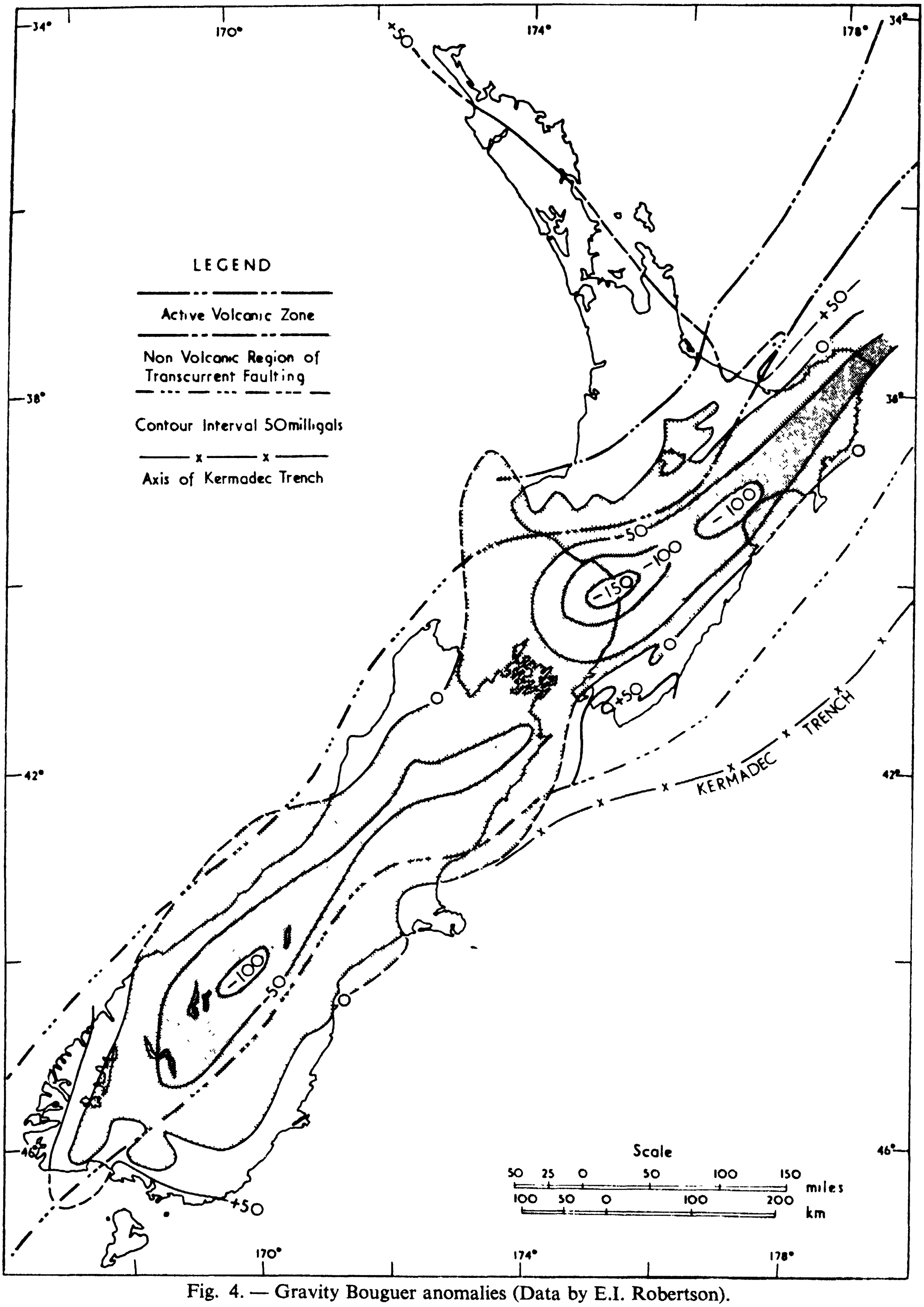

Fig. 4. — Gravity Bouguer anomalies (Data by E.I. Robertson).

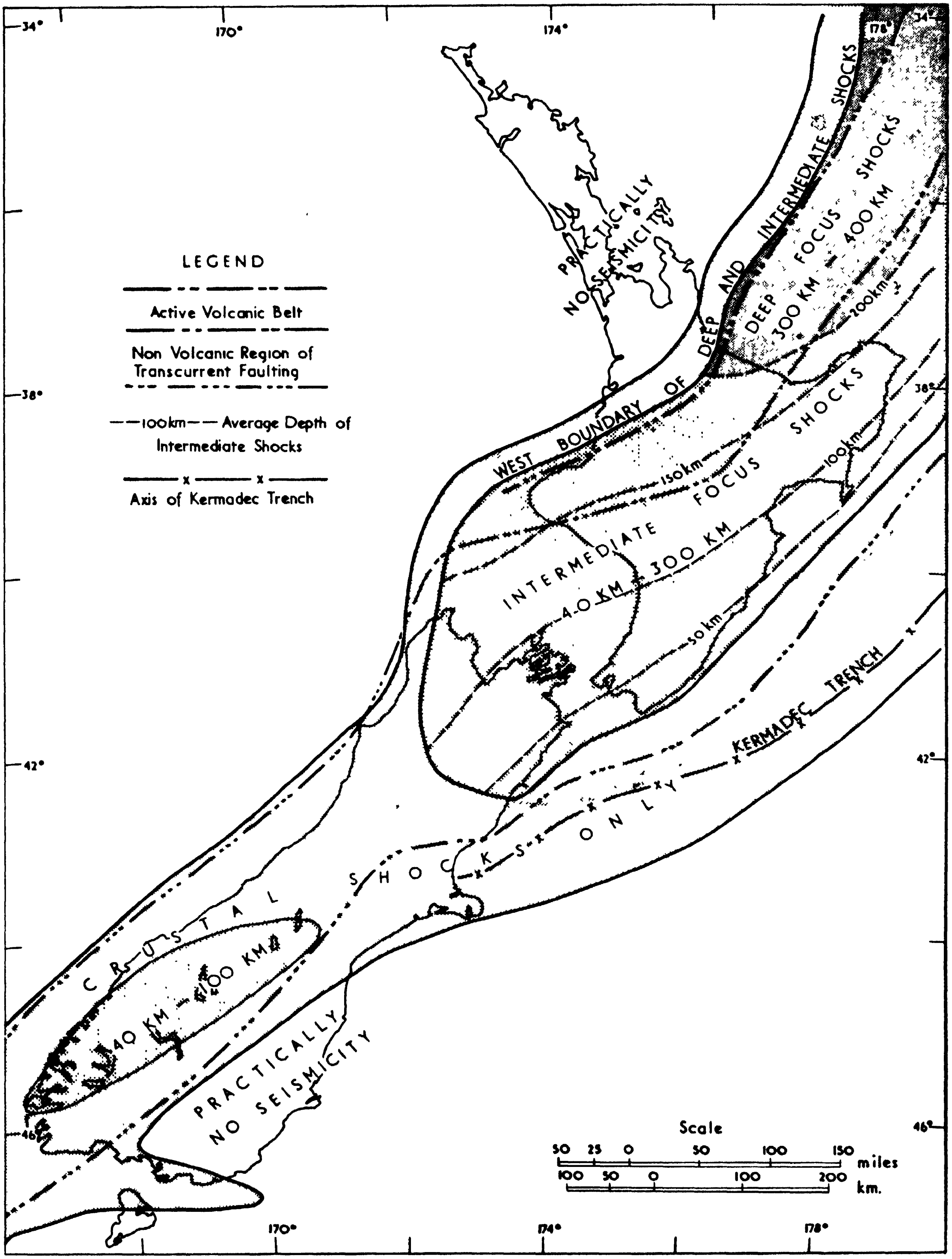

Fig. 5. — Seismicity (Data by G.A. Eiby).

LATE PALEOZOIC-EARLY MESOZOIC VOLCANIC ACTIVITY IN THE SUNDA LAND AREA

TH. H. F. KLOMPÉ, J. KATILI, JOHANNAS and SOEKENDAR

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Recent fieldwork in West Central Sumatra has revealed that in late paleozoic-early mesozoic time a volcanic-sedimentary sequence of strata was deposited, which was given the name of Silungkang Formation.

This stratigraphic sequence is compared with similar volcanic-sedimentary series in Djambi, Malaya (Pahang Volcanic Series) and West and Central Borneo (Bojan and Danau Series).

This correlation led to the assumption that the volcanic series of Malaya and West and Central Borneo and those of West Central Sumatra and Djambi can be grouped in two different zones of volcanic activity, a northern, more acid zone in Malaya and Central Borneo, and a southern, more basic zone in Sumatra.

On account of the similarity of the Sumatra volcanics and their differences with those of the northern zone, the conclusion is drawn that the Djambi volcanites do not originate from Malaya, but they form part of an authochthonous series.

This and the fact that nowhere in West Central Sumatra have any indications for thrustmovements been observed, make the occurrence of sheetstructures in Djambi and other parts of West Central Sumatra rather doubtful.

GENERAL INTRODUCTION

This paper deals with some results of recent field investigations in West Central Sumatra, where for a few years (1953-1957) students of the Geological Institute of the Faculty of Science have been preparing a geological map on a scale 1: 25,000 of a part of West Sumatra, known as the Padang Highlands.

The fieldwork, carried out under the supervision of the first author, has revealed the occurrence of an important and extensive sedimentary-volcanic sequence of strata in these Highlands, and in the following pages J. Katili and Johannas give a preliminary description of this interesting series, which has been given the name Silungkang Formation.

In his description of the Pahang Volcanic Series of Malaya in "The Geology of Malaya" Scrivenor (1931, pp. 93 and 94) concludes with the words: "the Pahang Volcanic Series is only a part of widespread volcanic rocks that are found in Sumatra and Borneo" and that all these occurrences have to be considered as remnants of an even greater volcanic activity in the late paleozoic and early mesozoic than the tertiary and quaternary period of volcanic activity in Sumatra, Borneo and Java.

In connection with this, short surveys on the occurrences of the sedimentary-volcanic series of similar age and character of Djambi (Sumatra), Malaya, and Borneo (fig. 1) are given to see whether it is possible to come to some general conclusions in regard to this appearance of late paleozoic—early mesozoic volcanic activity in the Sunda Land Area.

THE SEDIMENTARY-VOLCANIC SEQUENCE OF WEST CENTRAL SUMATRA AND DJAMBI

Introduction

The Lasi granite mass, between Sawahlunto and Solok, in the Padang Highlands (West Central Sumatra) is bordered in the East by a series of sediments which are of permo-carboniferous and triassic age and which was given the name of Silungkang Formation, after the village of Silungkang where this sequence is best developed and exposed (fig. 2). This series of strata is characterized by a considerable amount of interbedded lavas and pyroclastics, showing that in this area occurred in late paleozoic-early mesozoic time a fair amount of spasmodic volcanic activity.

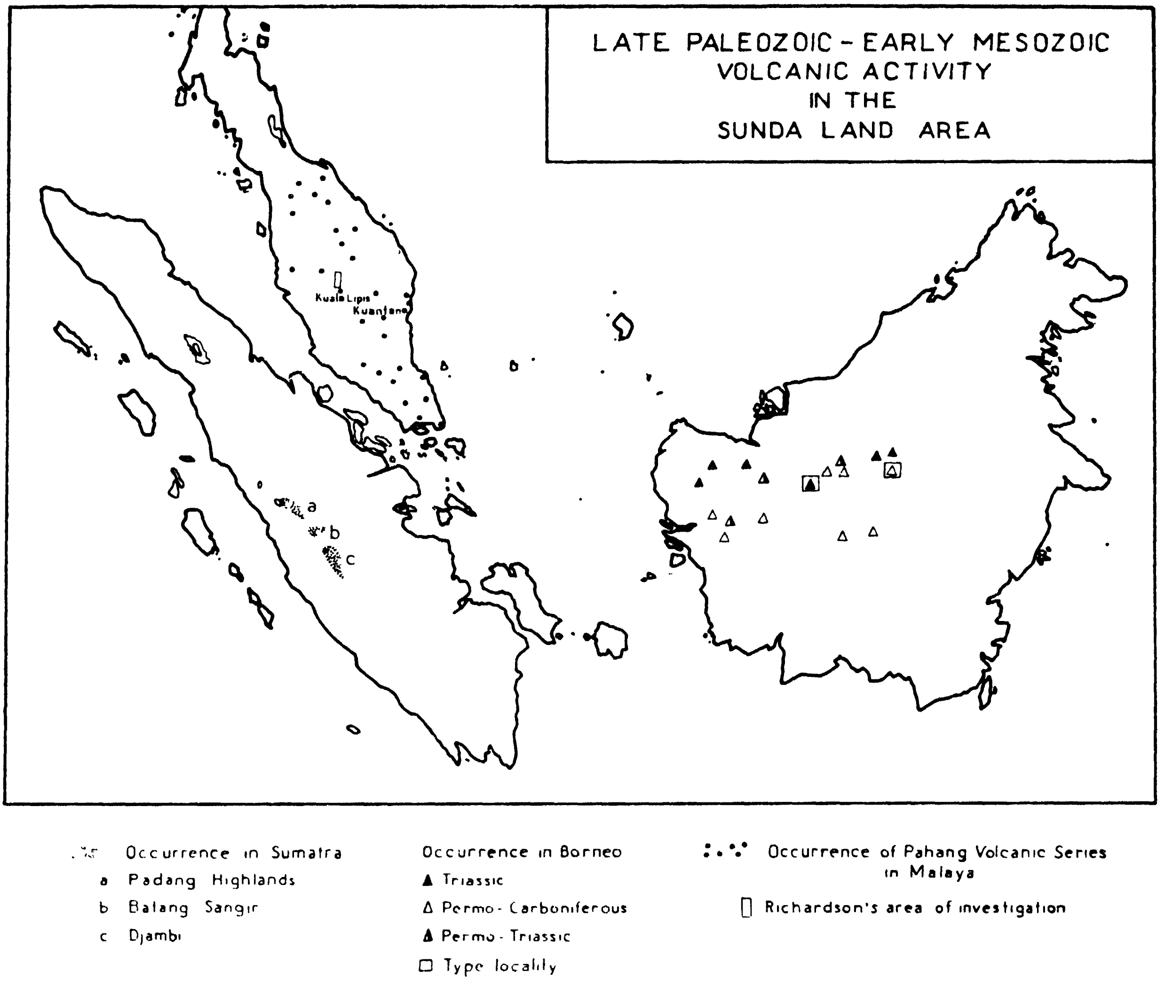

Fig. 1.

Also further southeast, in Djambi, occurs a series of permo-carboniferous and triassic sediments rich in intercalations of effusives and tuffs.

In this short account the authors will try to correlate the Silungkang Formation with the Djambi deposits of similar age and character. The information regarding the Silungkang Formation should be considered as a preliminary account. It is the result of detailed geological mapping in the Padang Highlands and will be more extensively dealt with in two theses describing the complete results of this mapping. The information on Djambi is obtained from publications by Tobler (1919), Kugler (1921) and Zwierzycki (1930).

Development in the Padang Highlands

a. Silungkang Formation.

Though there exists no sharp boundary between the two sections, the Silungkang Formation can clearly be subdivided in two series, a lower volcanic series and an upper calcareous series.

The Silungkang Volcanic Series is mainly

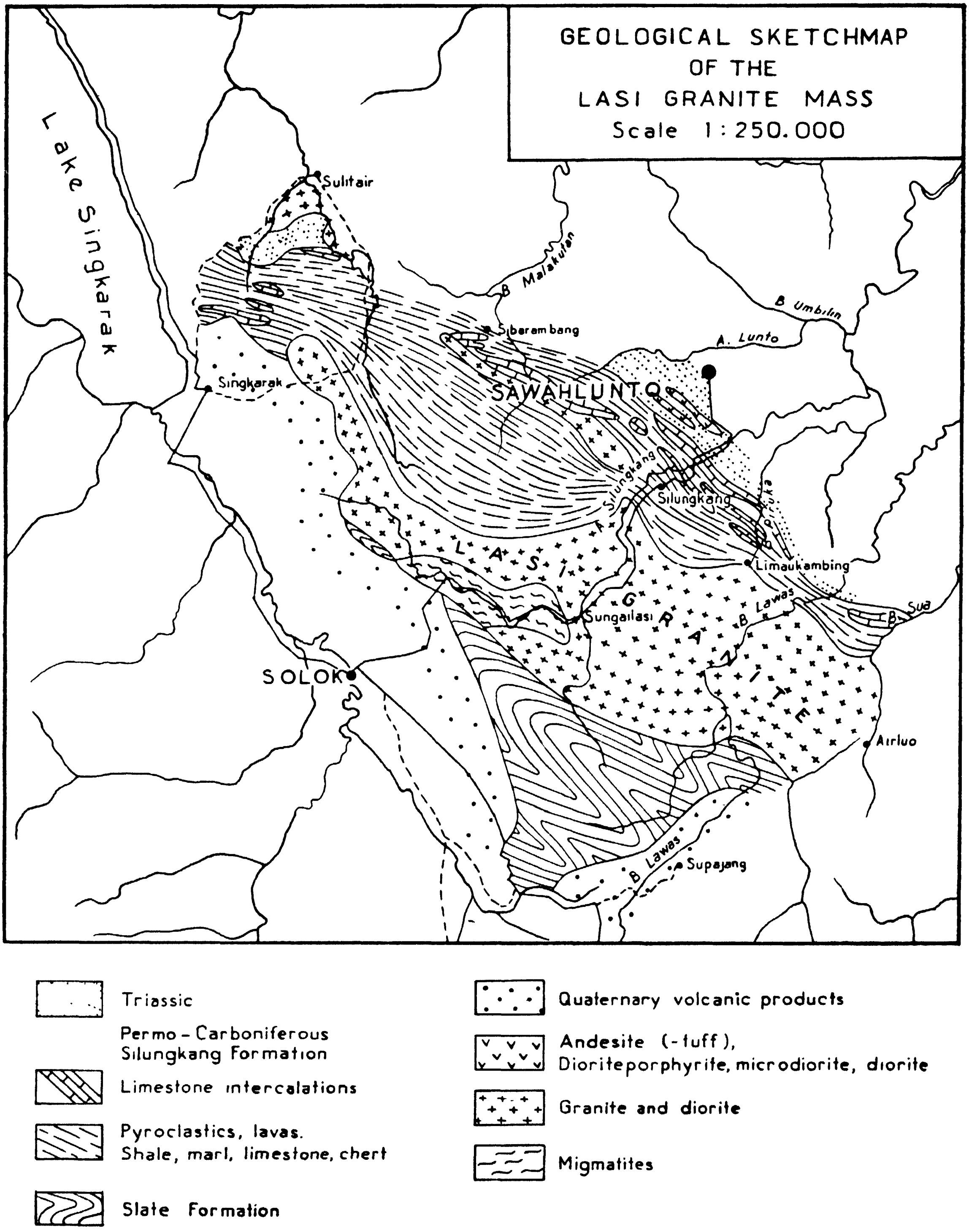
GEOLOGICAL SKETCHMAP
OF THE
LASI GRANITE MASS
Scale 1 : 250.000
Lake Singkarak
Sulitair
B. Malakutan
Sibarambang
B. Umbilin
A. Lunto
Singkarak
SAWAHLUNTO
Silungkang
Silungkang
Limaukambing
LASI GRANITE
Sungailasi
B. Lawas
B. Sua
SOLOK
Airluo
B. Lawas
Supajang
Triassic
Permo - Carboniferous
Silungkang Formation
Limestone intercalations
Pyroclastics, lavas.
Shale, marl, limestone, chert
Slate Formation
Quaternary volcanic products
Andesite (-tuff),
Dioriteporphyrite, microdiorite, diorite
Granite and diorite
Migmatites

Fig. 2.

built up of lavas and pyroclastics with interbedded limestones, shales, sandstones, some chert and silicified shales. The greenishgray to black volcanic rocks are hard and locally silicified, they are often chloritized and brittle. Also the interbedded normal sediments contain some pyroclastic material demonstrating that the volcanic activity, though less intensive, was continuing all the time. The occurrences of chert and silicified shales should also be ascribed to this occurrence of volcanic activity. During the paroxysmal stages mainly lavas and pyroclastics were deposited.

The tuffs are fairly well cemented. They show a distinct porphyric structure. Towards the top they become lighter in colour and their porphyric character becomes clearer because the phenocrysts of plagioclase become better distinguishable. The tuffs are predominating the lavas and can be classified as hornblende dacite tuffs.

The lavas are hornblende dacites, and microscopic examination shows that the main components are hornblende and plagioclase, represented as well by phenocrysts, as in the matrix. The plagioclases are of the oligoclase-andesine type; epidote and chlorite occur as weathering products of the hornblende.

The Silungkang Calcareous Series is chiefly composed of massive, fossiliferous limestones, sandy limestones, calcareous sandstones, marls and shales with interbedded agglomerates, tuffs and lavas. In contrast with the normal sediments of the Silungkang Volcanic Series those of the Silungkang Calcareous Series are not containing any pyroclastic material. Locally, e.g. South of Siberambang, the limestone alternates with agglomerates and tuffs, in other places, however, the tuffaceous material is considerably less.

The effusive rocks of this Silungkang Calcareous Series are represented by rather compact, dark coloured lavas. Microscopic examination shows that they are porphyric plagioclase rocks with phenocrysts of augite. Some plagioclases are of the oligoclase-andesine, some of the labrador type. Primary quartz is not found in these lavas which are augite andesites and -basalts.

Regarding the volcanic activity we see that in the upper section of the Silungkang Formation more limestones were deposited and that the volcanic activity was far less than in the lower section of this formation.

In the upper part more lavas were produced and lack of tuffaceous material in the sediments of this part shows that the volcanic activity was no longer continuous but periodic. It is also clear that the products of the volcanic activity changed from the intermediate (hornblende dacite) to a more basic type (augite andesite and augite basalt).

As far as the age of the Silungkang Formation is concerned we are entirely dependent from the fossils of the intercalated limestones. The limestones in the lower section are few and are in general recrystallized or silicified so that no fossils were preserved. Only in the upper part of the Silungkang Volcanic Series intercalations of a thin fossiliferous limestone occur.

The limestones of the Silungkang Calcareous Series are very rich in fusilinids, corals, crinoids, gastropods, brachiopods and ammonites. Some of the fusilinids were determined by Umbgrove (van Bemmelen, 1949) who considered them to be characteristic for the Permian and Carboniferous. Marks is of the opinion that they are indicating an upper permian age. Until further determinations have been made the formation should be considered as a representative of the Permo-Carboniferous.

b. Triassic.

The Silungkang Formation is conformably overlain by the Triassic and also this formation can be subdivided in two different parts. The lower section is built up of a clayshale-marl series. The shales are locally silicified. Intercalations of andesitic tuffs and intrusions of diorite porphyrite, microdiorite and diorite in dykes and sills occur frequently.

The upper part consists mainly of fossiliferous calcareous marls and marly limestones and the uppermost part is formed by a limestone breccia.

Fossils prove that these layers are of triassic age.

Conditions of Deposition

The following table shows the development of the Silungkang Formation and the Triassic in the area between Sawahlunto and Solok in the Padang Highlands:

AGE		SUBDIVISION	LITHOLOGY
TRIASSIC		Calcareous Section	Fossiliferous limestones, marly limestones, calcareous marls, limestone breccia.
		Shale-marl Section	Clayshales, locally silicified and marls. Intercalations of andesitic tuffs. Dykes and sills of diorite porphyrite, microdiorite and diorite.
PERMO-CARBONIFEROUS	SILUNGKANG FORMATION	Silungkang Calcareous Series	Massive fossiliferous limestones with fusulinids, sandy limestones, calcareous sandstones and some clayshales. Few intercalations of agglomerate and tuffs of the augite andesitic and-basaltic type. Several flows of augite andesite and-basalt.
		Silungkang Volcanic Series	Volcanic rocks represented by hornblende dacites and their tuffs. Few thin intercalations of limestones, shales and sandstones, mixed with tuffaceous material and silicified.

From this table we see that the sedimentation was accompanied by a sometimes continuous, sometimes periodic volcanic activity.

In general the activity was strongest in the time interval of the Silungkang Volcanic Series and came to an end in the lower section of the Triassic. Effusive and pyroclastic rocks of resp. dacitic, andesitic and basaltic composition were the result of this activity. The conclusion can be drawn that sedimentation took place in the shallow part of a seabasin, all sediments show a neritic-bathyal facies, bordered by one or more landareas (islands), crowned by active volcanoes. From time to time paroxysmal eruptions produced enormous quantities of pyroclastics, while in times of normal activity normal sedimentation predominated. No definite proof is found that submarine volcanic activity occurred.

During the period of sedimentation of the Silungkang Calcareous Series andesitic and basaltic lavaflows were produced and predominated the agglomerates and pyroclastics of similar composition. This phenomenon and the development of massive reeflimestones, possibly bioherms, indicate that the sediments were deposited closer to the land.

Also the sediments of the Triassic, clayshales, marls and wellbedded limestones, have a neritic to bathyal facies. The volcanic activity decreased considerably during the Triassic and came to a complete standstill in the upper section.

During the period of deposition of the Silungkang Volcanic Series the products were of a more acid nature (dacites) which turned more basic during the upper part of the Silungkang Formation and the lower part of the Triassic (andesites and basalts).

Development in Djambi

a. Permo-Carboniferous

Tobler subdivided in 1919 the Permo-Carboniferous of Djambi (fig. 1), more on a petrographic than on a stratigraphic base, in two sections and in 1930 Zwierzycki made a stratigraphic subdivision in three parts which were given the names: Karing-, Salamuku-, and Air Kuning layers.

According to Zwierzycki the Permo-Carboniferous forms an undisturbed sequence of strata. The main part of it is built up of volcanic products of dacitic, liparitic and andesitic composition which were deposited during periods of volcanic paroxysm or as denudation products along a descending coast. Lavaflows are rare and are only found in the upper part of the section.

The volcanic layers are interbedded with limestones, shales and conglomerates, and particularly the occurrence of foraminifera-limestones in various places points to a marine environment of deposition. Frequently occurring plant remains, bad layering and cross bedding indicate a littoral facies of the sediments.

The fossil flora and fauna put the age of these deposits as permo-carboniferous. The fusilinids reach till in the upper part of the section and are, according to Gerth, species characteristic for the Permian, so that the upper part of the series is of permian age.

The results of the volcanic activity are in the Karing layers represented by dacitic tuffs; in the Salamuku layers, during the deposition of which there was an increased activity, we find the disintegration products of liparites, silicified dacite tuffs and propylized hornblende andesites; and in the Air Kuning layers andesitic pyroclastics and lavas come to the front. During this time interval not only the character of the products changed but apparently the vents were shifted in the direction of the sedimentary basin. The lavas are chiefly augite andesites, though silicified dacitic tuffs also occurs.

b. Triassic

The Triassic is well exposed in the Batang Sangir Area (fig. 1) and was described by Kugler (1931). It is represented by a complex of massive reeflimestones and well bedded fossiliferous limestones. Thin intercalations of hornblende porphyrites indicate that the volcanic activity had decreased considerably in triassic time but was not yet completely extinct.

The stratigraphy of the Permo-Carboniferous and Triassic in Djambi and the Batang Sangir Area is given in the following table:

AGE	SUBDIVISION	LITHOLOGY
TRIASSIC		Massive reeflimestones and wellbedded fossiliferous limestones. Thin intercalations of hornblende porphyrite.
PERMO—CARBONIFEROUS	Air Kuning layers.	Limestones with fusilinids. Augite andesitic tuffs and lavas Dacitic conglomerates.
	Salamuku layers.	Conglomerates, breccias, sandstones; few shales and limestones with fusulinids. Desintegration products of dacites, silicified dacitic tuffs, propylized hornblende prophyrite or-andesite. Upper Carboniferous flora.
	Karing layers.	Shales, sandstones, few conglomerates, thin coallenses and in the upper part some limestones with fusulinids. Dacitic and liparitic tuffs. Upper Carboniferous flora.

Conclusions

This preliminary description of the Silungkang Formation and the review of the development of the Permo-Carboniferous in Djambi make it possible to draw the following conclusions:

1. The Silungkang Volcanic Series of the Padang Highlands shows a great similarity with the Karing and Salamuku layers of Djambi. In both regions the sequences are chiefly built up of volcanic products, dacitic and andesitic in composition, in Djambi some volcanites of the liparitic type occur. Pyroclastics are more common than lavas. Limestones remain entirely in the background.
2. The Silungkang Calcareous Series of the same area shows a very good correlation with the Air Kuning layers of Djambi. In both areas fusulinid-bearing limestones are predominating. Although tuffs are not entirely absent; far more lavas of the augite-andesitic and -basaltic type were produced.
3. Conglomerates in the Salamuku layers and the occurrence of plant-remains and stigmarias in the Karing and Salamuku layers of Djambi make it acceptable that at least part of these layers were deposited closer to, or even on the land, than their equivalents in the Padang Highlands.
4. Also the development of the Triassic in both areas shows a great similarity. The Triassic is characterized by volcanites of andesitic composition.
5. The Silungkang Formation and the Triassic of the Padang Highlands are developed with all the same characteristics as the permo-carboniferous-triassic sequence in Djambi and both series can very well be correlated with each other.

RECENT INVESTIGATIONS ON THE PAHANG VOLCANIC SERIES IN MALAYA

Introduction

In Malaya, spasmodic volcanic activity occurred in carboniferous to triassic time and the name Pahang Volcanic Series was first given by Scrivenor (1911) to the eruptive and intrusive rocks of the Malaya Peninsula, which were older than the mesozoic granite. The Pahang Volcanic Series can best be studied in Pahang, where good exposures are found along the Pahang River and its tributaries. The series is best developed East of the Main Range; West of this range these rocks are only found in few small outcrops (fig. 1).

The first detailed description was given by Scrivenor (1911). Later, Wilbourn (1917) published a fuller account and the same author contributed an article on this subject to Verbeek's "Gedenkboek", published in 1925.

Towards the close of the Carboniferous a very thick and widespread series of limestones had been laid down in the area of the Malaya Peninsula, accompanied by a strong volcanic activity. This series of limestones (Calcareous Series) was followed by an Arenaceous Series which was believed to be of triassic age. These rocks may represent the whole sequence from Lower Carboniferous to Rhaetic and the volcanic components represent undoubtedly an important manifestation of late paleozoic-early mesozoic volcanic activity.

According to Scrivenor and Wilbourn the types of rocks belonging to the Pahang Volcanic Series, interbedded with the various sediments of the Calcareous and Arenaceous Series, can be grouped in:

a. Lavas, represented by rhyolites, trachytes, dacites an andesites.
b. Tuffs, represented by rhyolite-, andesite-rhyolite-, and andesite tuffs.
c. Hypabyssal rocks, such as quartzporphyry and granophyre, porphyry, porphyrite, quartzdolerite and dolerite.

Results of recent investigations in Pahang

In recent time more detailed work has been done in areas where the Pahang Volcanic Series is well developed and the results of these investigations have made it necessary to make certain alterations in the original conceptions on the Series made by Scrivenor and Wilbourn.

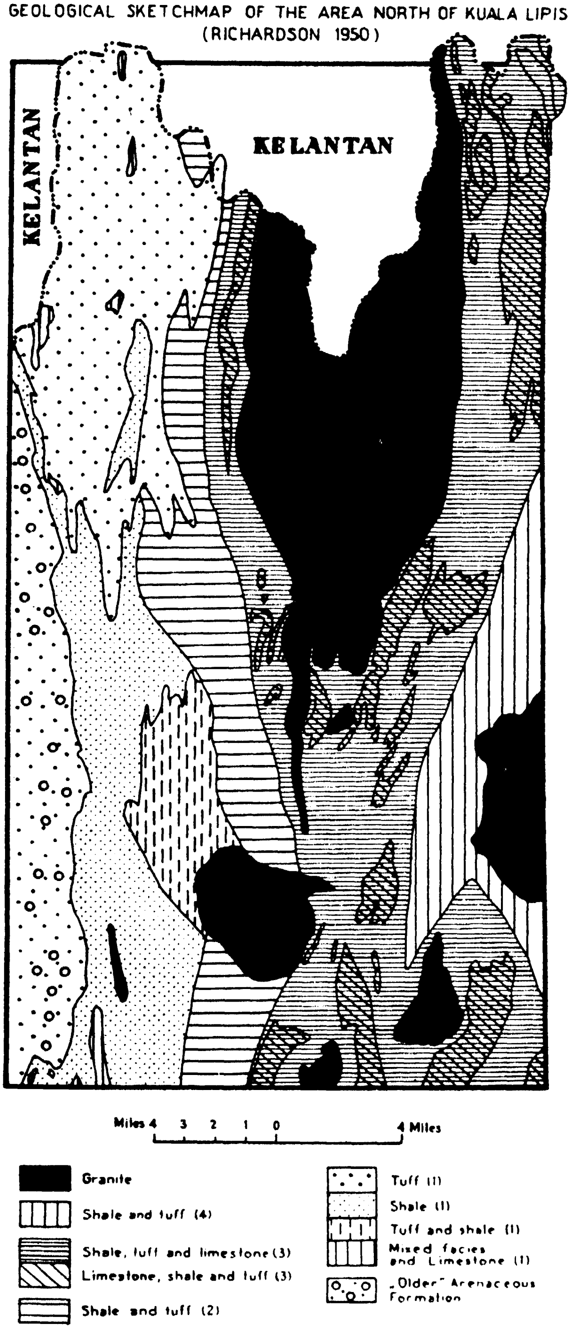

Fig. 3.

One of these areas lies North of Kuala Lipis (fig. 3) and the following information is obtained from Richardson's Memoir on: "The Geology and Mineral Resources of the Neighbourhood of Chegar Perah and Merapah, Pahang" (Geol. Surv. Dept. Memoir No. 4, Kuala Lumpur 1950).

The stratified sediments of the mapped area are referred to two groups, the Calcareous Series and the Arenaceous Series (fig. 3). Interbedded tuffs, agglomerates and lavas of the Pahang Volcanic Series are interbedded with all the rocks of the Calcareous Series and are virtually absent from the Arenaceous Series.

The Calcareous Series is considered to be of carboniferous- (?) permian age; the Arenaceous Series is provisionally referred to the Triassic. The sedimentary rocks belong to the neritic environment, except some of the coarsest conglomerates of the Arenaceous Series which were probably laid down in the littoral zone.

Up to 1939 little was known about the stratigraphy of the Calcareous Series but now we know that three lithological facies occur in the area under report: an argillaceous facies, predominantly shale; a calcareous facies, mainly limestone; and a "mixed" or "transitional" facies comprising of interbedded limestone and shale. Whereas the calcareous and argillaceous facies are widely developed, the "mixed" facies is restricted. The thickness of the Calcareous Series may be less than 3000-4500 meters.

In the Arenaceous Series, also three facies can be distinguished: a pebbly facies, comprising quartzite-conglomerate; an arenaceous facies, including quartzite, grit and quartz schists; and an argillaceous facies, containing shale, phyllite and micaschists; in addition there is a little chert. The thickness of the Arenaceous Series is of the order of 600-700 meters.

In the following table the stratigraphy of the Calcareous Series and the various interbedded elements of the Pahang Volcanic Series are given for the area North of Kuala Lipis (The numbers 1, 2, 3, and 4 correspond with the legend of fig. 3):

Stratigraphy of the Calcareous Series and the Pahang Volcanic Series in the area North of Kuala Lipis (Richardson 1950).

Group number	Lithology of the Calcareous Series and of the interbedded elements of the Pahang Volcanic Series.
4	Shales and green, chloritic tuffs of intermediate composition. Some of them coarse grained, together with subordinate agglomerates. They contain abundant fragments of trachyte, trachy-andesite and andesite, and in addition some rhyolite. Some types are predominantly andesitic.
3	Massively joined, white, grey and black upper limestone, intercalated with shales and pyroclastic rocks, largely of intermediate composition. They are more basic than those of group 2.
2	Shales and tuffs, and a few bands of limestone. The tuffs are rhyolite tuffs, medium to coarse grained; some contain fragments of trachyte, trachy-andesite and andesite. These tuffs are more basic than those of earlier age and form together with groups 3 a transitional series between basal dominantly rhyolitic tuffs (group 1) and the later chloritic rocks of intermediate composition of the upper group (4).
1	A variable group of rocks. In the northern part of the area predominantly rhyolitic tuffs with a few bands of shale and limestone. Further South shales are most abundant and only a few bands of rhyolite tuff and limestone are present.

There is some evidence that the Calcareous Series and the Arenaceous Series are not conformable as was originally supposed, for the change in lithology from quartzites, shales and conglomerates to shales and limestones containing interbedded volcanic rocks of the Pahang Volcanic Rocks is in general abrupt. "Passage beds" leading from the "Older" Arenaceous Series into the pelitic and calcareous rocks of the Calcareous Series have been found in few places. This marked lithological break from coarse-grained sediments, virtually devoid of bedded pyroclastic rocks, to shales and limestones with many stratified tuffbeds and agglomerates, indicates that important changes must have occurred in the area from where the sedimentary and volcanic detritus was derived, or in the marine basin where sedimentation was in progress, or in both areas.

Richardson (1950, pp. 40-46) proposes the following alterations in the classical conceptions on the Pahang Volcanic Series as given by Scrivenor and Wilbourn. The study of innumerable sections in which tuffs and lavas are interbedded with shales of the Calcareous Series is enough conclusive proof of the contemporaneity of pyroclastic and extrusive rocks with shales, limestones and cherts of the Calcareous Series, believed to be of carboniferous and (?) permian age in this region.

In the Arenaceous Series intercalations of volcanic rocks are very rare. Until recently this series has been referred to the Triassic. Nowadays there exists a growing tendency to consider some of the series, hitherto mapped as Trias, as belonging to the Calcareous Series, which is of carboniferous and (?) permian age. Based on structural, and lithological evidence the opinion is strengthened, that the Arenaceous Series is really more ancient than the Calcareous Series; it is though that it may be Lower Carboniferous, but the lack of fossil evidence prevents this question being settled. The two occurrences are, until more definite data are obtained, indicated as resp. Newer and Older Arenaceous Series.

There is conclusive evidence enough that the volcanic rocks are pre-granite, but there is not equally strong proof that the hypabyssal rocks are older than the granite. On the contrary there are indications that certain occurrences in other parts of Malaya are dated as contemporaneous with the granite. For this reason Richardson (1950) proposes that the term Pahang Volcanic Series should be restricted so as to include only those rocks which are indubitably of volcanic origin and also contemporaneous with the sedimentary rocks with which they are interstratified. So the following revised classification of the Pahang Volcanic Series is proposed by Richardson:

	LAVAS	PYROCLASTIC ROCKS
Acid	Rhyolite	Rhyolite tuff, felspar tuff.
Intermediate	Trachyte, Trachyandesite, Andesite.	Trachyte-rhyolite tuff, Trachyandesite-rhyolite tuff. Andesite-rhyolite tuff and agglomerate.

No basic volcanic rocks are represented, for it is not known whether the outcrops of serpentine should be classed as lavas or intrusions. According to the authors it is likely that these serpentines are representatives of an initial phase of the magmatic cycle connected with the formation of the Malayan Geosyncline out of which in mesozoic time the Malayan Mountain System was arched up. In that case, these serpentines, though more or less contemporaneous with the Pahang Volcanic Series do not belong to this series. According to Stille's nomenclature (1950) the Pahang Volcanic Series should be considered as the result of subsequent volcanic activity in a quasi-consolidated area in connection with the variscian cycle of orogeny of which the paroxysmal zone lies further Northeast in Indochina and submerged in the Gulf of Siam.

Conditions of Deposition

As well the lithology of the layers, as the nature of the scanty fossils obtained from them, indicate, that the Calcareous Series was laid down in a neritic environment located between the low-tide mark and the 100 fathom isobath; the shales and mudstones in water continuously charged with silt; and the limestones in water into which relatively little terrigenous material was present. The alternation of argillaceous and calcareous rocks is a clear indication that the conditions, controlling their deposition, were subject to rhythmic variations. The sediments of the Older Arenaceous Series are also characteristic of the neritic environment with quartzites and conglomerates deposited in shallow water near the coast, and the shales in deeper water off-shore.

These two series may be unconformable but the structure is so complex that evidence obtained so far is inconclusive.

The Pahang Volcanic Series consists largely of rhyolite tuffs, subordinate andesite-rhyolite tuffs and agglomerates together with rhyolite and andesite lavas in a few localities.

Although beds of contemporaneous volcanic rocks are confined to the Calcareous Series, fragments of volcanic material occur in the quartzites, grits, and conglomerates of the Arenaceous Series. The occurrence of such small percentages of volcanic material in the coarse sediments of the Arenaceous Series and the virtual absence of interbedded pyroclastic and extrusive rocks may be explained in two ways. Firstly, volcanicity may have occurred contemporaneously with the deposition of the Arenaceous Series, but so far away, that only small quantities of volcanic detritus reached the basin in which it was being laid down; or, secondly, the volcanic detritus may have been derived largely from pre-existing volcanic rocks older than the Arenaceous Series. The first supposition implies that volcanicity was contemporaneous with the Arenaceous Series, the second that it was even older. Richardson is of the opinion that the Arenaceous Series may be older than the Calcareous Series, so it is probable that volcanism may have been active at least as early as the Lower Carboniferous.

The paucity of volcanic material in the Arenaceous Series may be explained as due to the intermittent and feeble nature of the volcanicity characterizing the beginning during the Lower Carboniferous. All lavas are associated with neritic sediments, mainly shales and marine deposited pyroclastics. It seems therefore that some of the volcanoes from which they were extruded were probably located in part below water-level on the sea-floor, some little way offshore, but the main part of them were located above the sea-level on smaller or larger islands not too far from the coast. The lavas were either poured out directly on to the seafloor, or flowed over short distances down the slopes of subaerial volcanoes and thence into the sea. The outpouring of lavas directly on to the seabed would explain why none of them is scoriaceous, why the enclosing sediments show no signs of contact metamorphism, and why the extrusive and stratified rocks are conformably interbedded. Also all pyroclastics are interstratified with shales and limestones of the Calcareous Series.

The conditions of deposition of these strata further East, e.g. in the Kuantan Area (Eastcoast of Pahang) are similar to those just described. Here (Fitch 1952), the tuffs are bedded like normal submarine deposits but the rhyolitic rocks are in general very massive and uniform in texture. Several cases of banding, believed to be bedding, have been observed. This might have been due to deposition below the sea or to the falling of volcanic ash upon the surfaces of lava flows. In any case the deposition was on or near a shore line. Radiolarian cherts are in various places associated with rocks of the Pahang Volcanic Series and it is possible that the silica in the sea-water, necessary for the building up of Radiolarian tests, was supplied by pneumatolitic emanations from these eruptions.

Conclusions

From this synopsis the following conclusions can be drawn:

1. During the Permo-Carboniferous a series of sediments and volcanic products were contemporaneously laid down in a shallow sea basin.
2. This sea basin was situated either close to an extensive land area or from the floor of this sea basin rose several smaller and larger islands. The land area or the islands were crowned with volcanoes which supplied the volcanic material of the sequence.
3. In case it were islands, it is very likely that these were arranged in the shape of an arc.
4. The volcanic activity was continuous but of a spasmodic nature; periods of paroxysmal eruptions alternated with periods of low activity.
5. There are lithological changes as well from lower to higher horizons, but also in a lateral sense. In the lower group rhyolitic pyroclastic rocks are predominant, increasing in abundance northward and dying out southward. The middle group, containing a transitional series of rhyolitic and more basic tuffs and agglomerates, led on to the upper group which consists essentially of tuffs and some agglomerates of intermediate composition. Both groups increase in importance southwards and die out northwards.
6. It is clear that there was a marked decline in the activity of the volcanoes producing material dominantly of rhyolitic composition, and another group, producing more basic material (trachytic to andesitic) became increasingly important.
7. In case Richardson's interpretation is correct that the Arenaceous Series is really older than the Calcareous Series, then it follows that the volcanicity, producing rhyolitic lavas and fragmental material, commenced feebly before deposition of the Calcareous Series and reached its acme during the Upper Carboniferous or Permian.
8. There are no basic volcanic rocks in the series. The outcrops of serpentine which

occur in several localities have to be considered as the representatives of the initial (ophiolitic) phase of a magmatic cycle connected with the formation of the Malayan Geosyncline out of which in mesozoic time the Malayan Mountain System was formed.

9. The hypabyssal rocks, formerly included in the Pahang Volcanic Series, are younger than these volcanic products and are eventually related to the younger, possibly jurassic, granitic invasion occurring during the formation of the Malayan Mountain System.
10. The permo carboniferous-triassic volcanic products should be considered as the result of subsequent volcanic activity in a quasi-consolidated area connected with the variscian cycle of orogeny of which the diastrophic zone lies furher to the Northeast in Indochina.

DEVELOPMENT OF THE PERMO-CARBONIFEROUS—TRIASSIC SEDIMENTARY-VOLCANIC STRATA IN WEST AND CENTRAL BORNEO

Introduction

A sedimentary and a volcanic facies can be distinguished in the development of the Permo-Carboniferous and Triassic of West and Central Borneo. Both are interbedded with each other and are strongly dislocated by a mesozoic phase of orogeny.

The volcanic components of the Permo-Carboniferous are basic to intermediate in composition, while the triassic products are of a more acid type. Representatives of the permo-carboniferous sequence occur in the southern part of the area, while the triassic sequence is much better developed in the northern part of the area (fig. 1). In between lies a complicated mixture of both series as a result of strong structural movements, which Zeylmans van Emmichoven (1938) indicates on his map as Permo-Carboniferous-Upper Triassic.

The basic volcanic products can very well be correlated with the Pulu Melaju Series of the Danau Formation, and the triassic sequence of sediments including more acid volcanics with the Bojan Series.

In various localities the deposits contain sufficient well preserved fossils to allow an accurate age determination.

Development of the strata

a. Permo-Carboniferous.

Though a sedimentary and a volcanic facies can be distinguished in these deposits, it is not clear whether the sedimentary, or the volcanic complex forms the lower part. It is very likely, however, that both were deposited contemporaneously because basic volcanites were found as intercalations in the sediments. The sedimentary facies is represented by limestones, slates and phyllites, and silicified rocks such as hornstones, slates and jaspis. Apparently the original sediments of the permo-carboniferous were clays. They contain fusulinids and plantremains, such as *Calamites* and *Pecopteris*. The volcanic products are basic intermediate to basic lavas, pyroclastics and breccias, usually strongly decomposed. They are completely identical to the effusives of the Pulu Melaju Series of the Danau Formation. Because they are interbedded between the fossiliferous sediments, we know that they are also of permo-carboniferous age.

b. Triassic.

Again two different facies can be distinguished, but in West Borneo the proper succession of these is not yet known. From Central Borneo, however, Zeylmans van Emmichoven (1938) describes triassic deposits of which the lower section has a typical flysch facies and the upper part a volcanic facies. He gave this formation the name of Bojan Formation. Up to now no fossils were found but lithologically they are very similar to the Triassic of the Sanggau-Sarawak region.

The sediments of the lower part consist of arkosic sandstones, coarse grained polymict sandstones and shales. Their facies is littoral to neritic.

The composition of the volcanic series is trachytic to dacitic and consists of tuffs and agglomerates. Clayey and sandy tuffs, and tuffaceous slates show that the volcanic activity was continuous with, from time to time, paroxysmal stages.

Beside tuffs, also dykes, sills and lavaflows occur. The lavas are augite andesites, trachytes and granosyenite prophyries, the dykes are dacites and hornblende andesites.

c. Basic intrusives.

In the Kembajan Mts, in West Borneo, and in the middle Kapuas region of Central Borneo basic plutonic rocks occur, among which gabbro, olivine gabbro, norite and gabbrodiorite can be distinguished.

These basic intrusives were strongly influenced by the invading tonalitic intrusion in West Borneo, which is supposed to have taken place in post permo-carboniferous and prae upper triassic time. Fragments of these acid rocks are found in the clastic sediments of the Upper Triassic. The Permo-Carboniferous might be suggested as a possible age for these basic, ophiolitic intrusions.

d. Triassic in Sanggau-Sarawak.

This terrigenous series of strata consists of sandy claystones and finegrained claysandstones. Conglomerates form the basal part and are very widespread. *Monotis* and *Halobia* characterize these layers as Upper Triassic. The intercalated volcanic components of the series are represented by lavas, pyroclastics and agglomerates of acid to acid-intermediate composition. Transitions into alkali-rocks (trachytes) occur locally. The volcanites are usually in such a state of decomposition that it becomes impossible to make out whether they have an acid or basic character.

The following table gives the various rocktypes of both facies of these permo-carboniferous-triassic strata:

AGE	SEDIMENTARY FACIES	VOLCANIC FACIES
Triassic	Flyschfacies: sandstones clay-shales, tuffagglomerates. Fossils: *Monotis*, *Halobia*	Pyroclastics, locally alternating with sediments. Lavaflows, sills and dykes of acid-intermediate composition (dacite-trachyte)
Permo-Carboniferous	Limestones, claystones, slates, phyllites. Silicified rocks: hornstones, slates, jaspis. Fauna: fusulinids Flora: *Calamites*, *Pecopteris*.	Basic intermediate to basic lavas, tuffs and breccias, usually completely decomposed

Conclusions

From this short survey the following conclusions can be drawn:

1. During the Permo-Carboniferous a series of sedimentary-volcanic strata was deposited in which intrusions of the ophiolitic type occurred.
2. In triassic time a series of strata with a flysch facies was deposited. This sedimentary series is overlain by a series of volcanic products of intermediate-acid to intermediate composition interbedded with sediments.
3. The basic plutonics (ophiolities) of permo-carboniferous age are supposed to represent the initial phase of an orogenic magmatic cycle (Pacific cycle), intruded in the basal permo-carboniferous strata in a subsiding geosyncline.

GENERAL CONCLUSIONS

A comparison of these synopses on the occurrence of a late paleozoic-early mesozoic volcanic activity in various parts of the Sunda Land Area and a correlation of the conclusions of these reviews lead to the following general conclusions:

1. A permo-carboniferous-triassic period of strong volcanic activity occurred in various parts of the Sunda Land Area and resulted in the formation of a contemporaneously deposited sedimentary-volcanic sequence of strata. In Malaya this activity was probably started in the Lower Carboniferous, in Sumatra and Borneo in the Upper Carboniferous and lasted, though on a smaller scale. until the Triassic. In all described areas the volcanic paroxysm took place in upper carboniferous-permian time.

2. The various volcanic products were supplied by volcanoes close to the coast of an extensive land area or on small or large islands. These products, their distribution, and the facies of the contemporaneous sediments suggest that at least a large part of the Sunda Land Area was during that period covered by a shallow sea in which an island archipelago existed.

3. It is, according to the distribution of the various types of volcanic deposits and their chemical composition, not unlikely that these islands were grouped in two arcs, a northern one passing through the areas of Malaya and Central Borneo, characterized by acid to intermediate products, and a southern one passing through Sumatra of which the products are intermediate to basic in composition.
4. In all examined areas the first volcanic products are the most acid ones. During their further development more basic rocks, in the northern zone of the intermediate and in the southern zone of a basic type, were produced.
5. The late paleozoic—early mesozoic volcanic activity in the Sunda Land Area can be considered as the result of a subsequent magmatic activity in the quasi-consolidated foreland of the variscian cycle of orogeny of which the diastrophic zone lies further to the Northeast in Indochina.
6. The serpentines occurring at the base of the Pahang Volcanic Series and the intrusions of the ophiolitic rock types in the Permo-Carboniferous of West and Central Borneo are to be considered as the representatives of the initial phase of the magmatic cycle accompanying the Pacific cycle of orogeny. They were intruded in the base part of the permo-carboniferous section of the subsiding Malayan Geosyncline. Occurrences of ophiolites are not reported from the southern zone of volcanic activity in Sumatra.
7. The hypabyssal rocks of Malaya, formerly included into the Pahang Volcanic Series, and similar occurrences of dykes and sills of hypabyssal rocks in the Triassic of Borneo and Sumatra are the result of a younger intrusive activity which is probably a forerunner of the late mesozoic granitic invasions (jurassic and cretaceous) in the Sunda Land Area.
8. It was formerly accepted that the volcanic series in Djambi were not only similar to those of the Pahang Volcanic Series in Malaya but that they also originated from that area. Extensive thrust-movements were accepted to explain the transportation of these volcanic complexes. This correlation was one of Tobler's reasons to accept a sheetstructure for a part of Djambi.

   A close comparison of the Djambi volcanites with those of the Pahang Volcanic Series shows that this correlation is petrographically and chemically incorrect, but that there exists a perfect correlation between the Djambi volcanics and those of the Silungkang Formation.
9. Based on the differences between the Djambi volcanics and those of the Pahang Volcanic Series, the good correlation between the last and the Silungkang Formation, and the fact that during the years of fieldwork in the Padang Highlands not the slightest indication was found to accept thrustmovements on a small or large scale, as suggested by Tobler, Zwierzycki, de Haan and Osberger, make it rather uncertain that such structures exist.
10. The products of the late paleozoic-early mesozoic volcanic activity together with their contemporaneous normal sediments represent an autochthonous sequence of strata. This makes the occurrence of overthrustmasses in Djambi and in other parts of West Central Sumatra rather doubtful.

REFERENCES

Alexander, J.B., 1956, Lexique Stratigraphique International Vol. III; Asie; Fascicule 7, Malayan Archipelago; Malaya, pp. 285-315, Paris.

Bemmelen, R.W. van, 1939, De geologie van het centrale en oostelijke deel van de Wester Afdeling van Borneo. *Jaarb. mijnw.* Verh. **68.**

————, 1949, The Geology of Indonesia, Vol. I A, Government Printing Office, The Hague.

Fitch, F.H., 1952, The Geology and Mineral Resources of the Neighbourhood of Kuantan, Pahang. *Geol. Surv. Dep. Fed. of Malaya,* Memoir **6**, (New) Series), Kuala Lumpur.

Kugler, H., 1931, Geologie des Sangir—Batanghari Gebietes (Mittel Sumatra). *Verh. Geol. Mijnb. Gen. Geol. Serie* **5**.

Marks, P., 1956, Lexique Stratigraphique International, Vol. III, Asie, Fascicle 7, Malayan Archipelago, Indonesia pp. 6-242, Paris.

Molengraaff, G.A.F., 1900, Geologische verkenningstochten in Centraal Borneo. Amsterdam.

Richardson, J.A., 1950, The Geology and Mineral Resources of the Neighbourhood of

Chegar Perah and Merapoh, Pahang. *Geol. Surv. Dept. Fed. of Malaya*, Memoir **4**, (New Series), Kuala Lumpur.

Scrivenor, J.B., 1911, The Geology and Mining Industries of Ulu Pahang. Kuala Lumpur 1911.

——, 1925, Summary of the geological History of British Malaya and British Borneo. Gedenkboek, Verbeek, pp. 441-447. The Hague.

——, 1931, The Geology of Malaya. Mac Millan and Co., London.

Stille, H., 1950, Der "subsequente" Magmatismus. Abhandlung zur Geotektonik No. 3, Akademie Verlag Berlin.

Tobler, A., 1919, Djambi verslag. Uikomsten van Geol. Mijnb. onderzoek in de Residentie Djambi, 1909-1912. *Jaarb. Mijnw.* Verh. III, met atlas.

Wilbourn, E.S., 1917, The Pahang Volcanic Series. *Geological Magazine*, pp. 447-462 and pp. 503-514.

——, 1925, The volcanic Rocks of the Malay Peninsula and a comparison with their equivalents in the surrounding countries. Gedenkboek Verbeek pp. 601-616. The Hague.

Zeylmans van Emmichoven, C.P.A., 1938, Korte schets van de geologie van Centraal Borneo. *De Ingenieur v. Ned. Ind.* **5**: (9).

Zwierzycki, J., 1930, Die geologischen Ergebnisse der palaeobotanischen Djambi-Expedition 1925. *Jaarboek Mijnw. Ned. Ind.* 1930, Verh. II.

THE TECTONIC SETTING OF THE TONGARIRO VOLCANOES, NEW ZEALAND

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The Tongariro volcanoes, which form the Tongariro National Park, lie at the southern end of the volcanic belt that extends north-east through the centre of the North Island of New Zealand. The central part of the volcanic belt was described by Grange (1937). All the active volcanoes, boiling springs, and geysers of New Zealand are found along this line, which was described by Dieffenbach (1843: p. 358) as 'one connected hearth of volcanic action', and called by von Hochstetter (1864: p. 92) the Taupo Zone. Active faulting is widespread in the Zone, and earthquakes of intermediate focal depth are common. If this line of volcanic activity is projected to the north beyond White Island, the active volcano in the Bay of Plenty, it will pass through the volcanoes of the Tonga and Kermadec Islands. The Tongariro volcanoes, which include the three main volcanic edifices, Tongariro, Ngauruhoe, and Ruapehu, stand at the southern end of this belt of volcanism that stretches for a thousand miles across the south-west Pacific (Fig. 1).

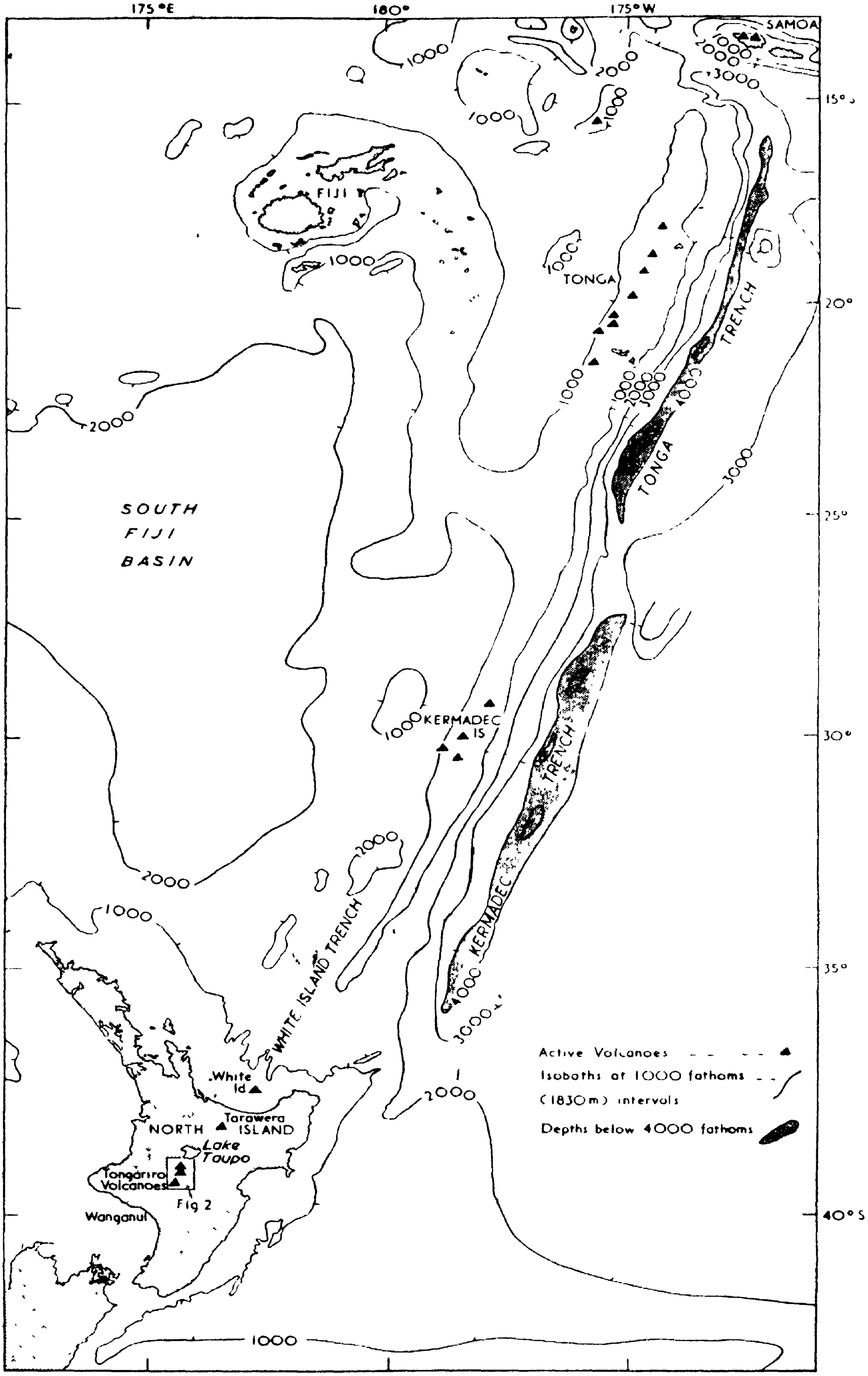
The lavas of the Tongariro volcanoes have been described as predominantly hypersthene-andesites and basalts (Grange and Williamson, 1930, 1933; Battey, 1949: p. 393-4). The few chemical analyses available show, however, that on the classification proposed by Rittmann (1952) they may be closer to dacite and labradorite-dacite. Inclusions of older rocks are very abundant in the recent lavas of Ngauruhoe (Battey, 1949: p. 394-5).

The basement rocks in the Tongariro area are Mesozoic greywackes and argillites of Wellman's (1952) alpine facies. They form the high Kaimanawa Mountains to the east of the volcanoes and lower mountains to the west. The basement rocks are overlain in places by pre-volcanic Tertiary marine sediments. The Quaternary volcanics rest on either the Mesozoic or Tertiary sediments. Generalised contours have been drawn on the basement surface (Fig. 2). These are based on observed heights of basement outcrops and on estimated depths to basement derived from gravity measurements made by the New Zealand Geophysical Survey. The estimates are preliminary and are based on approximations involving uncertainties in the heights of the stations, in the densities of the rocks, and in the regional gravity values. Density values of 2.62 for basement and 2.15 for covering strata have been used. The estimates are considered to be minimum values. There is little evidence for the basement contours in the areas covered by thick volcanics, and the low near Roto Aira has been tentatively connected with that to the south of Ruapehu.

Ruapehu erupted last in 1945, when Crater Lake was displaced by lava (Cotton, 1946). Ngauruhoe is the most continuously active volcano in New Zealand, and in its last major eruption, in 1954-55, discharged some 6,000,000 cubic metres of lava (Gregg, 1956). Te Mari, a crater on the northern slopes of Tongariro, was last active in 1896 when it threw out large quantities of ash and rock (Friedlaender, 1899: 500-2). Red Crater, another vent on Tongariro, was probably in eruption in 1855 (Hochstetter, 1864: 100). Great rhyolitic ash eruptions have originated near Lake Taupo, some 20 miles north of Tongariro, during the last few thousand years (Baumgart, 1954).

The main volcanic vents of the Tongariro volcanoes lie in a straight line running north-north-east (Figs. 2, 3, 4). This remarkable linearity was first pointed out by A.P.W. Thomas (1889: 346-7). On both sides of this line, and running parallel to it, are many faults showing recent displacements of small amplitude (Fig. 5). Some of these faults were mapped by Grange, Williamson, and Hurst (1938), and more have been found by the examination of air photographs. Many must have been buried by recent eruptions. Most of the fault traces do not extend for more than a few miles, and almost all are downthrown towards the volcanoes. In the few cases where the dip of the fault plane has been determined, the faults are normal. No definite horizontal displacement has been detected.

The Tongariro area thus forms the southern end of the Taupo Graben (Fleming, 1952). Fleming (1953: 298) has postulated that the Wanganui Basin, a region of thick late Tertiary and Quaternary marine sedimentation, is a


175°E
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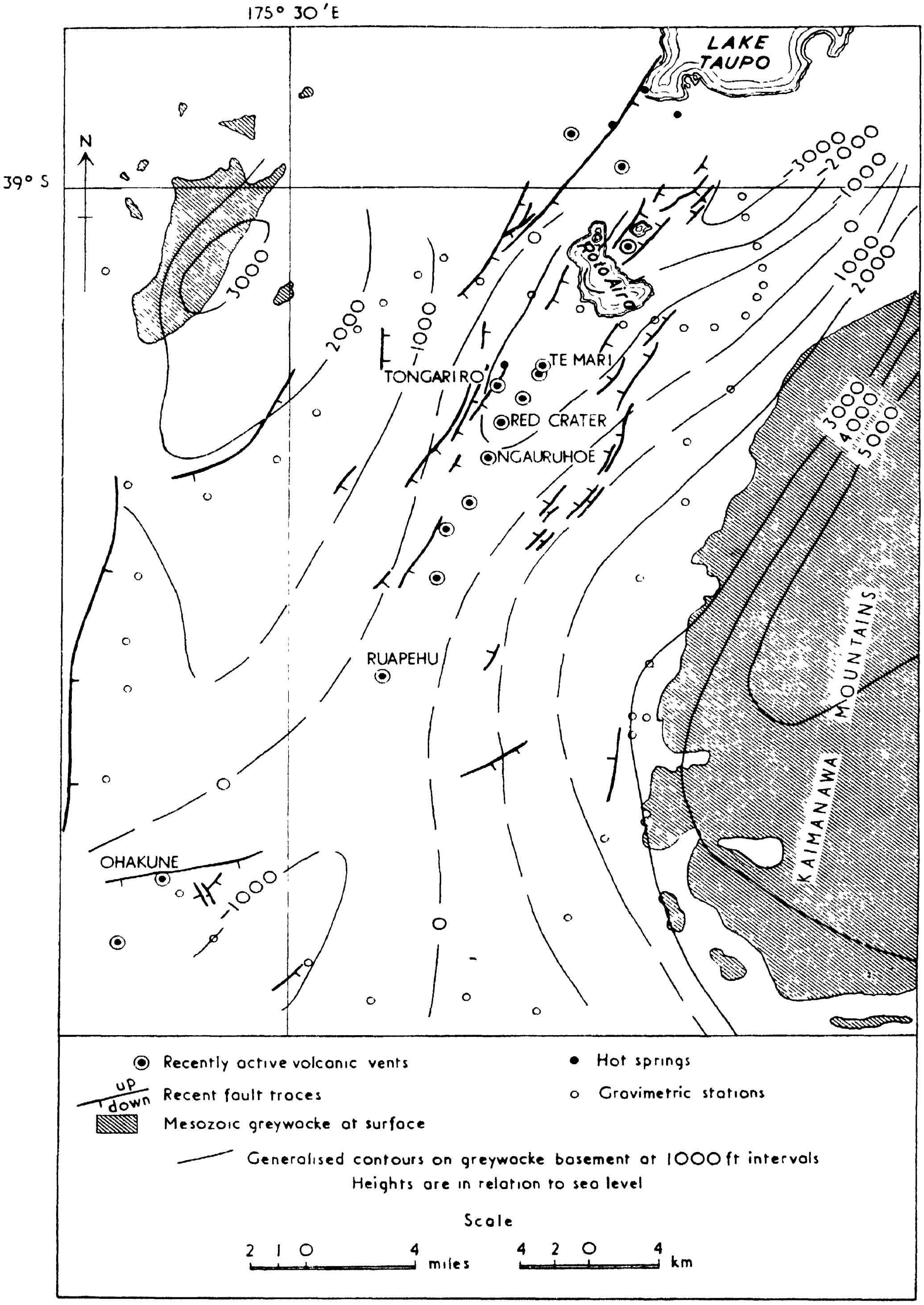
KERMADEC IS
30°
KERMADEC TRENCH
4000
WHITE ISLAND TRENCH
35°
White Id
Tarawera
NORTH ISLAND
Lake Taupo
Tongariro Volcanoes
Fig 2
Wanganui
40°S
Active Volcanoes
Isobaths at 1000 fathoms (1830 m) intervals
Depths below 4000 fathoms

Fig. 1.


175° 30'E
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N
LAKE TAUPO
Roto Aira
TE MARI
TONGARIRO
RED CRATER
NGAURUHOE
RUAPEHU
OHAKUNE
KAIMANAWA MOUNTAINS
3000
2000
1000
0
-1000
-2000
-3000
4000
5000
Recently active volcanic vents
Hot springs
up
down
Recent fault traces
Gravimetric stations
Mesozoic greywacke at surface
Generalised contours on greywacke basement at 1000 ft intervals
Heights are in relation to sea level
Scale
2 1 0 4 miles
4 2 0 4 km

Fig. 2.

Fig. 3.—The Tongariro volcanoes from the north, showing the alignment of volcanic vents. Snow-capped Ruapehu is in the background, with the prominent cone of Ngauruhoe in the centre of the photograph. Te Mari craters are in left foreground with a recent lava flow reaching down to forest in right foreground. On the right the white scar of Ketetahi hot springs shows on the slopes of the North Cone of Tongariro.

— Photo. V.C. Browne.

continuation of this graben, as was first suggested by Rev. Richard Taylor (1855: 223). Normal faults striking north-east have been found near Wanganui (Fleming, 1953: 90), and Wellman (1955) pointed out that the well-defined active normal faults of the North Island are confined to a narrow belt from Wanganui to the Bay of Plenty. Park (1910: 262) drew his rather hypothetical Whakatane Fault along the same line.

The linearity of the vents of the Tongariro volcanoes suggests that they are underlain by some kind of deep-seated fracture. To explain the petrogenetic relationship of the rocks of the Taupo Zone, Professor R.H. Clark, Victoria University College, Wellington, has postulated a clockwise transcurrent fault underlying the Zone (in a paper presented to Section C of the 32nd Meeting of the Australian and New Zealand Association for the Advancement of Science, Dunedin, January 1957). The direction of greatest horizontal stress in the Taupo Zone has been considered to be north-east and parallel to the normal faults (Wellman, 1954, 1955), but if Clark's suggestion is correct, the stress pattern at depth

EXPLANATION

Fig. 1.—Map of South-west Pacific, showing active volcanoes. Bathymetry from N.Z. Oceanographic Institute; Raitt, Fisher, and Mason (1955); and Admiralty Chart No. 780. Volcanoes from Thomson (1926), and Gutenberg and Richter (1949).

Fig. 2.—Map of Tongariro area, showing volcanic vents, fault traces, and basement contours.

Fig. 4.—Ngauruhoe and Tongariro from the south-west. Ngauruhoe in the cone near the centre of photograph, which is taken from above Ruapehu. Young lava flows from a vent on the north flank of Ruapehu are in the right foreground. Lake Taupo is in background.

— Photo. Whites Aviation Ltd.

would be the same as in Wellman's transcurrent zone with the direction of greatest horizontal stress running east-west.

It had early been suggested that subsidence in the Taupo area was a direct result of the discharge of large volumes of volcanic ash (Taylor, 1855: 226). The weight of the volcanoes themselves would add to the effect of the withdrawal of material from below and the stress pattern at the surface would be modified by this increased vertical stress. There is evidence, however, that a tectonic basin was in existence before the main eruptions took place (Grange, 1937: *47*), and certainly the co-axial Wanganui Basin was forming long before the most intense volcanism. Fleming (1953: 298-300) discussed the relation of the Taupo Zone to the Wanganui Basin and concluded that the South Island alpine geanticline, the Wanganui Basin, and the Taupo Zone were segments in a single zone of crustal weakness.

ACKNOWLEDGMENTS

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REFERENCES

Battey, M.H., 1949, The Recent Eruption of Ngauruhoe. *Rec. Auck. Inst. Mus.*, 3: 387-95.

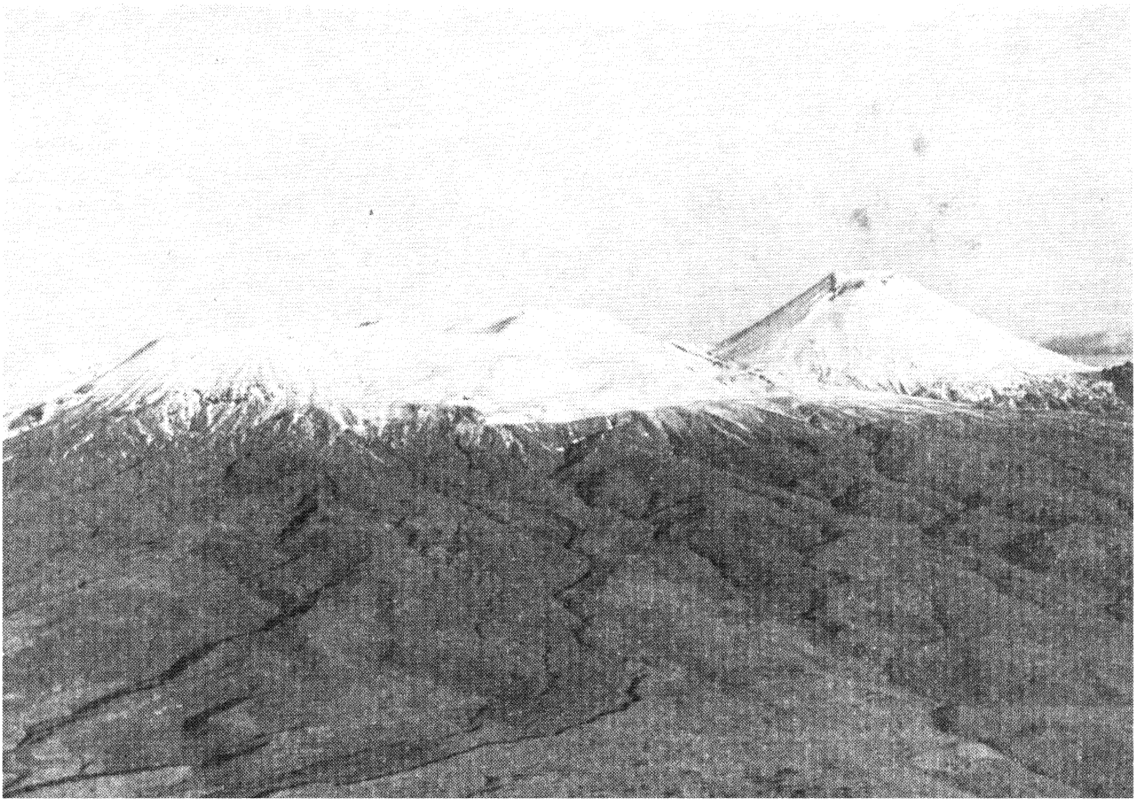

Fig. 5. — Ngauruhoe, on right, and Tongariro, viewed from the north-west. Several fault traces can be seen on the side of Tongariro. Ketetahi hot springs are at extreme left. Young lava flows show clearly on the cone of Ngauruhoe.
— Photo. Whites Aviation Ltd.

Baumgart, I.L., 1954, Some Ash Showers of the Central North Island. *N.Z.J. Sci. Tech.* **35**: 456-67.

Cotton, C.A., 1946, The 1945 Eruption of Ruapehu. *Geogr. J.*, **107**: 140-3.

Dieffenbach, E., 1943, "Travels in New Zealand." John Murray, London.

Fleming, C.A., 1952, White Island Trench, a Submarine Graben North-east of New Zealand. *Proc. 7th Pacif. Sci. Congr.*, **3**: 209-11.

————, 1953, The Geology of the Wanganui Subdivision. *N.Z. Geol. Surv. Bull.*, n. s. **52**.

Friedlaender, B., 1899, Some Notes on the Volcanoes of the Taupo District. *Trans. N.Z. Inst.*, **31**: 498-510.

Grange, L.I., 1937, The Geology of the Rotorua-Taupo Subdivision. *N.Z. geol. Surv. Bull.*; n.s. **37**: 138 pp.

Grange, L.I., Williamson, J.H., 1930, Tongariro Subdivision. *N.Z. geol. Surv. 24th annu. Rep. n.s.*: **10** (3).

————, 1933, Tongariro District. *N.Z. geol. Surv. 27th annu. Rep. n.s.*: 18-21.

Grange, L.I., Williamson, J.H., Hurst, J.A., 1938, Geological Maps of Tongariro Subdivision, to accompany *N.Z. geol. Surv. Bull.* n.s., **40** (text not published).

Gregg, D.R., 1956, Eruption of Ngauruhoe 1954-55. *N.Z.J. Sci. Tech.*, **37**: 675-88.

Gutenberg, G., Richter, C.F., 1949, "Seismicity of the Earth and Associated Phenomena." Princeton University Press, Princeton.

Hochstetter, F. von, 1864, Geologie von Neu Seeland. *Novara-Exped., Geol. theil, 1 (1)*:

Park. J., 1910, "The Geology of New Zealand." Whitcombe and Tombs, Christchurch. 488 pp.

Raitt, R.W., Fisher, R.I., Mason, R.G., 1955, Tonga Trench. *Geo. Soc. Amer. spec. Pap.* **62**: 237-54.

Rittmann, A., 1952, Nomenclature of Volcanic Rocks. *Bull. volcan.* ser. II. **12**: 75-102.

Taylor, R., 1855, "Te Ika a Maui or New Zealand and its Inhabitants." 1st ed. Wertheim and Macintosh, London.

Thomas, A.P.W., 1889, Notes on the Geology of Tongariro and the Taupo District. *Trans. N.Z. Inst*; **21**: 338-53.

Thomson, J.A., 1926, Volcanoes of the New Zealand-Tonga Volcanic Zone. A Record of Eruptions. *N.Z.J. Sci. Tech.*, **8**: 354-71.

Wellman, H.W., 1952, The Permian-Jurassic Stratified Rocks (of New Zealand). *Proc. 19th Int. Geol. Congr. Symp. Gondwana Ser.*: 13-24.

________, 1954, Stress Pattern controlling Lode Formation and Faulting at Waihi Mine and Notes on the Stress Pattern in the North-western part of the North Island of New Zealand. *N.Z.J. Sci. Tech.*, **36**: 201-6.

________, 1955, New Zealand Quaternary Tectonics. *Geol. Rdsch.* **43**: 248-57.

SOME CONSIDERATIONS ON THE RELATION BETWEEN CHEMICAL CHARACTER AND GEOGRAPHICAL POSITION OF THE VOLCANIC ZONES IN JAPAN

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Pleistocene and recent volcanoes in Japan and Kurile Islands have been generally classified geographically into those of the Tisima (Chishima), Daisetu, Nasu, Tyôkai (Chôkai), Huzi (Fuji), Norikura, Daisen and Ryûkyû volcanic zones from the northeast to the southwest. (Fig. 1.)

Volcanoes which are arranged on the Kurile arc from Alaid at the northeastern end of the Kurile Islands to Daisetu and Tokati in the central part of Hokkaidô, were formerly included in the Tisima zone. The western part of the above zone or the volcanic range running in NNE direction in central Hokkaidô was called the Daisetu volcanic zone from the petrological viewpoint by the authors (Ishikawa T., Katsui, Y. and Suzuki Y., 1952) since 1950, though it had been already distinguished as the Tokati volcanic chain geographically by some geologists. The lavas contain often hornblende as well as pyroxene and olivine, and are chemically more alkalic than those of most other volcanoes of the Tisima zone, which are petrographically pyroxene andesite and dacite or basalt of tholeiitic magma origin. Only Alaid and its parasitic volcano, Taketomi are made up of slightly alkaline olivine basalt comparatively rich in K_2O (Kuno, 1935) and locate distinctly at the west or inner side of the Tisima zone.

The Nasu volcanic zone which starts from western Hokkaidô and extends to central Honsyû comprises volcanoes mostly made up of pyroxene andesite and dacite, and rarely basalt or tholeiitic magma origin. But the lavas from several volcanoes at its south part contain often hornblende and are slightly more alkalic than those from other volcanoes of this zone. Risiri, a volcanic islet off the most northwestern coast of Hokkaidô is built of pyroxene andesite and slightly alkaline basalt comparatively rich in Na_2O. Shokanbetsu, a large dissected strato-volcano on the coast of Japan Sea, to the south of the just-mentioned volcano, is made up of hornblende pyroxene andesite and olivine basalt comparatively rich in alkalies. These volcanoes lie both on the extension line of the Nasu zone to the north and have been included in it by some researchers. But they seem not to belong to the Nasu proper zone from the petrological viewpoint. The authors will indicate them here as volcanoes of the northern subzone of the Nasu zone.

Volcanoes arranged parallel to the Nasu zone at the west or inner side of Honsyû arc are included in the Tyôkai zone. It starts from Oshima-ôshima, a volcanic islet off the most southwestern coast of Hokkaidô and runs near the coast of Japan Sea to central Honsyû. The lavas from volcanoes belonging to it are hornblende andesite, pyroxene andesite and olivine basalt of alkalic olivine basalt magma origin, being far different petrologically from those of the Nasu zone.

The Huzi zone which comprises the volcanoes within the Fossa Magna region and those on the Izu Islands, running in NNW direction, is divided into two subzones by Kuno (1952). The southern subzone comprises the volcanoes south of Hakone, which are made up of tholeiitic basalt and pyroxene andesite. While the northern subzone, which starts from Kôzu-sima among the Izu Islands, and extends to the Japan Sea coast passing the west side of the north end of the southern subzone, comprises volcanoes built of hornblende andesite, hornblende dacite and hornblende or hornblende biotite rhyolite as well as pyroxene andesite and basalt. The basalt is slightly more alkaline and less siliceous than that from the southern subzone. Iô-zima Islands located near the south end of the Huzi zone are built of trachy-andesite, and run nearly parallel to it at its west-side, constituting Iô-zima zone independent of the Huzi.

To the west of the Fossa Magna region, several volcanoes capping the so-called Japan Alps constructs the Norikura zone running in NNE direction. Their lavas are mostly hornblende andesite, biotite andesite and pyroxene andesite. This zone seems to be geographically the inner zone of the Huzi.

The Daisen zone which runs along the Japan Sea coast in southwestern Japan and extends to Unzen at the west part of Kyûsyû, is petrographically characterized by biotite hornblende andesite and dacite.

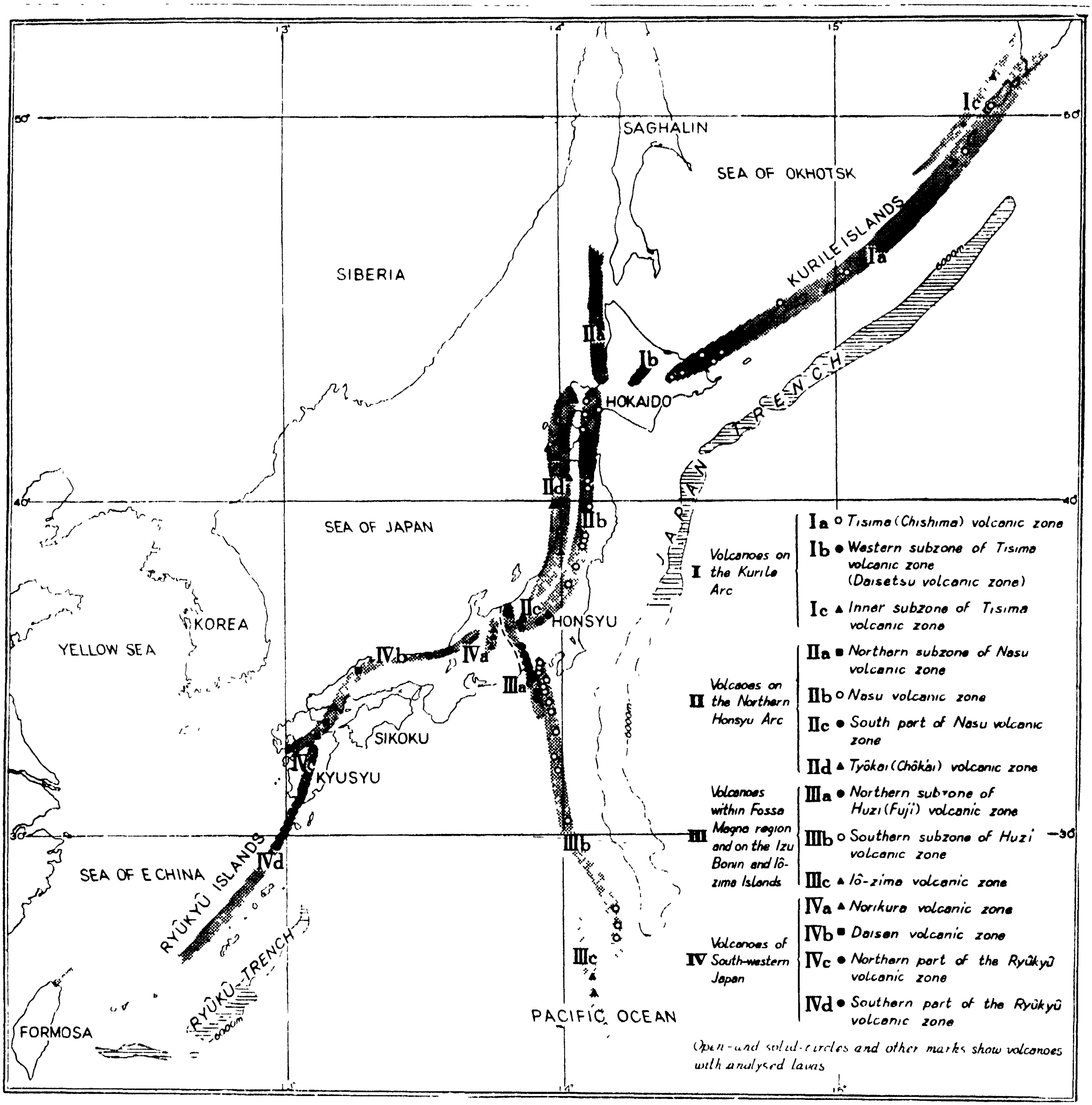

Fig. 1.

The Ryûkyû zone starts from Aso lying in the middle of Kyûsyû and runs to the SSW including Sakura-zima and volcanoes arranged at the inner or west side of the main arc of Ryûkyû. Volcanoes belonging to this zone are mostly built of pyroxene andesite, but the lavas from those at its northern part contain sometimes hornblende. Volcanoes lying at the north end of Formosa, on the extension line of this zone to the south, are made up of pyroxene andesite and biotite hornblende andesite, and are located on the inner or west side of this zone.

Volcanic rocks from Japan were chemically examined early by Yamada (1930), and the average chemical compositions of rhyolite, rhyolite-andesite, andesite, andesite-basalt and basalt were calculated respectively. Tomita (1935) studied on the chemical compositions of the Cenozoic alkaline suite of the circum Japan Sea region and cleared chemical characters of alkalic rocks in

Japan. Iwasaki collected 603 analysis of volcanic rocks from Japan and calculated the average chemical compositions of rock groups classified according to SiO_2 contents respectively (Iwasaki, 1937a). Furthermore he studied the lavas of each volcanic zone in Japan in detail (Iwasaki, 1937b). Taneda (1951) examined particularly the chemical compositions of the lavas from volcanoes in Japan and discussed on the chemical characteristics of every volcanic zone. Ishikawa (1952), one of the authors, compared the chemical compositions of the lavas in Niggli's value calculated from them, especially *al-alk*, *qz*, *al*/*al-alk* and *c-(al-alk)* values corresponding to *si* and *k-mg* relation.

According to him the lavas from volcanoes of Tisima, Nasu and Huzi zones are mostly higher in *al-alk* and *qz* values than the average of the young volcanic rocks of the Pelée Lassen-Peak type which is the highest in the above values among all types of the North American Cordillera. (Burri, 1926). As the more alkalic rocks are the lower in *(al-alk)* and *qz* values, the above three zones in Japan are considered to be of the most calcic type in the world. It is interesting also that large crystals of anorthite have often been found in the lavas or as crystal lapillis from the above zones or in Tertiary volcanic rocks constituting their basement and never reported from other districts. Ishikawa (1951) suggested from the above occurrence that the formation of the large anorthite may be due to magmatic assimilation of sedimentary rocks rich in Al_2O_3. The lavas from the Daisen and Ryûkyû zones are generally lower in *al-alk* and *qz* values than the average of volcanic rocks of the Pelee Lassen-Peak type, proving to be more alkalic. Katsui (1953, 1954 and unpublished) analyzed some lavas from Tyôkai and Daisetsu zones and from Rishiri and Syokan volcanoes, and studied the chemical characteristics of the above zones or volcanoes.

Comparing the chemical compositions of the lavas from all the volcanic zones in Japan in Niggli's values, the authors (Ishikawa and Katsui, 1955) noticed that the lavas of the inner most zone or subzone are the most alkalic. Accordingly the authors now classify the volcanoes in Japan and the Kuriles into the following zones and subzones;

- I. Volcanoes on the Kurile arc
  - Ia. Tisima volcanic zone
  - Ib. Western subzone of the Tisima volcanic zone or Daisetu volcanic zone
  - Ic. Inner subzone of the Tisima volcanic zone
- II. Volcanoes on the northern Honsyû arc
  - IIa. Northern subzone of the Nasu volcanic zone
  - IIb. Nasu volcanic zone
  - IIc. South part of the Nasu volcanic zone
  - IId. Tyôkai volcanic zone
- III. Volcanoes within the Fossa Magna region and on the Izu, Bonin and Iô-zima islands.
  - IIIa. Northern subzone of Huzi volcanic zone
  - IIIb. Southern subzone of Huzi volcanic zone
  - IIIc. Iô-zima volcanic zone
- IV. Volcanoes of southwestern Japan
  - IVa. Norikura volcanic zone
  - IVb. Daisen volcanic zone
  - IVc. Northern part of Ryûkyû volcanic zone
  - IVd. Southern part of Ryûkyû volcanic zone

The above zones and subzones distribute geographically as shown in Figure 1. The available chemical analysis of the lavas from volcanoes in Japan, selected by the authors for the present study totalled 441; their numbers from each volcano and zone are shown in Table I.

The chemical compositions represented in oxide form were calculated into Niggli's value and compared with one another in *qz*, *al-alk* and *c-(al-alk)* corresponding to *si* and *mg-k* relation as shown in figures 2 to 5. For comparison, also average values of young volcanic rocks in Japan (Taneda, 1951) and alkalic volcanic rocks in circum Japan Sea region (Tomita, 1936) are shown in each figure.

In figures 2 and 3, numbers of the lavas plotted above and on the line showing the average of volcanic rocks in Japan were counted in every zones or subzones, as shown in Table II.

As shown in figure 2 and Table II, the lavas from the Ia, IIb and IIIb zones are mostly higher in *qz* than the average value of volcanic rocks in Japan. IIc, IIIa and IVd zones are next to above three in *qz*. While the lavas from IIIc, IId, IIa, IVa, Ic, Ib, IVb and IVc zones are generally lower in *qz* than the average. Especially IIIc or Iô-zima zone is exceptionally low in *qz* and very near to the average of alkalic volcanic rocks in the circum Japan Sea region. Also in comparison of *(al-alk)* value, Ia, IIb and IIIbz ones are higher than the average of volcanic rocks in Japan. The third zone is not very much higher than the average, but it is distinctly higher than the Pelée Lassen-Peak type (Ishikawa, 1952). IIc, IIIa, IVc, IVd

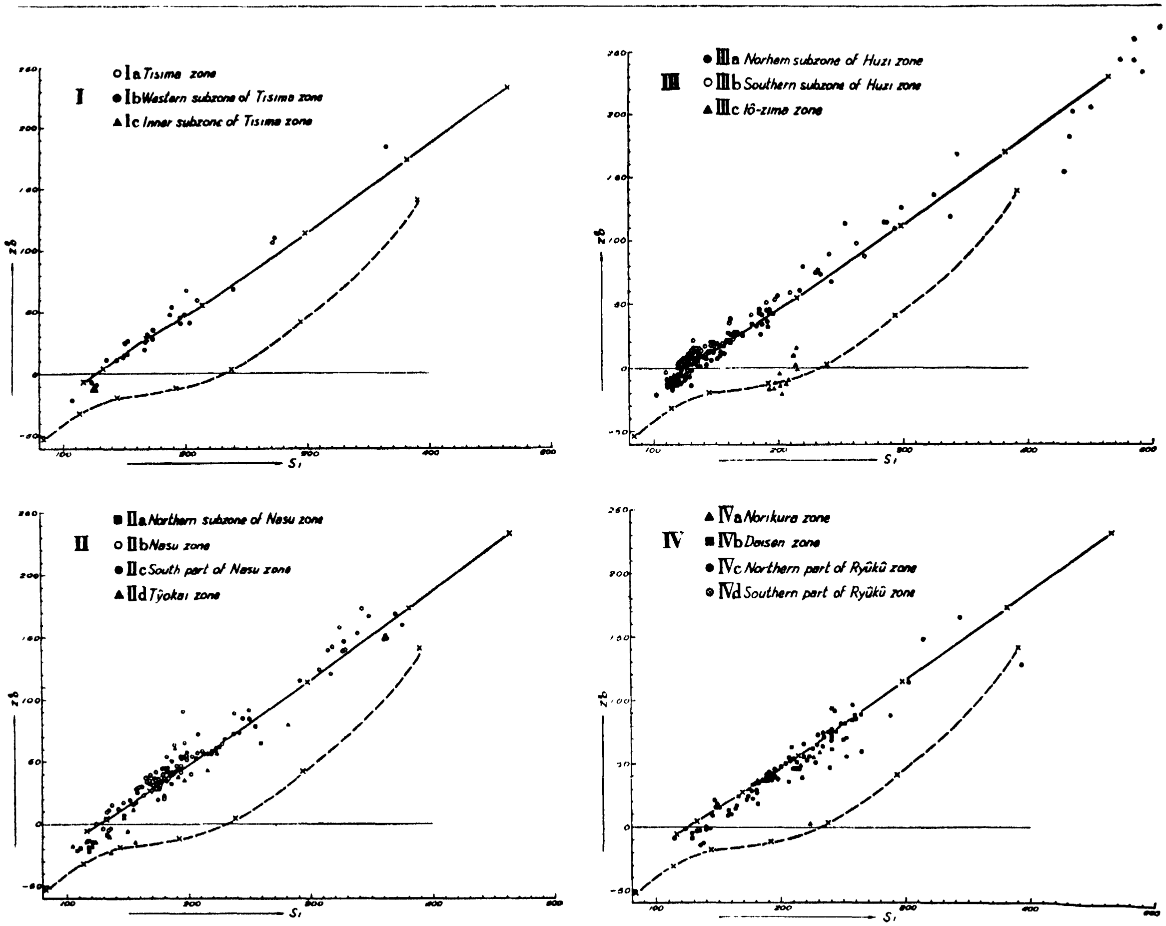

Fig. 2.—Variation diagrams of *qz* values corresponding to *si*. The full line shows the average value of young volcanic rocks in Japan, and the dashed line that of alkalic volcanic rocks in the circum Japan Sea region.

and IVb zones are next to the above three and near to the average. While IIIc, IId, IIa, IVa, Ib and Ic zones are lower in *(al-alk)* value than the average. Especially IIIc is remarkably low in *(al-alk)* as such in *qz*.

As the more alkalic rock group is the lower either in *qz* or in *(al-alk)*, as already stated by Ishikawa (1952), the descending order of zones in the above values may represent gradual change from more calcic to less calcic characters. Among volcanoes on the Kurile arcs, the Tisima zone is the most calcic, and the more inner and western zones are rather alkalic. On the northern Honsyû arc, the Nasu zone is the most calcic in chemical character, and the Tyôkai zone and the northern subzone of the Nasu are more alkalic. Volcanoes at the southern part of the Nasu zone are more alkalic than the Nasu and near to the northern subzone of the Huzi zone, with which they join geographically at the southern end. Of volcanoes within the Fossa Magna region and on the Izu, Bonin and Iô-zima Islands, the southern subzone is the most calcic, and the northern subzone running at its inner side is rather alkalic. The lavas from the Iô-zima Islands are remarkably alkalic, and seem to constitute the inner subzone of the Huzi.

In general the above three geographical units, the volcanoes of the outer side are more calcic than those of the inner side in chemical character, and thus the zonal arrangement of volcanoes with calcic to more alkalic lavas from the southeast to the north-west is well shown. To the outside of the most calcic zone, Japan trench, more than 8,000 m in depth, lies as shown in figure 1, and seems to suggest that the magmatic character of the volcano is closely related to its tectonic position.

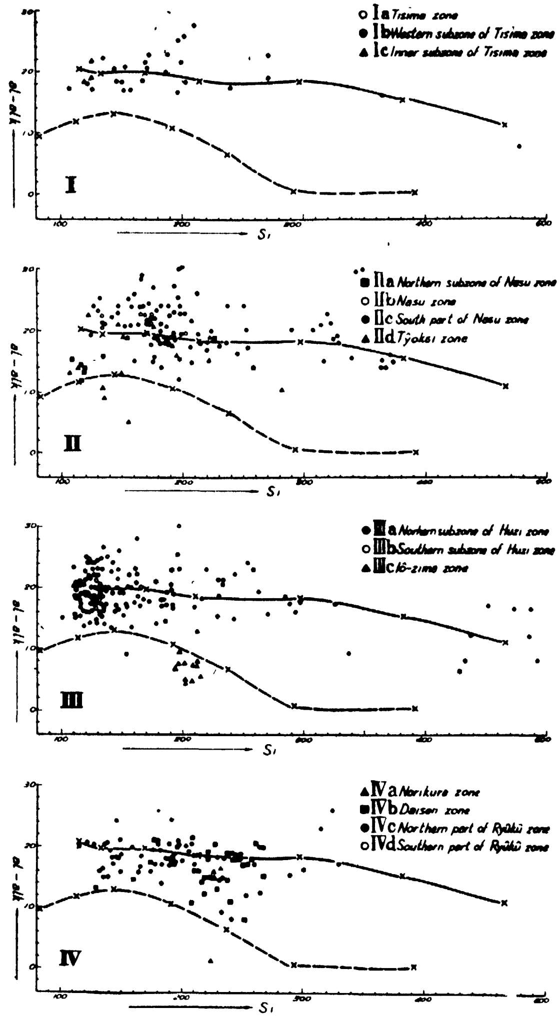

Fig. 3.—Variation diagrams of *al-alk* values corresponding to *si*. The full line shows the average value of young volcanic rocks in Japan, and the dashed line that of alkalic volcanic rocks in the circum Japan Sea region.

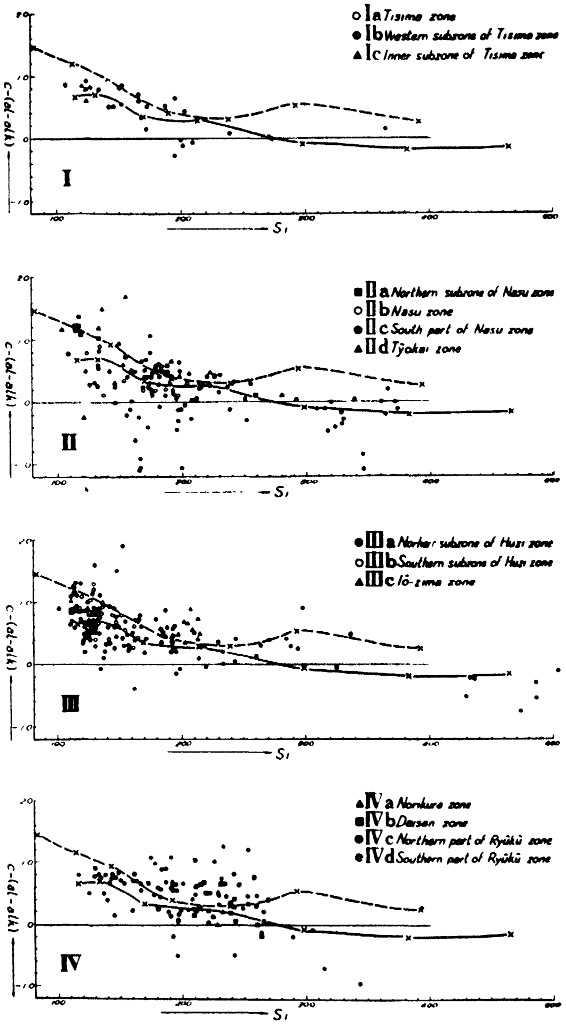

Fig. 4.—Variation diagrams of *c-(al-alk)* values corresponding to *si*. The full line shows the average value of young volcanic rocks in Japan, and the dashed line that of alkalic volcanic rocks in the circum Japan Sea region.

High *qz* value corresponding to *si* suggests the existence of free silica as quartz, tridymite and cristobalite in mode. In andesite and basalt of calc-alkalic type in Japan, richness in *qz* or Norm Q is generally represented in the form of silica minerals in the groundmass or as glass containing excess silica.

al-alk Value is related to anorthite content of plagioclase in mode. Plagioclases in calc-alkalic volcanic rocks in Japan are mostly more calcic than those from other countries in the world. Large anorthite crystals which have been often found in volcanites of the Tisima and Nasu zones and the southern subzone of the Huzizone, whose lavas are rich in *(al-alk)*, are genetically related to the magmatic character. The more calcic type is generally the higher in *qz* or *(al-alk)* value.

C-(al-alk) value is related to the lime content in pyroxene in mode. Accordingly the low value of *c-(al-alk)* suggests richness in rhombic pyroxene in mode. Pyroxene andesite and basalt rich in hypersthene are considered to be very low in *c-(al-alk)* value. Numbers of the lavas below and on the lines show the average value of volcanic rocks in Japan and that in the circum Japan Sea region are shown in Table III. The lavas from Ia and IIb zones of most calcic type are mostly plotted below the average line of volcanic rocks in Japan. And IIIb, IIIa, IIc and IVc zones are low in *c-(al-alk)* value next to them. While the lavas of IIIc, IIa and IVa are mostly higher than the average line or more alkalic in magmatic character. IId, Ic, Ib and IVd zones are comparatively high in *c(al-alk)* value next to the above three.

From the *k-mg* relation diagrams (figure 5), numbers of the lavas plotted below and on the lines representing the average values of volcanic rocks in Japan and in the circum Japan Sea region were counted as in Table IV. Most lavas of Ia. IIb and IIIb zones are below or at the left side of

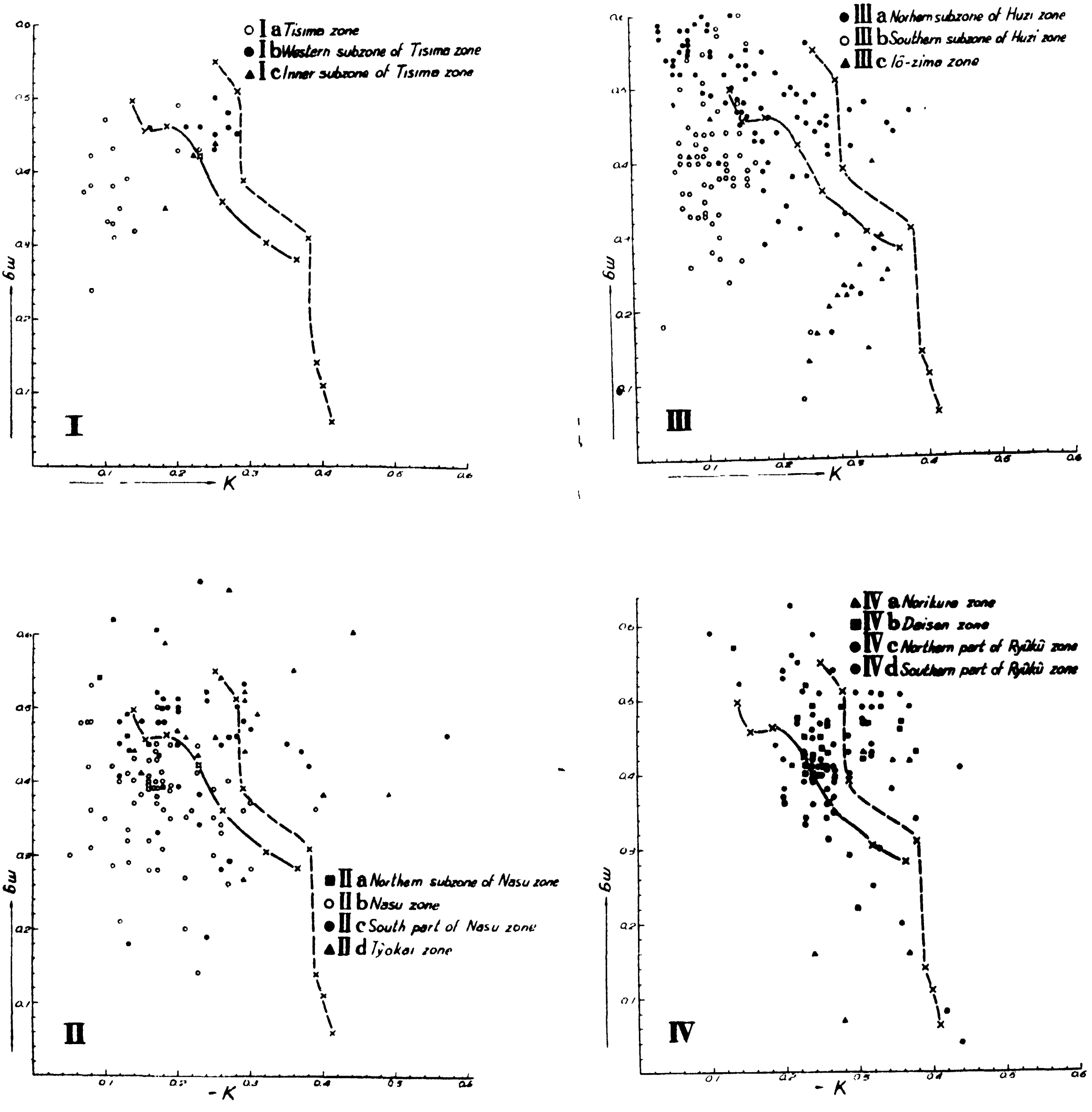

Fig. 5.—Variation diagrams of *mg-k* relation. The full line shows the average value of young volcanic rocks in Japan, and the dashed line that of alkalic volcanic rocks in the circum Japan Sea region.

the average line of volcanic rocks in Japan. Especially IIIb zone show the lowest value ranging from 0.02 to 0.17 in k, though *mg* is variable between 0.07 and 0.60. The above three zones are of the most calcic type also from *qz* or (*al-alk*) value. The lavas from IIIc and Ic zones are mostly plotted below the average line, but the former zone comprises volcanoes made up of alkalic rocks rich in Na_2O and the latter consists of slightly alkalic basalt. IIIa, IVd and IIc zones include more lavas above the average line than those below it respectively.

While the lavas from IId, IVb, IVc, IVa and Ib zones are mostly above or at the right side of the average line of volcanic rocks in Japan, and not a few lavas from the former three are even above the average line of volcanic rocks in circum Japan Sea region. Accordingly each zone is chemically characterized by *k-mg* relation, and concentration area and arrangement are also significant to consider the trend of magmatic differentiation.

Structurally, the geological units are distributed zonally in the Kurile arc or in the northern Honsyû arc from the west or the inner to the east or the outer sides as follows (Minato, M, Yagi, K, and Hunahashi, M., 1956);

(1) Japan Sea basin or Okhotsk Sea basin
(2) Inner zone with volcanic belt
(3) Outer zone
(4) Pacific ocean basin surrounded by the Japan trough.

Quaternary volcanoes are distributed only in the inner zones of the above arcs where the so-called green tuffs are distributed widely. Minato and his collaborators stated that Quaternary volcanoes have been formed upon uplifted green tuff regions.

From the result obtained by the authors, it is concluded that, among Quaternary volcanoes formed in the inner zone, those made up of more calc-alkalic lavas are arranged on the outer side. Rittmann (1953) studied already the magmatic character and tectonic position of the Indonesian volcanoes, and stated that the calc alkaline character of the magmas of the volcanoes decreases regularly from the foredeep to the hinterland. It is interesting that a similar zonal arrangement of volcanoes is shown in the Japanese islands and their environs.

REFERENCES

Burri, C., 1926, *Schweiz. Min. Petr. Mitt.*, **VI**: 115-208.

Hamaguchi, H. and Tatsumoto, M., 1953, *Jour. Tokyô Univ. Fisheries*, **40**: (2) (sp. number), 21.

Hayashi, H., 1955, *Jour. Geol. Soc. Japan*, **61**: 240-248.

Hirokawa, O. and Murayama, M., 1955, Explanatory text of the geological map of 1/50,000 scale "Iwanai sheet", 15.

Hobbs, W. and Hunt, W.F., 1926, *Proc. 3rd Pan Pac. Sci. Cong.* Tokyô, **1**: *715*.

Honma, F., 1922, Graduation Thesis for Tokyô Univ. (Manuscript)

———, and Mukae, M., 1938, *Bull. Volc. Soc. Japan*, **4**: 71.

———, 1944, *Globe Tikyu*, **24**: 245.

Ichiki, M., 1929, *Bull, Earthq. Res. Inst.*, **7**: 370.

Iddings, J.P., 1913, Rock minerals, **11**: 611.

Inoue, R., 1913, *Bull. Geol. Surv. Japan*, **41**: 76-77.

Ishikawa, T., 1951, *Jour. Fac. Sci. Hokkaidô Univ.*, Ser. IV, **7**: 339-354.

———, 1952, *Jour. Fac. Sci. Hokkaidô Univ.*, Ser. IV, **8**: 107-135.

Ishikawa, T., Katsui, Y. and Suzuki, Y., 1952, *Jour. Geol. Soc. Japan*, **58**: 268.

Ishikawa, T. and Katsui, K., 1955, 62 Ann. Meet. Geol. Soc. Japan. Symposium.

Isshiki, N., 1955, *Jap. Jour. Geol. Geogr.*, **26**: 209-218.

Iwasaki, I., 1936, *Bull. Chem. Soc. Japan*, **57**: 1328.

———, 1937a, *Bull. Chem. Soc. Japan*, **58**: 339-353.

———, 1937b, *Bull. Chem. Soc. Japan*, **58**: 482-506.

Kani, K., 1934, *Proc. Imp. Acad. Tokyô*, **10**: 79.

———, 1935, *Jour. Jap. Assoc. Petr. Min. Econ. Geol.*, **14**: 15-22.

Katô, T., 1913, *Rep. Imp. Earthq. Investig. Comm.*, **75**: 60.

Katsui, Y., 1953, *Jour. Fac. Sci. Hokkaidô Univ.*, Ser. IV, **8**: 245-258.

———, 1954, *Jour. Geol. Soc. Japan*, **60**: 185-191.

Katsui Y., 1955, *Jour. Geol. Soc. Japan*, **61**: 481-491.

———, 1955, *Jour. Jap. Assoc. Min. Petr. Econ. Geol.*, **39**: 190-194.

———, 1956, Appendix of explanatory text to geological map of 1/50,000 scale "Rusutu sheet" 1-14.

Kawano, Y., 1937, *Jour. Jap. Assoc. Petr. Min. Econ. Geol.*, **18**: 196-197.

———, 1939, *Jour. Jap. Assoc. Petr. Min. Econ. Geol.*, **22**: 6.

Kikuchi, Y., 1890, *Jour. Coll. Sci. Imp. Univ. Tokyo.*, **3**: 73.

Kochibe, T., 1896, *Jour. Geogr. Tokyo*, **8**: 242.

Komada, K., 1916, *Rep. Imp. Earthq. Investig. Comm.*, **84**: 76.

Kozu, S., 1909, *Jour. Geol. Soc. Japan*, **16**: 456-467.

———, 1911, *Jour. Geol. Soc. Japan*, **18**: 314.

———, 1927, *Tikyu (Globe)*, **7**: 447.

———, 1928, *Tikyu (Globe)*, **2**: 263.

———, 1932, *Bull. Volc. Soc. Japan.* **1** (1): 13.

Kuno, H., 1935, *Jap. Jour. Geol. Geogr.*, **12**: 158.

———, 1950, *Bull. Geol. Soc. Amer.*, **61**: 957-1020.

———, 1952, *Trans. New York Acad. Sci.* Ser, II, **14**: 225-231.

——, 1954, *Jour. Fac. Sci. Univ. Tokyo*, sect. II, **9**: 241-265.

Kurasawa, H., 1956, Read at the 63th annual meeting of Geol. Soc. Japan.

Matsumoto, H., 1956, *Kumamoto Jour. Sci.*, ser. B, sect. 1, 2, 41-48.

Morimoto, R. *et al.*, 1953, *Jour. Geogr. Soc. Japan.* (Tirigaku), **1**: 80-97.

———, 1954, Read at the 61th annual meeting of Geol. Soc. Japan.

Murauchi, S., 1954, *Bull. Nat. Sci. Museum, Tokyo*, 1, **2**: 26.

Minato, M., Yagi, K. and Hunahashi, M., 1956, *Bull. Earthq. Res. Inst.*, **34**: 237-264.

Nagai, S., 1931, Chemistry of inorganic industrial materials, 4.

Nemoto, T., 1934, *Bull. Volc. Soc. Japan*, **2**: 90.

——— 1937, *Bull. Volc. Soc. Japan*, **3**: 182.

Ogawa, T., 1924, *Jour. Fac. Sci. Kyoto Univ.*, **1**: 253.

Ota, R., 1953, Explanatory text of the geological map of 1:50,000 scale "Numata sheet" 30.

Rittmann, A., *Bull. Volc. Ser.* II, Tome, **14**: 45-58.

Sakai, E., 1939, *Jour. Geol. Soc. Japan*, **46**: 274-277.

Satô, D., 1925, Ganseki-tisitu-gaku (Petrological Geology), 338-339.

Sekiya, S. and Kikuchi, Y., 1890, *Jour. Coll. Sci. Tokyo Univ.*, **3**: 153.

Seto, K, and Yagi, T., 1931, *Jour. Jap. Assoc. Petr. Min. Econ. Geol.*, **5**: 130-131.

Seto, K., 1931, *Jour. Jap. Assoc. Petr. Min. Econ. Geol.*, **6**: 256-262.

Shiga, Y., 1929, *Jour. Jap. Assoc. Petr. Min. Econ. Geol.*, **1**: 22-23.

Sugano, I. and Arimura, G., 1957, Kagaku (Science), Iwanami, **27**: 144.

Sugi, K., 1942, *Mem. Fac. Sci. Kyusyu Imp. Univ.*, Ser., IV, **1**: 82.

Suzuki, J. and Sasa, Y., 1932, *Bull. Volc. Soc. Japan*, **1** (1): 40-43.

Tada, F. and Tsuya, H., 1927, *Bull. Earthq. Res. Inst.*, **2**: 49-84.

Takahashi, K. and Sawamura, K., 1957, Read at the 10th annual meeting of Chem. Soc. Japan.

Tanakadate, H., 1935, *Proc. Imp. Acad. Tokyo*, **11**: 371.

Taneda, S., 1951, *Sci. Rep. Fac. Sci. Kyûshû Univ.* (geol.) Ser. VII, **2**: 55-75.

— 1952, *Jour. Geol. Soc. Japan*, **58**: 517-521.

Tomita, T., 1935, *Jour. Shanghai Sci. Inst.*, sect. 2, **1**: 227-306.

Tsuboi, S., 1920, *Jour. Fac. Sci, Tokyo Univ.*, **43**, (6): 85.

Tsuboya, K., 1932, *Jap. Jour. Geol. Geogr.*, **9**: 210.

Tsuya, H., 1929, *Bull, Earthq. Res. Inst.*, **7**: 283-300 and 324.

———, 1930, *Bull. Earthq. Res. Inst.*, **8**: 258-263.

———, 1933, *Bull. Earthq. Res. Inst.*, **11**: 585-589.

Tsuya, H., 1934a, *Bull. Earthq. Res.Inst.*, **12**: 66.

———, 1934b, *Bull. Volc. Soc. Japan*, **3**: 53-71.

———, 1936, *Bull. Volc. Soc. Japan*, **3**: 28-52.

———, 1937, *Bull. Earthq. Res. Inst.*, **15**: 257. **279**: 291-286, 295 and 339.

———, *et al.*, 1953, *Jour. Tokyo Univ. Fisheries*, **40** (2): 17.

Volc. Soc. Japan, 1936, *Bull. Volc. Soc. Japan*, **3**.

Washington, H.S., 1917, *U.S.G.S.* Prof. Paper **397**.

Yagi, K., 1953, *Trans. Amer. Geoph, Union*, **34**: 449-456.

Yamada, S., 1930, *Jour. Geol. Soc. Japan*, **37**: 1-6.

Table I.
Numbers of the available chemical analyses from each volcano and zone with their sources or analysts.

I *Volcanoes on the Kurile Arc*

Ia, Tisima (Chishima) volcanic zone; 16

Praramusiru	2:	J. Suzuki&Y.Sasa(1932)
Harimkotan	1:	T. Nemoto (1934)
Urup	4:	T. Nemoto (1935)
Etorohu	1:	Y. Katsui (unpublished)
Kunasiri	1:	S. Kôzu (1909)
Siretoko-Iô-zan	1:	S. Kôzu (1909)
Masyû	5:	Y. Katsui (1955)
Me-akan	1:	Y. Katsui (unpublished)

Ib, Western subzone of Tisima volcanic zone (Daisetu volcanic zone); 9

Daisetu	5:	Y. Katsui (unpublished)
Takanegahara	1:	Y. Katsui (unpublished)
Tokati	2:	F. Taba & H. Tsuya (1927)
Furanodake	1:	Y. Katsui&T. Takahashi (unpublished)

Ic, Inner subzone of Tisima volcanic zone; 3

Alaid	1:	J. Suzuki & Y. Sasa (1932)
Taketomi	2:	H. Kuno (1935)

II *Volcanoes on the Northern Honsyû Arc*

IIa, Northern subzone of Nasu volcanic zone; 10

Risiri	9:	Y. Katsui (1953)
Syokan	1:	Y. Katsui (unpublished)

IIb, Nasu volcanic zone; 68

Yôtei (Ezo-huzi)	4:	Y. Katsui (1956)
Tarumai	18:	T. Ishikawa (1952)
Usu	5:	K. Yagi (1953)
Komaga-take	14:	S. Kôzu (1909), H. Tsuya (1930), K. Seto & T. Yagi (1931) and K. Seto (1931)
Hakkôda	1:	Y. Kawano (1939)
Towada	6:	Y. Kawano (1939)
Iwate	2:	S. Yamane (1915)
Kurikoma	1:	Y. Katsui (unpublished)
Onikôbe	1:	Y. Katsui (1955)
Naruko	6:	Y. Shiga (1929)
Zaô-san	2:	S. Nishiyama (1887) and T. Kochide 1889
Azuma-san	2:	S. Nishiyama (1887)
Adatara	1:	S. Nishiyama (1887)
Bandai	5:	S. Nishiyama (1887)

IIc, South part of Nasu volcanic zone; 33

Nyohô-Akanagi	8:	M. Yamasaki (1954)
Akagi	5:	R. Ôta (1953)
Kusatu-sirane	5:	H. Tsuya (1934a)
Asama	15:	S. Kôzu (1932), H. Tsuya (1933), K. Kani (1935) and I. Iwasaki (1936)

IId, Tyôkai (Chôkai) volcanic zone; 16

Iwaonupuri	2:	O. Hirokawa & M. Murayama (1955) and S. Kôzu (1909)
Osima-ôsima	4:	Y. Katsui (1954)
Oshima-Kozima	1:	Y. Katsui (unpublished)
Iwaki-san	1:	Y. Katsui (1954)
Kanpu	5:	Y. Katsui (1954)
Ichinomegata	1:	H. Havashi (1955)
Tyôkai-san	1:	Y. Katsui (1954)
Sumon	1:	F. Honma (1922)

III *Volcanoes within Fossa Magna region and on the Izu, Bonin and Iô-zima Island*

IIIa, Northern subzone of Huzi (Fuji) volcanic zone; 82

Kurohime	3:	H. Tsuya (1937)
Iizuna	3:	H. Tsuya (1937)
Kayaga-take	2:	M. Ichiki (1929)
Kurohuzi	1:	H. Tsuya (1937)
Huzi (Fuji) & Asitaka	14:	H. Tsuya (1934 & 1937)
Amagi & Ômuro-yama	51:	D. Satô (1925), H. Tsuya (1937), (1954), H. Kuno (1954) and H. Kurasawa (1956)
Nii-zima	3:	H. Tsuya (1929), K. Kani (1935) and S. Nagai (1936)
Kôzu-sima	5:	H. Tsuya (1929)

IIIb, Southern subzone of Huzi volcanic zone; 66

Hakone	8:	R. Inoue (1913) and H. Kuno (1950)
Taga	12:	H. Kuno (1950)
Usami	8:	H. Tsuya (1937)
Ô-sima	12:	S. Tsuboi (1920), S. Kôzu (1927), K. Kani (1934), H. Kuno (1950) and R. Morimoto *et al.* (1953)
To-sima	1:	S. Kôzu (1927)
Utone-zima	1:	S. Kôzu (1927)
Miyake-zima	6:	H. Tsuya (1929 & 1937) and S. Kôzu (1928)
Mikura-zima	1:	H. Tsuya (1937)

Hatizyô-zima 1: H. Tsuya (1937)
Aoga-sima 4: H. Tsuya (1937) and N. Isshiki (1955)
Myôzin-syô 6: H. Tsuya *et al* (1953), H. Hamaguchi and M. Tasumoto (1953) and R. Morimoto (1954)
Tori-sima 1: H. Tsuya (1937)
Ogasawara (Bonin) 5: Y. Kikuchi (1890), W.H. Hobbs & W.F. Hunt (1926), K. Tsuboya (1932) and H. Tsuya (1937)

IIIc. Iô-zima volcanic zone; 14
Iô-zima Islands 14: H. Tsuya (1936) and I. Iwasaki (1937)

IV *Volcanoes of South-Western Japan*

IVa. Norikura volcanic zone; 8
Iô-dake 1: T. Katô (1913)
Yakeyama 2: D. Satô (1925)
Norikura 4: S. Kôzu (1911), H.S. Washington (1917) and D. Satô (1925)
Ontake 1: J.P. Iddings (1913)

IVb. Daisen volcanic zone; 31
Sambe 4: S. Kôzu & B. Yoshiki (1929)
Kuzyû 1: D. Satô (1925)
Ône-zima 1: E. Sakai (1939)
Hutago 13: K. Komada (1916) and Y. Kawano (1937)
Unzen 11: Volc. Soc. Japan (1936), K. Kani (1935) T. Ogawa (1924) and D. Sato (1925)

IVc, Northern part of Ryûkyû volcanic zone: 32
Aso 16: F. Honma & M. Mukae (1938), K. Yamaguchi (1938) and I. Sugano & G. Arimura (1957)
Kirisima 16: D. Satô (1925) and K. Takahashi & K. Sawamura (1957)

IVd, Southern part of Ryûkyû volcanic zone; 33
Sakurazima 16: Volc. Soc. Japan (1936)
Iô-zima 2: H. Tanakabate (1935)
Kuchinoerabu 2: F. Honma (1944)
Suwanose-zima 13: S. Murauchi (1954) and H. Matsumoto (1956)

Table II.

Numbers of the lavas plotted above and on the line showing the average of volcanic rocks in Japan respectively in figures 2 and 3.

Zone	Total numbers	*qz* value		*(al-alk)* value	
		above	on	above	on
Ia	16	14	0	13	1
Ib	9	0	2	1	0
Ic	3	0	0	1	0
IIa	10	0	1	1	0
IIb	68	55	5	50	4
IIc	33	19	4	16	2
IId	16	1	0	3	0
IIIa	82	24	8	28	5
IIIb	66	58	3	33	2
IIIc	14	0	0	0	2
IVa	8	1	0	2	0
IVb	31	5	6	10	3
IVc	32	2	5	13	1
IVd	33	18	6	8	5

Table III.

Number of the lavas below and on the lines showing the average values of volcanic rocks in Japan (Average J) and in circum Japan Sea region (Average JS) in *c-(al-alk)* values in figure 4, counted in every zones.

Zones	Total numbers	Average JS		Average J	
		below	on	below	on
Ia	16	14	1	5	4
Ib	9	6	0	3	0
Ic	3	3	0	1	0
IIa	10	4	1	0	0
IIb	68	59	1	44	2
IIc	33	23	1	11	2
IId	16	8	1	5	0
IIIa	82	64	2	25	7
IIIb	66	56	1	28	1
IIIc	14	4	1	1	0
IVa	8	2	0	1	1
IVb	31	13	3	9	2
IVc	32	27	3	12	2
IVd	33	11	0	7	0

Table IV.

Numbers of the lavas below and on the lines showing the averages of volcanic rocks in Japan (Average J.) and in circum Japan Sea region (Average J.S.) in k-mg relation in figure 5, counted in every zone.

Zones	Total numbers	Average J.		Average J.S.	
		below	on	below	on
Ia	16	13	2	16	0
Ib	9	0	1	9	0
Ic	3	2	0	3	0
IIa	10	4	0	10	0
IIb	68	61	1	67	1
IIc	33	12	0	24	1
IId	16	3	0	7	1
IIIa	82	39	3	75	1
IIIb	66	60	2	66	0
IIIc	14	12	0	13	0
IVa	8	3	0	5	0
IVb	31	6	1	22	0
IVc	32	5	1	15	0
IVd	33	10	2	31	0

RELATIONS BETWEEN THERMAL SPRINGS AND STRUCTURE IN VIET-NAM

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(Abstract)

The 85 thermal-mineral springs of Viet-Nam are for the largest part related to large faults formed during block-movements at the end of the Tertiary and during the Quaternary.

Though they almost never emerge in the basalts of the same geological period, they are nevertheless related to these and are situated on the same lines of weakness.

THE KAMCHATKA VALLEY OF TEN THOUSAND SMOKES

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For the first time in history an eruption of the Bezymianny Volcano of the Klyuchevskaya group of volcanoes on Kamchatka took place in 1955-1956. The most important event of the eruption was a giant explosion on March 30, 1956, which occurred at 5.11 p.m. local time (0.6.11 a.m. G.M.T.). In a few minutes a colossal fan-shaped cloud of ashes had risen above the volcano. The lower border of the newly-formed giant "fan" was at 6-8 km, and the upper one at about 36 km. An extremely intense ash-fall stretched NNE from the volcano. Thus in the Klyuchi settlement (45 km distant from the volcano) the ashes fell for 3.5 hours and reached 20 mm in thickness or 24.5 kg/m^2 in weight (the total from the beginning of the eruption being 45 mm or 40 kg/m^2). Impenetrable darkness reigned in the area of the ash-fall; people were walking in the streets in search of their homes. Deafening rumblings of a thunderstorm followed one another. The air was charged with electricity, telephones rang spontaneously, broadcasting loud-speakers fused, lead-ins of antennas sparkled. Ashes blown into the stratosphere by the explosion were caught by currents and passed over the North Pole, they were observed in England 3 or 4 days later.

It is interesting to note that the explosion on March 30 was not heard either near or at a distance. Nevertheless all the meteorological stations in the radius of over 1,000 km. registered the blast wave on barogramms. Thus, in Klyuchi (45 km. distant from the volcano) pressure changed to 23.5 millibar while in Markovo on Chukotka Js. (1,100 km. from the Bezymianny), to 1 millibar.

Sensitive microbarographs recorded the explosion wave everywhere which ran one and a half time round the Globe.

As a result of the explosion the Bezymianny Volcano changed beyond recognition: from a slightly truncated cone it was transformed into a semi-circular caldera-volcano. The newly formed, immense crater embraced not only the summit but also the whole south-eastern slope to the foot, stretching 1.5 × 2 km. The top of the volcano became 150-180 m, lower its absolute height being reduced to about 2900 m, instead of the former 3085 m.

The Sukhaya (Dry) Khapitsa Valley situated on the eastern slope of the volcano was found to be buried over a distance of 18 km. by an agglomeratic flow of a chaotic mixture of ash, sand and lava blocks of all possible sizes. Thousands of secondary fumaroles were rising from the surface of this flow.

The eastern surroundings of the volcano were covered with a layer of volcanic sand up to 0.5 m in thickness till a distance of 10-13 km. Further East, at a distance of 27-29 km, the thickness of the sand rapidly decreased to a few cm only. During the explosion ashes were blown out of the crater with a colossal energy, like a stream out of a giant sand ejecting apparatus. The strength of the explosion broke and cut big trees with diameters up to 25-30 cm. at a distance of 25 km.

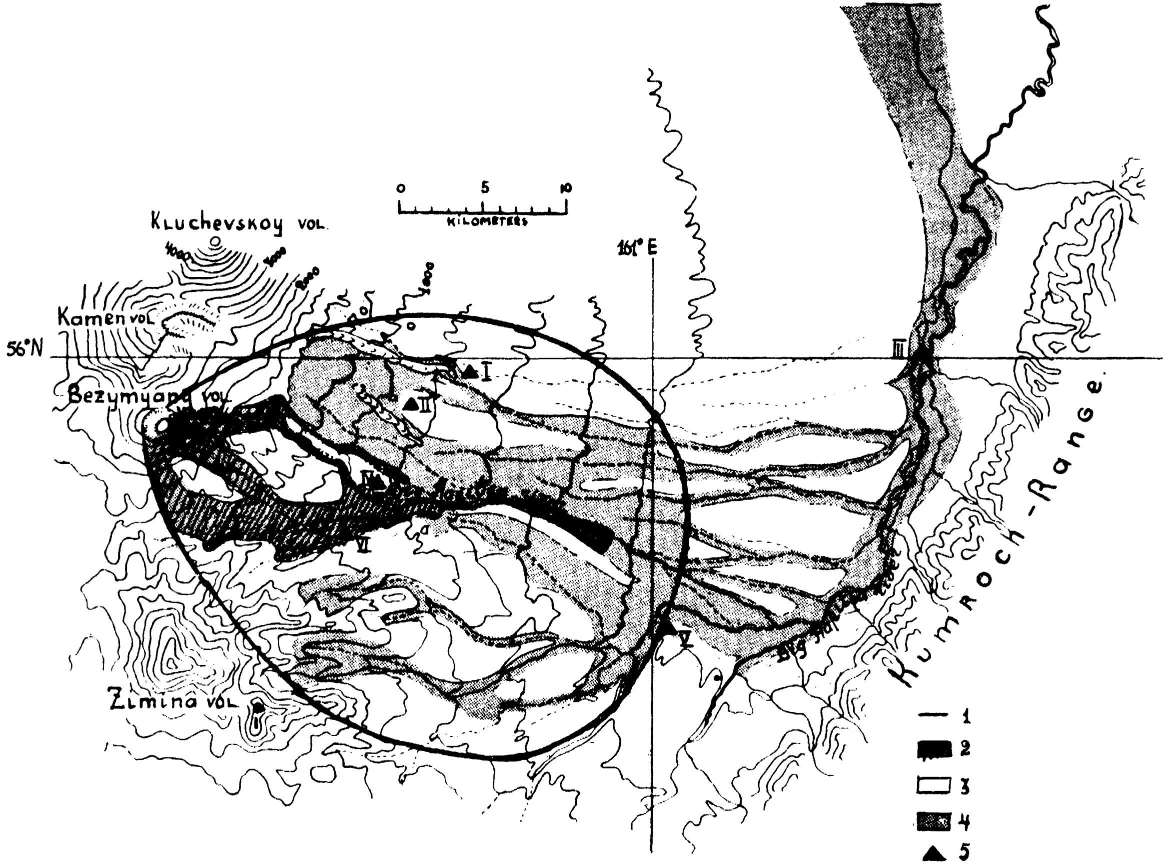
The ash which fall on the ground still contained a certain amount of gases and was very mobile ("flowing"). It moved down the hills and steep slopes filling all the river valleys in the neighbourhood of the volcano with sandflows several meters thick.

At the moment of the explosion the ash was so hot that it burned the bark of trees and bushes at distances of 27-29 km from the erupsion centre, while some trunks were burned completely. Rapid melting of snow took place, under the cover of hot ashes, over an area of about 500 km^2.

In the Sukhaya Khapitsa and on the slopes of the Zimina and Klyuchevskaya Volcanoes mud flows (lahars) developed which rushed down, transporting big stones and destroying everything on its way.

The mud flows ran eastward to the B.Khapitsa River turned north following the valley and discharged themselves into the valley of the Kamchatka River. Two large lakes were found burried under mud flow deposits.

The most interesting consequence of the explosion on March 30 was the formation of a large agglomerate flow with thousands of secondary fumaroles in the Valley of the Sukhaya Khaŭitsa River. This picture so much resembled the



Sketchmap of the area influenced by the explosion of Bezymianny on March 30, 1956, 1. boundary of the area ruined by the explosion, 2. agglomerate flow, 3. mud deposits, 4. routes of mud flows (lahars), 5. expedition camps. (Compiled by the author).

description of the famous Katmai flow in Alaska that the Sukhaya Khapitsa valley was given the name: "Kamchatka Valley of Ten Thousand Smokes".

The agglomerate flow has been investigated three weeks after the explosion and more thoroughly in the summer of 1956. The contours of the flow were found to be rather complex (see sketchmap)

In many parts of the agglomerate flow explosive craterlets were scattered. The explosions occurred after the flow stopped and judging from all data were caused by the ejection of incandescent masses on thick concentrations of ice or snow.

At the moment of the eruption the agglomerate saturated with gases had a strong fluidity and could not stay on steep slopes of the volcano. Due to this, agglomerates practically lack on the volcanic slopes and the agglomerate flow starts, if not from the crater, from the foot of the volcano where the angle of the slope does not exceed 4 or 5°.

The length of the agglomerate flow is 18 km, its max. width is 4 km. The area covered by the flow is 55-60 km^2. The thickness of the flow in the marginal part amounts to 20-30 m, in the central part it is, doubtless, higher and probably, reaches 70-80 m. If we accept an average thickness of 50m, the volume of the agglomerate flow is about 3 km^3.

The overwhelming majority of the fumaroles are found on the walls and beds of constant and temporary water ways. The temperature of the fumarole gases sometimes rises to 200° but is in the main about 100°. According to composition the fumaroles represent steam flows with admixtures of air and acid gases (CO_2, H_2S, SO_2). The air lacks oxygen: the ratio of oxygen to nitrogen is 1:48 instead of 1:4 in the atmosphere. It is evident that in the thickness of the agglomerate flow vigorous oxidizing processes take place.

On clear and hot days when mountain glaciers melt more vigorously and water rapidly arrives at the bed of the Sukhaya Khapitsa the banks composed of hot agglomerates soon wash away and fall into the water. Every crumbling of caused a steam eruption, a kind of a "secondary eruption", with ash clouds rising to 200-300 m. Especially strong explosions took place on days when rain fell in the mountains.

Then, hundreds, even thousands of secondary eruptions occurred at the surface of this agglomerate flow.

Ash clouds rose to 0.5 km. and drifted off 2 or 3 km., dispersing ashes.

The waters of the Sukhaya Khapitsa were overfilled with loose materials forming a dense but rather mobile mud in which large rocks were easily transported. Enormous quantities of hot material crumbled down into the water and caused a noticeable rise of temperature in these cold glacial waters (up to 35-45° in the Sukhaya Khapitsa). Throughout the winter of 1956/1957 the agglomerate flow remained warm and was not covered with snow. Fumarolic activity on the flow was still observed in 1957.

The strength of the 1956 eruption of the Bezymianny Volcano can be compared with that of the eruptions of Krakatao in 1883, Katmai in 1912 and Pelée in 1902. The nature of the eruption resembles that of Mt. Katmai.

The first preliminary results of a comparative study of the eruption of the Bezymianny volcano with that of the Katmai Volcano in Alaska, enables, us to reveal some erroneous conceptions on the eruptive conditions of the Katmai and the origin of the Valley of Ten Thousand Smokes.

We think the source of tuffs in the Katmai valley not to be fissures under the valley, but central craters of the Katmai and Novarupta, besides it is very doubtful to speak of an assimilation of moraine material by rhyolite magma in the by-surface conditions.

A REPORT ON THE PUNA RIFT ERUPTION OF KILAUEA VOLCANO, FEBRUARY 28 - MAY 26, 1955

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(As an eye-witness throughout the eruption, the reporter has relied heavily on the assistance of Drs. Gordon A. Macdonald and Jerry P. Eaton of the U.S. Geological Survey. Ref. The Volcano Letters 529—530; July-December, 1955.)

The volcano Kilauea (4,090 feet), which does not need introductory description to geologists anywhere, rests against the southern flanks of the greater shield volcano, Mauna Loa (13,680 feet) on the island of Hawaii. At the present time, its principal vent, Halemaumau, is located within a summit caldera, 2,800 acres in area. Halemaumau marks the junction of the two major and one minor rift zones that radiate outward and have been the scenes of ten eruptions recorded since 1823 when visit and observation of the volcano was first recorded in print. Of the three rifts, the Puna extends southeasterly from Halemaumau, curves easterly, and with a trend of NO/65/E disappears beneath the sea at Cape Kumukahi, the easternmost point of the island as well as of the triangularly shaped Puna District which has been built from flows from the rift. Some 70 vents, a dozen pit craters, and long, deep fissures extend throughout the surface trace. An eruption of Heiheiahulu Crater is dated 1750, just before the discovery of the Hawaiian Islands by Captain Cook in 1778. Subsequent activity along the rift has occurred in 1790 (?), 1840, 1922, and 1923. The rift was site for swarms of earthquakes in 1924 whose epicenters extended outward from twelve miles east of the summit caldera. These preceded the celebrated 1924 steam-blast eruption of Halemaumau. Two strong earthquakes with foci twelve miles deep were registered south of Pahoa on March 30, 1954. These and the spectacular though short-lived summit activity on May 31, 1954 might be considered premonitory and prelude to the 1955 eruption.

The 1955 acivity was the first flank eruption of Kilauea since 1923 and the first in East Puna since 1840, the interval of quiet being 115 years. It had aspects of three separate eruptions, each of which being accompanied by premonitory seismic disturbance. Activity shifted irregularly over twenty miles of the rift, in part progressing up the slope of the volcano. Scientists observed and photographed at close range the entire sequence of activity from the initial opening of cracks and fissures, the first appearance of fume, then lava, the progressive development of fountains, vents, cones, and flows, to the final cessation of activity. The actual formation of a pit crater was also observed.

The 1955 eruption occurred in what for the island of Hawaii is a relatively heavily populated and cultivated area. It is a region of limited access and mobility by road, which presented problems of evacuation and relief that were aggravated by clamor of tourists and locals wishing to see the spectacle at close range. Because of the threats of danger it was necessary to evacuate numbers of people with all of their moveable possessions. Attempts, in part successful, were made to throw up barriers to divert the course of advancing lava streams.

In the latter part of 1954 and in early 1955 hundreds of earthquakes with foci in the Puna area grew in number and intensity. Activity broke out on the east rift twenty miles below Halemaumau within a few minutes of 8 a.m. on February 28. First cracks opened in the ground. Soon milky-white fume, mostly water vapor and sulfur oxides, appeared in increasing volume to be followed by the first lava either as red hot lapilli or as a viscous swelling bulb.

A chronological, detailed discussion accompanies presentation of the film. It starts with scenes of cultivated and forested land and Kapoho village, later threatened by flows. The first activity scenes, taken later in the morning from an airplane, shows fume pouring densely from long fissures arranged en echelon. The first extrusions of viscous lava are shown which move slowly into adjacent caneland. A small cone of welded spatter is built up. Close views taken at night looking directly into the vents show seething activity and the rapidity with which the incandescent blobs of lava are tossed out to darken as they are plastered on the lip and sides of the cone. A typical flow of the opening days is shown and a lava fall of hot liquid plunges into an earthquake crack fifty feet deep. The phreatic explosions at noon of March 1 ended this early phase. All external evidence of extrusion ceased, but great seismic disturbance continued and wide cracks were torn open in the ground. Extrusive activity was renewed on the afternoon of March 2 with rows of fountains playing 100 to 150 feet high. Flows from these endangered Kapoho. By March 4, one fountain with a temperature of 1100-1120° C. as measured with optical pyrometer, grew to a height of 800 feet and played hour after hour through the long night.

The intense activity of March 13 is shown at length with the opening of the fissures, first in cleared land, then across the Kalapana Road from which wisps of dark brown volatilized asphalt show against the milky background. The first blob of lava appears that grows into a cone thirty feet high by noon of next day. Scenes of the Hayashi homestead nearby are shown which, though not covered by lava flow, later caught fire from the intense heat and burned to the ground. Nearby trees are plastered with lava. A day later another great fountain appeared a mile downslope which afforded artistic views through the sparse branches of trees. A turbulent flow develops from this fountain. Great blocks of incandescent lava, some of them weighing twenty or more tons, are rafted with ease down the molten stream. Heat waves dance above the rapidly flowing stream. This was the first flow eventually to reach the ocean.

Close views are taken from the top of a cone which show the great force with which the stream of lava is ejected and the manner in which spatter cones are built. The vents are shown during an interval of quiet, blue flames of burning sulfur playing above them. When fountaining is resumed, a succession of scenes shows the spatter developing into a flow which grows to a mighty flood moving across the Kalapana Road next day. A deep channel is melted by the mobile, hotter lava as it moves down earlier expansive flow already chilled. The camera is pointed into the channel to register the surface of the stream in detail. The forward front of the flows have cooled to a slow advance of a wall about ten feet high. Chunks of solid matter on the surface tumble over the face with a melodious tinkling sound. Burning gases, derived from organic matter picked up along the course, play along the edge and top. Aa lava is characterized by a rough, clinkery surface. The aa flow pushes slowly, irresistably ahead pushing over pandanus and coconut trees in its path. Air views are shown of braided pahoehoe streams rushing over chilled, blackened earlier flows. The source fountains are shown as a new stream develops and moves rapidly into an ohia forest, the burning trees appearing as scintillations on the orange-yellow stream.

At last the streams reach the sea from which a column of steam ascends thousands of feet into the air. Occasional littoral explosions occur as the lava plunges over the thirty foot wave-cut cliff into the cold water. These appear as black jets of finely divided, black, glassy material which is reworked by wave action to form black sand beaches for which Hawaii is famous. These are luminous at night, as can be seen on the screen.

The intense fountaining and mighty pahoehoe rivers of May 25 and 26 are especially interesting. Fountaining and extrusion of lava came to an abrupt close at 11:15 a.m. on May 26.

The film closes with scenes taken from a helicopter to show cones, sulfur-yellow and white incrusted vents, the great new pit crater, the widespread destruction and desolation. It ends with a rapid recapitulation of a half dozen highlights of the eruption as a summary.

VOLCANISM IN NORTHERN AND CENTRAL SUMATRA

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(Abstract)

Geological and volcanological investigations were carried out in 1952-1953 in the eastern part of Northern Sumatra (Lake Toba and immediate surroundings) and in Central Sumatra (Lake Manindjau, Lake Singkarak, the surroundings of Muara Labuh and Lake Korintji).

The longitudinal fault-troughs extending from the area south of lake Toba to the volcano Talang in Central Sumatra with the two lakes Danau di Atas and Danau di Bawah were studied in detail. During the early Quaternary and also more recently this area was the scene of violent eruptions of acid pumice tuffs. The existence of long lines of fumaroles and mofettes and occurrence of many earthquakes along the Tarutung-Angkola-Gadis rift valley, and further to the south show that the bordering faults are still active.

Of volcanism in the areas of Northern and Central Sumatra could be said that really active volcanoes seem to be concentrated in the last mentioned region. With the exception of the Marapi volcano in the neighbourhood of Bukittinggi no other Sumatran volcanoes have poured out lava in recent historical time.

VOLCANISM ON THE ISLAND OF FLORES AND THE GEOLOGICAL HISTORY OF THE COLOURED LAKES OF THE KELI MUTU VOLCANO

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(Abstract)

One of the Lesser Sunda Islands is Flores which has 17 active volcanoes on a relatively small area of 15.000 sq. kms. The western and central parts of the island of Flores consist of older (Tertiary) volcanic rocks and igneous intrusions.

The young Quaternary volcanoes occur along the southcoast of West Flores. In the Central part of the island they are present not only along the southcoast but on the northern shore too (Paluweh volcano). On Eastern Flores the geanticline shows an axial plunge, older volcanic rock and granodioritic intrusions are not exposed, and only young volcanoes are found.

Aerial reconnaissances above the volcanoes of the island of Flores were first made in 1953 by the Volcanological Survey of Indonesia, followed afterwards by volcanological and geological investigations carried out in detail by three different field-parties.

An outline is given concerning the geological history of the Keli Mutu volcano in Central Flores. The three coloured lakes discussed are the showpieces of Flores and of Indonesia: blue-ish-green (Tiwu Atu Mbupu=Lake of the Aged People), troubled-green (Tiwu Nua Muri Koöh Fai=Lake of the Young Men and Virgins) and red (Tiwu Ata Polo=Lake of the Bewitched).

GEOCHEMICAL EFFECT OF THE BEZYMIANNY VOLCANO ERUPTION

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During the eruption of the Bezymianny Volcano an immense quantity of pyroclastic material was ejected.

As a result of the rains and still more of the intensive melting of snow, great quantitives of water passed through the agglomerate flow and the ashes, carrying away considerable quantities of dissolved matter to the ocean.

To determine the potential quantity of mineral matter carried away by the surface water into the Pacific an extraction of easily dissolved substances from fresh pyroclastic material was made. The extraction was carried out from a loose fraction with a diameter of less than 1 mm. The analysis was made from water drawings obtained by four-time extraction of samples in equal amounts of water, at room temperature, during 48 hours.

These conditions of extraction resemble a miniature process of the washing of eruptive products by surface water and are able to give an idea about the quantity of matter carried away by the water.

The water extracts were used to determine the contents of Cl′, SiO_2, Fe, Ca″, Mg″, Na, K and SO''_4.

The results obtained are given in Table 1, where:

I = water extract from ashes fallen in the neighbourhood of the volcano during the initial period of eruption.

II = water extract from ashes fallen during the main explosion.

III = water extract from the material of the agglomerate flow.

(mean values from the analysis of five samples).

Table 1.

Samples	Contents in mgr/100 g. of the material							
	Cl′	SO_4''	SiO_2	Fe	Mg″	Ca″	Na	K
I	95.88	400.4	2.95	10.57	21.5	157	8.1	3.11
II	55.04	198.4	2.71	8.83	10.2	81.2	5.15	1.68
III	22.7	165	2.4	5.6	3.11	54	5.5	1.7

During the main explosion on March 30,1956 about 0.5 km³ of ashes was ejected and the same quantity during the initial period of the eruption. The volume of the agglomerate flow is about 3 km³. The specific weight of loose rock is assumed to be 1.8. Hence the weight of the eruption products is: $0.9.10^9$ tons for ashes of the first and the main phases and $5.5.10^9$ tons for the agglomerate flow.

Considering that the fine fraction of the agglomerate flow is but about 80 per cent of the whole mass we obtain the following values of easily-dissolved components of pyroclastics:

Table 2.

	Contents in tons							
	Cl′	SO_4''	SiO_2	Fe	Mg″	Ca″	Na	K
I	8.6×10^5	3.6×10^6	2.7×10^4	1.0×10^5	1.9×10^5	1.4×10^6	7.2×10^4	2.7×10^4
II	5.0×10^5	1.8×10^6	2.4×10^4	0.8×10^5	0.9×10^5	0.7×10^6	4.5×10^4	1.5×10^4
III	10.0×10^5	7.4×10^6	10.0×10^4	2.5×10^5	1.4×10^5	2.4×10^6	29.5×10^4	7.6×10^4
Total	23.6×10^5	12.8×10^6	15.1×10^4	4.3×10^5	4.2×10^5	4.5×10^6	41×10^4	11.8×10^4

Thus, the total quantity of dissolved material is found to be 21.10^6 tons.

GEOLOGICAL SKETCH OF EL SALVADOR, C.A.

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(Abstract)

Reconnaissance geology of the Republic of El Salvador, C.A. is presented. 95% of the territory is covered by volcanic rocks. They distinguish the following topographic units: coastal plain, coastal mountains, young volcanic chain, interior mountains, interior valley and northern mountains. The coastal plain is covered by alluvial sediments. The volcanic coastal mountains as well as the interior mountains are considered to be of Pliocene age. The young volcanic chain belongs to the Pleistocene and volcanism is still active. The interior valley partly is covered by alluvial sediments, its basementrock consists of tertiary volcanic rocks. The northern mountains are build up by tertiary volcanic rocks, in their western part exist cretaceous sedimentary rocks as well as granitic intrusions of probably miocene age.

There are three prevailing tectonic trends: NNW, NNE and WNW. The last mentioned tectonic element partly forms two parallel graben, occupied by the young volcanic chain and the interior valley.

Mineral deposits are connected with the mentioned granitic intrusions (Fe, Cu, Pb, Zn, Mo) as well as with probably younger protrusions (Au, Ag). None of these deposits is considered to be of great value. Along the coast there are placer deposits of magnetite and ilmenite.

Symposium: *Stratigraphic Correlation for the Pacific Area*

Convener: Teiichi Kobayashi (Japan)

CIRCUM- OR TRANS-PACIFIC CORRELATION OF PALAEOZOIC CORAL FAUNAS

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Taking the Ordovician faunas first. When these were reviewed recently (Hill, 1951) nothing was known of the Pacific faunas. But Hill (1955) has since described a fauna from Tasmania and referred to another from New South Wales, and Duncan (1956) has discussed those of the western U.S.A.; these latter are largely undescribed, but Duncan indicates that a 'Chazy' faunule is present, comparable with that of the Appalachian province, and that the late Ordovician fauna is related to that of western Canada (Wilson, 1926) and the Arctic. No E. Asiatic Ordovician coral faunas are known. The S.E. Australian fauna includes one that is either of or below the Zone of *Nemagraptus gracilis;* two of its five genera are unknown so early elsewhere in the world, and had the graptolites not been found, I would have thought the coral fauna Trenton at earliest. It appears then, that we know at present too little of the ranges of the earliest coral genera to use them safely in correlation by stages from continent to continent: for the Ordovician close circum- or trans-Pacific correlation of coral faunas is not yet possible, due mainly to paucity of knowledge.

Silurian corals are known in more Pacific countries. Only in eastern Australia are Valentian corals reported. and these are not yet described. Horizons for the Wenlock and Ludlow Pacific faunas have been determined by reference to the standard N. European sequences, where the middle and upper Silurian and Gedinnian faunas form a well-marked unit that reaches its acme at the top of the Wenlockian and then declines. In E. Australia a fauna less rich than the European has been correlated with the top of the Wenlockian and possibly the base of the Ludlovian (Hill, 1940). In Japan (Sugiyama, 1940) a fauna more similar to the Australian than to the European indicates approximately the same horizon, and in China (Lindström, 1883; Grabau, 1925, 1930; Wang, 1947) and Korea (Ozaki, 1934) a similar fauna appears more European than Australian. On the eastern Pacific margin, the Silurian coral faunas are ill-described. Duncan (1956) compares those of the U.S.A. with the Niagaran faunules of eastern N. America which are indeed quite similar to those of Europe. Hume (1954) and Laudon and Chronic (1949) list names of genera for West Canada, and compare them with Niagaran faunas.

Thus present knowledge of American Silurian forms is too slight for trans- or circum-Pacific correlation, but on the western side of the Ocean, the Japanese and N.S. Wales faunas are more similar to each other than either is to the European faunas from which their equivalent horizon was deduced.

Devonian Pacific corals are better known and the faunal sequences have been reviewed recently (Hill, 1957). Gedinnian Pacific faunas are known only in E. Australia. Emsian faunas occur in Indochina (Fontaine, 1954) and in E. Australia, Couvinian in Burma (Reed, 1908), Indochina (Fontaine, 1954), China (Wang, 1948), E. Australia and New Zealand (Hill, 1956). The New Zealand and East Australian faunas have in common at least one genus not known in Europe or Asia. Givetian faunas occur in Yunnan (Fontaine, 1954) China (Yoh, 1937; Wang 1948) and E. Australia, remarkably similar to those of Europe and Asia, and for these there is no greater similarity of Chinese to Australian faunas than there is of either to European faunas.

Indeed the Western Pacific Devonian coral faunas seem to form one zoogeographic unit with those of Europe. Frasnian faunas are not known in E. Australia, but occur in Burma (Reed, 1908), and China (Smith, 1945) where again they are remarkably like those of W. Europe. Smith however has shown that two phillipsastraeid species are very similar to and another is identical with species of similar age from W. Canada. This is a remarkable instance, suggesting circum-or trans-Pacific migration, and though the age of the deposits on each side of the Pacific was determined by reference to European sequences, it seems that further study of the Chinese faunas is desirable to show whether more species common to China and Canada can be found, and close trans-Pacific correlation established.

In the Western Pacific all the European Devonian stages can be recognised by the genera present. There is in general however a difficulty in correlating to a smaller unit than the stage and correlation by identity of species is not yet possible. There are variations in the relative abundance of genera apparently both with time and with place, and we cannot yet distinguish the time variation from the place variation; subgeneric differentiation may help in this problem; and the discovery of deposits in intervening regions may permit some correlations by assemblages of identical species over limited areas.

In the eastern Pacific, the oldest known Devonian coral fauna is in the basal 500 ft. of the Nevada limestone. Many of its genera are endemic, but it has some links with the Atlantic Onandagan, regarded as Emsian or early Couvinian. It has little resemblance to that of the W. Pacific. In the Nevada limestone between 500 and 1800 feet above the base, three species show remarkable resemblance to three Australian early Couvinian species, and *Heliolites* makes its first known Devonian appearance in N. America; this is possibly evidence of trans-Pacific migration; whether it can be used in trans-Pacific correlation is not yet clear, as there is still some controversy in America about the horizon of this section of the Nevada limestone in terms of both the European and east American standards.

Givetian and Frasnian faunas are widespread in western N. America, and are of European and hence west Pacific type, rather than eastern American, Hill (1957) concluding that the W. Pacific and European and Australian regions then formed one zoogeographical province. Indentity of Canadian and Chinese Givetian species has been noted above.

During Famennian times coral faunas probably occurred in Canada, but have not been clearly distinguished from Frasnian faunas.

The Carboniferous coral fauna seems to have begun in Famennian times. In Tournaisian faunas, in the West Pacific, except perhaps in China (Yü, 1933) corals are too rare for use in stage correlation. In the eastern Pacific, a distinctive fauna of colonial Rugosa is present (Hill, 1948), but its age is best established by the non-coral elements. In the Viséan and Namurian, coral faunas in E. Australia, China and Japan may be correlated with the European stages largely on their colonial Rugose genera, the solitary Rugosa tending to be distinctive in each region; the resemblance between Australian and Sino-Japanese faunas is less striking than in the Silurian. East Pacific Viséan and Namurian faunas are rather distinctive, even in their colonial Rugosa, but contain one genus (*Lithostrotionella*) known elsewhere at the time only in China. This may indicate some degree of migration and hence possibilities of direct circum-Pacific correlation.

In the Bashkirian and Moscovian, reasonably rich Pacific coral faunas are known only in Southeast Asia, and are closely correlatable with those of Russia. In N. America the equivalent early Pennsylvanian coral faunas are rather scanty. Post-Moscovian and pre-Sakmarian corals are not known in sufficient numbers in Pacific countries for reliable correlations.

The east Asiatic Sakmarian coral fauna is quite rich in colonial corals and is directly correlatable with east European Tethys (not with the Urals). In Indonesia and Australia however, only solitary, non-dissepimented corals are known, but are of universal, long-ranging genera, similar to those of the eastern Pacific Wolfcampian, where however some colonial Rugosa in British Columbia and Texas do permit correlation with the Asiatic fauna.

In the Artinskian, this Tethyan colonial fauna continues in east Asia, but only solitary, long-ranging, universal genera (and some endemic genera) occur in Indonesia, E. Australia, New Zealand, and in the Eastern Pacific in the Leonardian of U.S.A., so that we have no good grounds here for trans- or circum-Pacific correlation.

In the Kungurian this Tethyan colonial fauna reaches the height of its development in China and Japan (in the *Neoschwagerina-Verbeekina* Zone with *Leptodus* = *Lyttonia*) but in Australia and on the eastern side of the Pacific (Ward) only small solitary Rugosa and long-ranging Tabulata are known, of no great value for trans-Pacific correlation.

In the Kazanian, in Japan (*Yabeina* Zone) and also in the *Lepidolina* Zone which however may be younger than Kazanian, the Tethyan 'colonial' fauna is still rich, and has spread to New Zealand, where representatives occur at the northern tip, so that a New Zealand - Japan correlation is possible. But in China, Indonesia and Australia only small solitary Rugosa (some endemic) occur, of no great value for correlation. On the eastern side of the Pacific in the Capitanian, a few colonial Rugosa permit correlation with Tethys and East Asia.

In the highest Permian, corals are so rare in the Pacific region that they are at present of no value for correlation.

REFERENCES

The coral literature on which this review is based is too extensive for listing here, but may be found in the following compilations or review papers:

Bassler, R.A., 1950, Faunal lists and descriptions of Palaeozoic Corals. *Mem. Geol. Soc. Amer.* **44**.

Duncan, H., 1956, Ordovician and Silurian Coral Faunas of Western United States. *Bull. U.S. Geol. Surv.* **1021-F.**

Hill, D., 1948, The distribution and sequence of Carboniferous Coral Faunas. *Geol. Mag.* **85**: 121-148.

——, 1951, The Ordovician corals. *Proc. roy. Soc. Qld.* **62**: 1-27.

——, 1955, Ordovician corals from Ida Bay, Queenstown and Zeehan, Tasmania. *Pap. Proc. roy. Soc. Tas.* **89**: 237-254.

——, 1957, The sequence and distribution of upper Palaeozoic coral faunas. *Aust. J. Sci.* **19**, (3a, ANZAAS): 42-61.

CORRELATION OF FUSULINID ROCKS FROM SOUTHERN SUMATRA, BANGKA AND BORNEO, WITH SIMILAR ROCKS FROM MALAYA, THAILAND AND BURMA

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(Abstract)

Four occurrences of Upper Palaeozoic rocks containing fusulinids are described.

The first record of Upper Palaeozoic from Borneo comes from J.G.H. Ubaghs who discovered pebbles with *Fusulina* spp., determined by Tan Sin Hok in a Lower Tertiary conglomerate in Kutai, East Borneo (1930).

The Permo-Carboniferous Fusulinidae in limestones, marbles, jasperoids and combustible clay shales silicified into cherts from various localities in West Borneo were found by F. Krekeler (1932, 1933).

Two localities of limestone, containing *Neoschwagerina* and *Fusulina* spp. in the Palembang area, South Sumatra (East of Bukit Pendopo) were discovered by K.F.G. Keil. Probably these limestones could be considered as continuations of the Tebo-Tabir facies of A. Tobler occurring in the Djambi area. Little is known concerning their geology, it may be probable that they are relics of overthrust sheets.

About 18 kms. west of Palembang, in the Sekaju area pebbles with *Radiolaria*, *Crinoidea* and Fusulinids were found in a conglomerate of Old Neogene age by J. Van Tuyn (1931).

From the island of Banka fusulinid foraminifera were determined by the author in cavernous silicified limestones and fine crystalline quartzites of the Sungailiat area near Aerduren collected by W.P. de Roever.

Stratigraphic correlation is discussed of the above fusulinids containing rocks with those of the Perlis area in Malaya, the Ban Ta-kli area in Thailand and the Shan States and Tenasserim Yomas in Burma.

FUSULINID ZONES OF EAST ASIA

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During the last decade, our knowledge concerning the Upper Paleozoic stratigraphy and paleontology have been much increased, and many new genera and species of fusulinids have been discovered and described in Japan. However, it is not much of an advancement in some regions in East Asia.

It is generally accepted to divide the Middle-Upper Carboniferous (Pennsylvanian) and Permian rocks into nine fusulinid zones, namely, the *Millerella*, *Profusulinella*, *Fusulinella*, *Fusulina*, *Triticites*, *Pseudoschwagerina*, *Parafusulina*, *Neoschwagerina-Verbeekina*, and *Yabeina-Lepidolina* zones in ascending order, all of which are now recognized in Japan. This paper briefly summarizes the recent advancements concerning the fusulinid zones of East Asia.

1. Millerella zone: In Japan the *Millerella* zone was first recognized in the Kitakami massif by Yabe *(1)* who confirmed that it is of Onimaruan age. Kanmera *(2)* described four species of *Millerella* with several species of Viséan corals from the Kakisako formation of Kyushu, which was also correlated with the Onimaruan series of the Kitakami massif. Igo *(3)* recently reported the *Millerella* zone in the Ichinotani formation of the Hida massif, the lower subzone of which contains exclusively species of *Millerella* and is of Onimaruan age. In the Akiyoshi limestone the *Millerella* zone has also been found recently, although its paleontological work has not been completed yet.

Outside of Japan, the Onimaruan rocks are known to occur in North and South China and Indo-china, and probably in Thailand and Burma, but no species of *Millerella* of the Onimaruan age has been reported nor described, except *M.* sp. from Minchen, Chilin of North Manchuria *(4)*.

2. Profusulinella zone: The *Profusulinella* zone is most poorly known in East Asia. In Japan it was first found in the Akiyoshi limestone with typical species of *Profusulinella* and two species of *Akiyoshiella (5, 6)*. Igo *(3)* recently confirmed the existence of the *Profusulinella* zone in the Hida massif with undescribed species of *Profusulinella* and *Paramillerella*. It is in conformable relation to the underlying *Millerella* and overlying *Fusulinella* zones. Except the above, *Profusulinella* zone has not been reported in any place in Japan. As I *(5)* already pointed out, however, it is highly possible that the Moscovian rocks hitherto referred to "*Fusulinella bocki* or *F. biconica* zone" may, if not always, comprise *Profusulinella* zone, and even *Millerella* zone in some case, in their lower part. In fact Onuki and Yamade *(7)* clarified that even the upper part of the Nagaiwa series of the Kitakami massif, which has long been regarded the standard of the *Fusulinella* zone in Japan, is not referrable to the *Fusulinella* zone but to the *Profusulinella* zone.

In South China the lower part of the Huanglung limestone (Mα. zone of Lee, Chen, and Chu) is seemingly referable to the *Profusulinella* zone, although it contains a mixed fauna of *Profusulinella* and *Fusulinella*. The stratigraphical range of the genus *Profusulinella* seems to be considerably wider in the Tethys region than in North America.

3. Fusulinella zone: Rocks referred to the *Fusulinella* zone are widely developed in East Asia. Most of them are characterized by *F. bocki* Möller or *F. biconica* (Hayasaka) and their allied forms. Recent studies of Japanese geologists have shown that most, if not all, of the *Fusulinella* zone in the Moscovian formations is divisible into two parts, the lower part of which is characterized by rather primitive species of *Fusulinella* and the upper one by more advanced forms of *Fusulinella* and primitive forms of *Fusulina*.

The Penchi series of North China and the upper part of the Huanglung limestone of South China are also characterized by nearly the same faunal assemblage as that in Japan.

4. Fusulina zone: Paleontologically well-defined *Fusulina* zone is only known in Southwest Japan. Quite different from the typical fauna of the Moscovian *Fusulinella* zone, a characteristic fusulinid fauna was described by Kanmera *(8)* from the Yayamadake limestone of Kyushu, and recently reported by Igo *(3)* from the Hida massif of Central Japan. The fauna comprises certain advanced species of *Fusulina* and *Wedekindellina* and most advanced forms of *Fusulinella*. *Hidaella*, an aberrant descendant of *Fusulinella*, also occurs in the *Fusulina* zone of the Hida

Dominant fusulinid genera found in the fusulinid zones in East Asia

Fusulinid zone	Russian Division	Northeast Japan	Southwest Japan		North Manchuria		North China incl South Manchuria		South China		Indochina	Thailand
Yabeina-Lepidolina	Tartarian (Chideruan)	Lepidolina Parafusulina Codonofusiella	Kuman	Lepidolina Yabeina Codonofusiella	Toman f	Lepidolina Yabeina Pseudodoliolina Parafusulina	?		Wuchiaping ls	Paleofusulina Codonofusiella	Sumatrina Lepidolina Yabeina Schwagerina	
Neoschwagerina-Verbeekina	Kazanian	Neoschwagerina Verbeekina Parafusulina	Akasakan	Yabeina Neoschwagerina Verbeekina Neoschwagerina Parafusulina	?		Tsaichia s Shihotzu s	(no fusulinids)	Maokou ls.	Yabeina Schwagerina Neoschwagerina Verbeekina	Yabeina Neoschwagerina Verbeekina Misellina Parafusulina Schwagerina	Neoschwagerina Verbeekina Schwagerina
	Kungurian											
Parafusulina	Artinskian	Parafusulina Pseudodoliolina Eoverbeekina	Nabeyaman	Misellina Parafusulina Pseudofusulina			Liutang s Shansi s		Chihsia ls	Parafusulina Nankinella Misellina	Misellina Parafusulina Pseudofusulina	
Pseudoschwagerina	Sakmarian	Pseudoschwagerina Pseudofusulina Triticites Nipponitella	Sakamotozawan	Pseudofusulina Pseudoschwagerina Triticites		Pseudoschwagerina	Huangchi s. Taiyuan s	Pseudoschwagerina Schwagerina Quasifusulina	Chuanshan ls.	Pseudoschwagerina Pseudofusulina Triticites	Pseudoschwagerina Pseudofusulina Triticites	Pseudoschwagerina Schwagerina Boultonia
Triticites	Uralian		Hikawan	Triticites Fusulina	Chilin f	?						
Fusulina	Moscovian		Kurikian	Fusulina Fusulinella Wedekindellina								
Fusulinella			Akiyoshian	Fusulina Fusulinella Fusulinella		Fusulinella	Penchi s	Fusulina Fusulinella	Huanglung ls	Fusulina Fusulinella Fusiella	Fusulinella Staffella	
Profusulinella		Profusulinella	Nagaiwan	Profusulinella Akiyoshiella		?						
Millerella	Bashkirian	Millerella		Millerella						Millerella		
	Visean	Millerella	Onimaruan	Millerella		Millerella						

massif. It should be noted that the rocks of the *Fusulina* zone are unconformably overlain by the limestone of *Triticites* zone in Kyushu.

5. Triticites zone: The Carboniferous-Permian boundary problem has long been discussed in Japan, and Japanese geologists' efforts have born fruit of discovering the Uralian *Triticites* fauna in several places in Central and Southwest Japan in 1951 and later *(10, 11, 12, 13)*. Kanmera *(12, 14)* pointed out that the *Triticites* fauna of the Yayamadame limestone contains more primitive species than any form hitherto found in the lower Permian formations which associates with species of *Pseudoschwagerina* and *Paraschwagerina*.

At present our knowledge concerning the Carboniferous-Permian boundary will be summarized as follows: (1) A clear unconformity exists below the base of the Lower Permian Sakamotozawan formation, and the Uralian formation is missing—Kitakami massif of Northeast Japan, Penchi and Huangchi series of North China, and Huanglung and Chuanshan limestones of South China. (2) No physical hiatus is recognizable in spite of the fact that the rocks of the *Pseudoschwagerina* zone directly overly those of *Fusulinella* or lower zones. —Akiyoshi and Taishaku limestones in Japan, Koten and Jido series in Korea. (3) Although the Uralian *Triticites* zone is present, the *Pseudoschwagerina* and *Triticites* zones are still presumed to be an unconformable relation—Yayamadake limestone in Kyushu. (4) *Pseudoschwagerina* zone directly follows the Uralian *Triticites* zone without any physical break—Omi limestone and Ichinotani formation in the Hida massif.

6. Pseudoschwagerina zone: Among the Permian fusulinid zones, the *Pseudoschwagerina* zone is most widely developed in East Asia, and is flourished by extremely abundant species of schwagerinids including *Pseudoschwagerina*, *Paraschwagerina*, *Pseudofusulina*, *Schwagerina*, *Dunbarinella*, *Triticites* and smaller fusulinids. It must be remembered that the zone fossil, *Pseudoschwagerina*, does not occur in the very basal part of the Sakamotozawan rocks, and that part of the Akiyoshi limestone, for example, is characterized by the predominance of species of *Triticites (5)*. Careful comparative studies on the Lower Permian and Uralian *Triticites* faunas seem to be necessary.

The similarity of the fauna of the *Pseudoschwagerina* zone found in Japan, North and South China, Indochina *(15, 16)* and Thailand *(17)* indicates that all these areas belonged to one and the same faunal province in the Early Permian time. *Minojapanella (18)*, *Hayasakaina (19)* and *Toriyamaia (20)*, recently described new genera in the *Pseudoschwagerina* zone, have not been found outside of Japan.

7. Parafusulina zone: Not likewise in the Midcontinent region of North America, the *Parafusulina* zone of East Asia is sometimes hard to define paleontologically, and the stratigraphical range of the genus seemingly wider in East Asia than in North America, ranging up to the *Yabeina-Lepidolina* zone. So far as known, the best displays of the *Parafusulina* zone are seen in the Nabeyama region of the Kwanto massif, near Tokyo, and, hence, the Nabeyaman series and epoch are here proposed respectively for the time-rock and time units of the *Parafusulina* zone in Japan.

Limestone conglomerates and conglomerates containing various kinds of rocks as pebbles have been found in many places in Japan, many of which are considered to be equivalent in age to the *Parafusulina* zone. Because of their stratigraphical and tectonical significance future studies on these conglomerates seem to be very important.

8. Neoschwagerina-Verbeekina zone: Correlation of the *Neoschwagerina-Verbeekina* zone of East Asia with the Russian divisions of the type Permian has not been satisfactorily established. Quoting from Kahler's result *(21)*, Minato *(22)* recently distinguished the *Neoschwagerina* facies of Southeast Asia and the non-*Neoschwagerina* facies of the Mongolian geosyncline. Southwest Japan is considered to be the boundary area between these two facies.

The Akasaka limestone of Central Japan forms the best exposure of the *Neoschwagerina-Verbeekina* zone in East Asia, which was divided by Ozawa into four subzones. It is probable that the Ozawa's Nn subzone is equivalent in age to a part of the *Parafusulina* zone of Nabeyama and other places.

The terms Akasakan series and epoch are also proposed respectively for the timerock and time units of the *Neoschwagerina-Verbeekina* zone of Japan.

9. Yabeina-Lepidolina zone: Correlation of the *Yabeina-Lepidolina* zone has been still uncertain even in the Japanese islands. Kanmera *(23)* emphasized the stratigraphical and paleontological significance of the Kuma series of Kyushu, fusulinid fauna of which is characterized by the advanced forms of *Yabeina* and *Lepidolina*. Similar conglomerate-bearing formations have been reported from many localities in Japan. Outside of Japan, the Upper Permian formation of Cambodge *(24)* and the Toman Formation *(25)* of Northern Manchuria are certainly correlated with the Kuman series, and the *Paleofusulina* zone of Changhsing limestone *(26)* and *Codonofusiella* zone of Wuchiaping limestone *(27)* are seemingly referable to the Kuman series.

REFERENCES

(1) Yabe, H., 1949, *Proc. Japan Acad.*, **24**: 165-167.

(2) Kanmera, K., 1952, *Mem. Fac.Sci., Kyushu Univ.*, Ser. D., **3** (4):157-177.

(3) Igo, H., 1956, *Jour. Geol. Soc. Japan*, **62** (278): 217-240.

(4) Minato, M., 1950, Ditto., **56** (658):379-382.

(5) Toriyama, R., 1954, *Mem. Fac. Sci., Kyushu Univ.*, Ser.D., **4** (1):39-97.

(6) Toriyama, R., 1953, *Jour. Paleont.*, **27** (2): 251-256.

(7) Onuki, Y. and Yamada, Y., 1955, *Jour. Geol. Soc. Japan*, **61** (718) : 305.

(8) Kanmera, K., 1954, *Japan. Jour. Geol. Geogr.* **25** (1-2) :117-144.

(9) Kanuma, M., 1951, *Jour. Geol. Soc. Japan*, **57** (670) : 266.

(10) Fujimoto, H. and Igo, H., 1955, *Trans. Proc. Paleont. Soc. Japan*, N.S. **18** : 45-48.

(11) Fujimoto, H. and Kawada, S., 1951, *Jour. Geol. Soc. Japan*, **57** (670) : 266.

(12) Kanmera, K., 1952, Ditto., **58** (676): 17-37.

(13) Morikawa, R., 1953, *Sci. Rep. Saitama Univ.*, Ser.B, **1** (2) : 115-122.

(14) Kanmera, K., 1955, *Japan. Jour. Geol. Geogr.* **27** (3-4) : 177-192.

(15) Saurin, E., 1950, *Bull. Serv. Géol. Indochina*, **29** (5).

(16) Saurin, E., 1954, *Archives géol. Viet-nam*, **1**: 1-30.

(17) Konishi, K., 1953, *Trans. Proc. Paleont. Soc. Japan*, N.S., **12**:103-110.

(18) Fujimoto, H. and Kanuma, M., 1953, *Jour. Paleont.* **27** (1): 150-152.

(19) Fujimoto, H. and Kawada, S., 1953, *Sci. Rep. Tokyo Bunrika Daigaku*, Sec.C, **2** (13): 207-209.

(20) Kanmera, K., 1956, *Trans. Proc. Paleont. Soc. Japan*, N.S., **24** : 251-257.

(21) Kahler, F., 1939, *Senckenbergiana*. **21**: 169-215.

(22) Minato, M., 1956, *Earth Science* **28**: 1-13.

(23) Kanmera, K., 1954, *Mem. Fac. Sci. Kyushu Univ.*, Ser. D, **4** (1): 1-38.

(24) Gubler, J., 1935, *Mém. Soc. Géol. France*, N.S. (4): 1-171.

(25) Noda, M., 1956, *Rep. Earth Sci. Dep. General Educ. Kyushu Univ.*, **2**: 1-22.

(26) Sheng, J., 1956, *Acta Paleont. Sinica*, **4**(2): 175-228.

(27) Sheng, J., 1955, *Acta Paleont. Sinica*, **3** (4): 287-308.

FORAMINIFERA IN AUSTRALIAN PERMIAN STRATIGRAPHY

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(Abstract)

During the last few years Permian stratigraphy in Australia has received considerable attention from geologists engaged in the search for oil and coal. Many lithological units have been recognised, the majority of them containing characteristic foraminiferal assemblages.

Investigations in Western Australia have proved the record of Fusulinids (Chapman and Parr, 1937) in the deposits of the Fitzroy Basin to be incorrect. The beds are Triassic, not Permian, in age and the "Fusulinids" probably fish remains.

Publications on Australian Permian foraminifera are few; the most recent contribution is by Crespin and Belford (1957) in which two new genera of the family Opthalmidiidae, *Streblospira* and *Electospira*, have been described from Western Australia.

With the detailed geological work, changes in stratigraphical nomenclature in Australian Permian deposits have been necessary. Old names such as "Lower Marine Series" and "Upper Marine Series" of New South Wales stratigraphy have been superseded by rock-unit names in conformity with the Australian Code of Stratigraphic Nomenclature.

Extensive deposits of Permian marine rocks are known from all parts of Australia except Victoria and South Australia. Recently Permian foraminifera were found in a bore on Yorke Peninsula, South Australia (Ludbrook, 1957), but so far none have been discovered in Victoria. The present paper gives a summary of Permian stratigraphy in Queensland, New South Wales, Tasmania and Western Australia. The formations are listed in stratigraphical sequence and characteristic foraminifera are noted from those formations in which they have been recorded. New genera and species are listed as manuscript names; these will be described shortly in a Bureau Bulletin by the writer. Comments are given on genera and species found. The assemblages in subsurface deposits are characterised by numerous tests of the family Lagenidae, including *Nodosaria*, *Dentalina*, *Frondicularia*, *Lingulina*, *Geinitzina* and *Lenticulina* (*Astacolus*). Arenaceous species dominate all outcrop deposits, except those in the Mantuan *Productus* Bed, Springsure area, Queensland and in the Fossil Cliff Formation, Irwin Basin, and Callytharra Formation, Carnarvon Basin, Western Australia. Calcareous imperforate forms are common in the last two formations. Some species from the Pennsylvanian and Permian deposits of United States and from the upper Carboniferous and Permian of Europe have been determined. Eight foraminiferal assemblages have been recognised in the Australian Permian deposits; these should be useful in stratigraphical work.

Australian stratigraphers and palaeontologists are not agreed on the basis for the division of the Permian System into lower, middle and upper Permian and whether the Sakmarian Stage of Europe should be included in the lower Permian or in the upper Carboniferous. With the absence of Fusulinids in Australia, little evidence is given by the foraminifera for correlation with European Stages. However, the larger fossils have yielded certain reliable data.

RECENT ADVANCES IN THE CORRELATION OF NEW ZEALAND PALEOZOIC AND LOWER MESOZOIC SEDIMENTS

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This paper summarises some of the knowledge gained since the Eighth Pacific Science Congress (1953) on the correlation of New Zealand Paleozoic, Triassic and Jurassic rocks.

PALEOZOIC

CAMBRIAN

The discovery of the first Cambrian fossils in New Zealand was briefly announced by Benson (1952) at the 7th. Pacific Science Congress. Benson has subsequently (1956) published a preliminary note listing agnostid trilobites of the genera *Peronopsis*, *Hypagnostus*, *Ptychagnostus*, *Phoidagnostus*, and *Oidalagnostus*, identified by Dr. O.P. Singleton, and non-agnostids *Dorypyge*, "*Amphoton*", *Solenoparia*, ? *Solenopleura*, ? *Anomocare*, and a *Koptura*-like genus, identified by Dr. Singleton and Dr. A.A.Opik. The trilobites have affinities with those of Manchuria, the Baltic region and especially western Queensland, and are dated as late Middle Cambrian. Benson also listed a rich microfauna obtained by Dr. F.H.T. Rhodes by acetic acid digestion, including sponges, brachiopods, gastropods, brachiopods and ostracods.

ORDOVICIAN

Field work in the Cobb River — Mount Arthur region (Nelson) and in the Preservation Inlet — Cape Providence area (Fiordland) has resulted in new collections of Ordovician graptolites, but no results are yet available. Decker (1952) has recorded many New Zealand species of graptolites from the Athens Shale of U.S.A.

DEVONIAN

The standard section of New Zealand Middle and Lower Devonian sediments at Reefton has been remapped and the structure of the Devonian outliers re-interpreted by Suggate (1957). The Lower Devonian Reefton mudstone (about Coblenzian) of which the brachiopod fauna was revised by Allan (1947) has yielded further fossils, including a carpoid echinoderm and a new genus of Solenomorph lamellibranch, *Paleodora* Fleming (1957). Gill (1953) has discussed the relationship of Australian, New Zealand and North African Lower Devonian faunas.

Devonian corals of the Reefton area have been revised by D. Hill (1956). A new genus *Tipheophyllum* (type species, *Eridophyllum bartrumi* Allan) and two new species (*Hexagonaria allani* and *Thamnopora reeftonensis*) were described. Two species (*T. bartrumi* and *Favosites murrumbidgeensis* Allan) are common to Reefton and Australia. The age of the Reefton Limestone is assessed as early Couvinian or perhaps topmost Emsian.

Poorly preserved brachiopods above the Middle Devonian coral horizon have long been known to include "*Meganteris*" (i.e. *Beachia*) cf. *neozelanica* Allan, suggesting Lower Devonian age. Recently E.D. Gill (in Suggate 1957) recognised *Fascicostella* aff. *gervillei* (Defrance), a Lower Devonian species of a genus unknown in the Australian Middle Devonian (but ranging up to Couvinian elsewhere), from a horizon 40-50 ft. above the Middle Devonian coral limestone at Reefton. Further collecting and study is necessary to resolve such conflict of evidence.

CARBONIFEROUS

In several recent discussions of the mighty pile of Upper Paleozoic sediments overlying the Otago Schist in the New Zealand Geosyncline, the terms "? Carboniferous" (Wood, 1956:17), "probably Carboniferous" (Wellman, 1956:24) or "Carboniferous" (Mutch, 1957:502) are applied to rocks underlying the Lower Permian Maitai Series. It is important to emphasize that no Carboniferous fossils have yet been determined from New Zealand, and what little fossil evidence is available from the pre-Maitai rocks (*Maitai* from the Waipahi Group; *Euryphyllum*(?) from the Takitimu Group) favours Permian rather than Carboniferous age. New collections made by A.R. Mutch from the Takitimu Group are being studied by J.B. Waterhouse in Cambridge, but no results are yet available.

PERMIAN

New fossil collections have been made from the beds in Southland (Productus Creek Group) and Nelson which provided faunas determined as Artinskian, closely related to those of the Upper Marine Series (Branxton Stage) of New South Wales (Fletcher, Hill & Willett, 1952), and are being studied by J.B. Waterhouse; this work, as yet incomplete, will greatly increase the list of Lower Permian fossils (particularly Brachiopoda) known from New Zealand. McQueen (1954) has described the first Permian fossil plants from New Zealand, which include *Noeggerrathiopsis hislopii* (Bunbury) and resemble those of the Bowen Series, Queensland.

Leed (1956) has fully described Upper Permain Reef-building corals which accompany the fusulines *Neoschwagerina margaritae* Deprat, *N. multisepta* Deprat, *Verbeekina* sp. and *Gabeina* sp. (Hornibrook, 1951) in certain North Auckland limestones. Two coral species are recognised, *Waagenophyllum novaezelandiae* Leed and *Wentzelella maoria* Leed, the former closely related to a form from the Capitanian of Texas, the latter species from the Salt Range of Kashmir. They represent a strong and previously unsuspected Tethyan element in New Zealand Permian and from their affinities indicate Capitanian-Ochoan age.

MESOZOIC

TRIASSIC

The stimulus provided by Marwick's (1953a) revision of faunas and divisions of the Hokonui System (Triassic and Jurassic) has led to much new work in field and laboratory on Triassic geology and fossils. Field studies of important Triassic sections have been contributed by Coombs (1950, 1954), Watters (1952), Campbell (1955, 1956) and Campbell & McKellar (1956), the last three papers being detailed descriptions of sequence and fauna in the Oretian and Otapirian Stages (approximately Lower Carnian & Rhaetian) throughout New Zealand. The thick poorly fossiliferous greywacke-argillite rocks that form the Southern Alps have provided Norian *Monotis* at several new localities (Wellman, Grindley & Munden, 1952) and a Carnian (?) *Palaeoneilo* (Fleming, Munden & Suggate, 1954). Campbell & Warren (1955) relocated and described Norian limestones from Okuku, North Canterbury, containing abundant *Monotis richmondiana* Zittel & M. *Calvata* Marwick, also brachiopods and polyzoans. Wood (1953, and 1956) and Mutch (1957) have contributed descriptions and discussions of the stratigraphy and structure of the southern end of the New Zealand geosyncline, in which thick Triassic sediments accumulated. J.D. Campbell is working on the systematics of the Oishintive N.Z. Triassic Brachiopod fauna.

The most notable recent advance in correlation of the New Zealand Trias has been the identification by Dr. B. Kummel, Harvard *(pers. comm.)* of several ammonites, collected by Mr. A.R. Mutch from the Lower Gore Series of Western Southland, as mid Scythian forms of the *Owenites* Zone. Hitherto, the Anision, represented by *Parapopanoceras* (=*Beaumontites* Browne, see Kummel, 1955) and other ammonites of the New Zealand Etalian Stage, has been the oldest Triassic known in this country.

Kummel (1953) has also described the New Zealand Carnian nautiloid *Bisyphytes trechmanni* (=*Grypoceras* cf. *mesodicum* (Hauer), of Trechmann) and discussed its significance in nautiloid evolution. Comparisons of Triassic Mollusca of Japan and New Zealand are found in papers by Kobayashi (1954), Ichikawa (1954) and Kobayashi & Ichikawa (1952). Marwick (1953 b) analysed Triassic and Jurassic faunas from the point of view of faunal migration and routes, endemism and isolation. "At no age, from Anisian to Tithonian, was ammonite immigration barred from New Zealand seas, though it was evidently limited by geographic factors."

Routhier (1953) and Avias (1953) have greatly strengthened the paleontological links between the Trias of New Zealand and New Caledonia, the latter recording such distinctive New Zealand Brachiopods as *Clavigera*, *Mentzeliopsis*, *Spiriferina laihikuana* Trechmann, and *Rastelligera* from the New Caledonian Trias (described by Mlle. J. Drot, in Avias, 1953).

JURASSIC

Several of the papers cited in the preceding section deal with Jurassic as well as Triassic problems (Marwick, 1952 a, b.; Watters, 1952; Wood, 1956; Routhier, 1953; Avias, 1953). As with the Triassic, Marwick's revision (1953 a) has greatly stimulated further work on important sections, especially in the Kawhia region (Kear & Fleming, unpublished) and in Southland (I.C.McKellar; I.G. Speden, in prep.). Ammonites found in the course of these projects will greatly improve Jurassic correlations, but few determinations are available for citation at present.

From the Hokonui Hills, Southland, Arkell (1953) has identified *Ectocentrites* cf. *petersi* Hauer (Hettangian) from a horizon now known to be higher than that of *Psiloceras* spp. previously recorded from that area. In 1956, G.R.Stevens identified the first New Zealand specimens of the Upper Hettangian zonal ammonite *Schlotheimia* cf. *angulata* from the well known Flag Hill section, and recognised in old collections a specimen of *Coroniceras* from the same area—the first ammonite evidence of Sinemurian in the Lias of the Hokonui Hills (Anon. 1957).

From beds at Totara Peninsula, Kawhia, which Marwick (1951) first included in his Heterian Stage, but later (1953) in the underlying Temaikan, Arkell (1956, p. 455) has determined *Idoceras* cf. *humboldti* Burchkardt, *Epicephalites* cf. *epigonus* Burckhardt, and *Subneumayria*, Lower Kimeridgian forms of strongly Mexican affinity. The indications of Himalayan and European Bajocian-Bathonian affinity which Marwick found in the Pelecypoda and Brachiopoda from this (or, in fact, a slightly higher) horizon are thus deceptive. Arkell (1953) has also demonstrated the presence of the Mexican genus *Idoceras* in the South Island. Field work has recently clarified the relationship between the thick Kimeridgian sequence on the north shore of Kawhia and the ammonite horizon at Puti Point on the north shore which has yielded an ammonite assemblage (*Aulacosphinctoides*, *Uhligites*, etc.) reminiscent of the Middle Spiti Shales (Lower Tithonian). Dr. Arkell is undertaking study of the ammonite succession in the Kawhia section, which promises to contribute to the solution of zonal correlations elsewhere in the Tethyan region.

Hornibrook (1953) has described a small Jurassic foraminiferal fauna from an oil prospecting well in North Taranaki, including *Lingulina evansi* Hornibrook, closely related to *L. tenera* Bornemann (Jurassic of Europe). Fell (1954) has described the first known New Zealand Jurassic Asterozoan, *Odontaster prescies* Fell from the Temaikan stage. Couper (1953) has recorded the pollen grains and spores from certain non-marine beds, attributed to Upper Jurassic, in Westland and southwest Nelson, west of the areas of marine Jurassic sedimentation.

REFERENCES

Allan, R.S., 1947, A Revision of the Brachiopoda of the Lower Devonian Strata of Reefton, New Zealand. *J. Paleont.* **21** (5):436-452.

Anon., 1957, McKay Hammer Award, 1956, *Geol. Soc. N.Z. Newsletter*, **4**:8.

Arkell, W.J., 1953, Two Jurassic Ammonites from South Island, New Zealand, and a Note on the Pacific Ocean in the Jurassic. *N.Z. J. Sci. Tech.* **B 35** (3): 259-64.

—— ——, 1956, Jurassic Geology of the World (Oliver & Boyd, Edinburgh and London).

Avias, J., 1953, Contribution à l'Etude Stratigraphique et Paléontologique des formations Antécrétacées de la Nouvelle Caledonie Centrale. *Science de la Terre.* **1** (1-2).

Benson, W.N., 1952, Meeting of the Geological Division of the Pacific Science Congress in New Zealand, February, 1949. *Interim Proc. geol, Soc. America*, 1950 **1**: 11-13.

Benson, W.N., 1956, Cambrian Rocks and Fossils in New Zealand (Preliminary Note). In: *El Systema Cambrico, su Paleogeographia y el Problema de su Base, XX. Congr. Geol. Intern.* **2** (2): 285-8.

Campbell, J.D., 1955, The Oretian Stage of the New Zealand Triassic System. *Trans. roy. Soc. N.Z.* **82** (5) : 1033-47.

—— ——, 1957, The Otapirian State of the Triassic System of New Zealand. Part II. *Ibid.*, **84** (1) : 45-50.

Campbell, J.D. and McKellar, I.C., 1956, The Otapirian Stage of the Triassic System of New Zealand. Part I. *Ibid.*, **83** (4): 695-704.

Campbell, J.D. and Warren, G., 1955, A Note on Upper Triassic Limestone from the Okuku Valley, North Canterbury. *N.Z. J. Sci. Tech.* **B 36** (5) : 531-2.

Coombs, D.S., 1950, The Geology of the Northern Taringatara Hills, Southland. *Trans. roy. Soc. N.Z.* **78** (4): 426-48.

——, 1954, The Nature and Alteration of Some Triassic Sediments from Southland, New Zealand. *Ibid.*, **82**: 65-109.

Couper, R.A., 1953, Upper Mesozoic and Cainozoic Spores and Pollen Grains from New Zealand. *N.Z. Geol. Surv. Pal.*, Bull. **22**.

Decker, C.E., 1952, Stratigraphic Significance of Graptolites of Athens Shale. *Amer. Assoc. Petr. Geol.* **36** (1): 1-145.

Fell, H.B., 1954, New Zealand Fossil Asterozoa. 3. *Odontaster prescies* sp. nov. from the Jurassic. *Trans. roy. Soc. N.Z.* **82**: 817-19.

Fleming, C.A., 1957, A New Devonian Lamellibranch from Reefton, New Zealand. *Ibid.* **84** (4).

Fleming, C.A., Munden, F.W. and Suggate, R.P., 1954, An Upper Triassic Lamellibranch from the Southern Alps of North Westland, New Zealand. *Ibid.* **82** (1): 111-114.

Fletcher, H.O.; Hill, D.; Willett, R.W., 1952, Permian Fossils from Southland. *N.Z. Geol. Surv. Pal.* Bull. **19**.

Gill, E.D., 1953, Relationship of the Australasian and North African Devonian Faunas. *Proc. 19th. Internat. geol. Congr. Sec.* **2** (2): 87-92.

Hill, D., 1956, The Devonian Corals of Reefton, New Zealand. *N.Z. geol. Surv. Pal.*, Bull. **25**: 1-14.

Hornibrook, N. de B., 1951, Permian Fusulinid Foraminifera from North Auckland Peninsula, New Zealand. *Trans. roy. Soc. N.Z.* **79**: 319-21.

———, 1953, Jurassic Foraminifera from New Zealand. *Ibid* **81**: 375-8.

Ichikawa, K., 1954, Late Triassic Pelecypods from the Kochigatani Group ....II. *J. Inst. Polyt. Osaka, Ser. G.* **2**:53-75.

Kobayashi, T., 1954, Studies on the Jurassic Trigonias in Japan. Part I. *Jap J. Geol. Geog.* **25**: 61-80.

Kobayashi, T. and Ichikawa, K., 1952, Triassic Fauna of the Heki Formation... *Ibid.* **22**: 55-84.

Kummel, B., 1953a, The Ancestry of the Family Nautilidae. *Breviora, Mus. Comp Zool.* **21**, 7 pp.

———, 1953b, Middle Triassic Ammonites from Peary Land. *Med. om Grönland* **127** (1): 1-21.

Leed, H., 1956, Permian Reef-building Corals from North Auckland Peninsula, New Zealand. *N.Z. geol. Surv. Pal.* Bull. **25**: 15-23.

McQueen, D.R., 1954, Upper Paleozoic Plant Fossils from South Island, New Zealand. *Trans. roy. Soc. N.Z.* **82**: 231-6.

Marwick, J., 1951, Series and Stage Divisions of New Zealand Triassic and Jurassic Rocks. *N.Z. J. Sci. Tech.* **32** (3): 8-10.

———, 1953a, Divisions and Faunas of the Hokonui System (Triassic and Jurassic). *N.Z. geol. Surv. Pal.*, Bull. **21**.

———, 1953b, Faunal Migrations in New Zealand During the Triassic and Jurassic. *N.Z.J. Sci. Tech.* **34**: 317-21.

Mutch, A.R., 1957, Facies and Thickness of the Upper Paleozoic and Triassic Sediments of Southland. *Trans. roy. Soc. N.Z.* **84** (3): 499-511.

Routhier, P., 1953, Etude Géologique du Versant Occidental de la Nouvelle Caledonie ... *Mem. Soc. geol. Fr.* **67** (n.s.).

Suggate, R.P., 1957, The Geology of Reefton Subdivision. *N.Z. geol. Surv.* **56**.

Watters, W.A., 1952, The Geology of the Eastern Hokonui Hills, Southland. *Trans. roy. Soc. N.Z.* **79**: 467-84.

Wellman, H.W., 1956, Structural Outline of New Zealand. *N.Z. Dep. Sci. ind. Res.* **121**.

Wellman, H.W., Grindley, G.W. and Munden, F.W., 1952, The Alpine Schists and the Upper Triassic of Harpers Pass (S52), South Island, New Zealand. *Trans. roy. Soc. N.Z.* **80**: 213-27.

Wood, B.L., 1953, Paleozoic and Mesozoic Stratigraphy and Structure in Southland. *Roy. Soc. N.Z. Rep. 7th Sci. Congr.*: 106-14.

———, 1956, The Geology of the Gore Subdivision. *N.Z. geol. Surv.* **53**.

THE OCCURRENCE OF A JURASSIC AMMONITE, RECENTLY FOUND IN TAIWAN, CHINA

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A Phylloceratinid Ammonite was obtained from the bore hole of PK No. 2 well sunk by the China Petroleum Corporation (CPC) at about two km. south of Ssuhu near Peikang. Chiayihsien, Taiwan. The fossil *Phylloceratina* was found preserved in the hard, compact fine-grained, carbonaceous sandstone of the boring core from the depth of 1692.8 m. This phylloceratinid fossil was lent to me for study by CPC along with some illpreserved Belemnites, Pelecypods, Brachiopods, plants and a few fragments of another kind of Ammonite from different depths of the same well. The occurrence of Jurassic fossils is quite new to science in Taiwan.

DESCRIPTION

Family: *Phylloceratidae* Zittel

Subfamily: *Calliphylloceratinae* Spath

Genus: *Holcophylloceras* Spath, 1927

Holcophylloceras aff. *mediterraneum*
(Neumayr)
(Plate 1, Figures 1-5.)

MATERIAL

Only a single specimen was obtained in the boring core; it is relatively well preserved, but the shell is compressed, and partly broken or deformed. The specimen is stained with a black color by carbonaceous materials. As some of the inner parts are cemented by hematite, we find the shape of the suture lines relatively clear from its reddish color. The apertural part and outer margin of its body chamber were damaged by the boring bit.

DESCRIPTION

The shell is involute and flattened, with a sharp, angular siphonal part due to compression. The shell itself is provided with six constrictions on each whorl, which are deeply cut in at the siphonal part, and continue as a straight or slightly curved or indistinctly line. These constrictions are somewhat broad and shallow at the middle of the height of each whorl. Most part of the surface of the shell is smooth, but there exist fine filiform ribs on the siphonal side of the shell between the constrictions. The umbilicus is narrow.

The suture lines are generally similar in shape to those of most specimens of *H. mediterraneum* figured by Waagen and some of H. aff. polyolcum (Beneck), figured by Spath. The external saddle is diphyllitic and the first lateral saddle triphyllitic, and every branch of these has a round apex. I am sorry I have not seen the figure of Neumayer's in his original paper, but according to Waagen, the lobes of his Indian specimen seems a little more finely divided on the whole than those in Neumayr's figure; I can only say that relative to the Indian specimen, the lobes of the Taiwan specimen seems a little more coarsely (and simply) divided.

DIMENSIONS

The specimen is not complete; but from the restored figure, we know the diameter of last whorl that is preserved is about 47 mm.; the diameter of the umbilicus is 7-8 mm. (17%); the height off the last whorl is 15 mm.; the width of the last whorl about 5-6 mm. The diameter of Neumayr's holotype is 115 mm., of his other specimens 129 mm. and 102 mm.; of Waagen's Cutch specimens 70 mm., 110 mm. and 165 mm.; of Lemoine's specimen 70 mm., of Spath's specimens 197 mm. The Taiwan specimen is small compared to these.

REMARKS

"*Phylloceras*" *mediterraneum* is a well founded and easily recognizable species. Spath established the genus *Holcophylloceras* in 1927, and selected this species as its genotype. The surface character of the Taiwan specimen is quite similar to E. Koken's figure (fig. 52) of "*Phylloceras*" *mediterraneum*, in his "Die Leitfossilien" p. 73, except for the number and shape of constrictions. But the character of the constrictions may not be the dicidedly important character in this species. Spath said: "It should be mentioned that a compressed example of the present species (*H. mediterraneum*), with only five constrictions at 125 mm. diameter has now been found by Mr. J.H. Smith in the Katrol

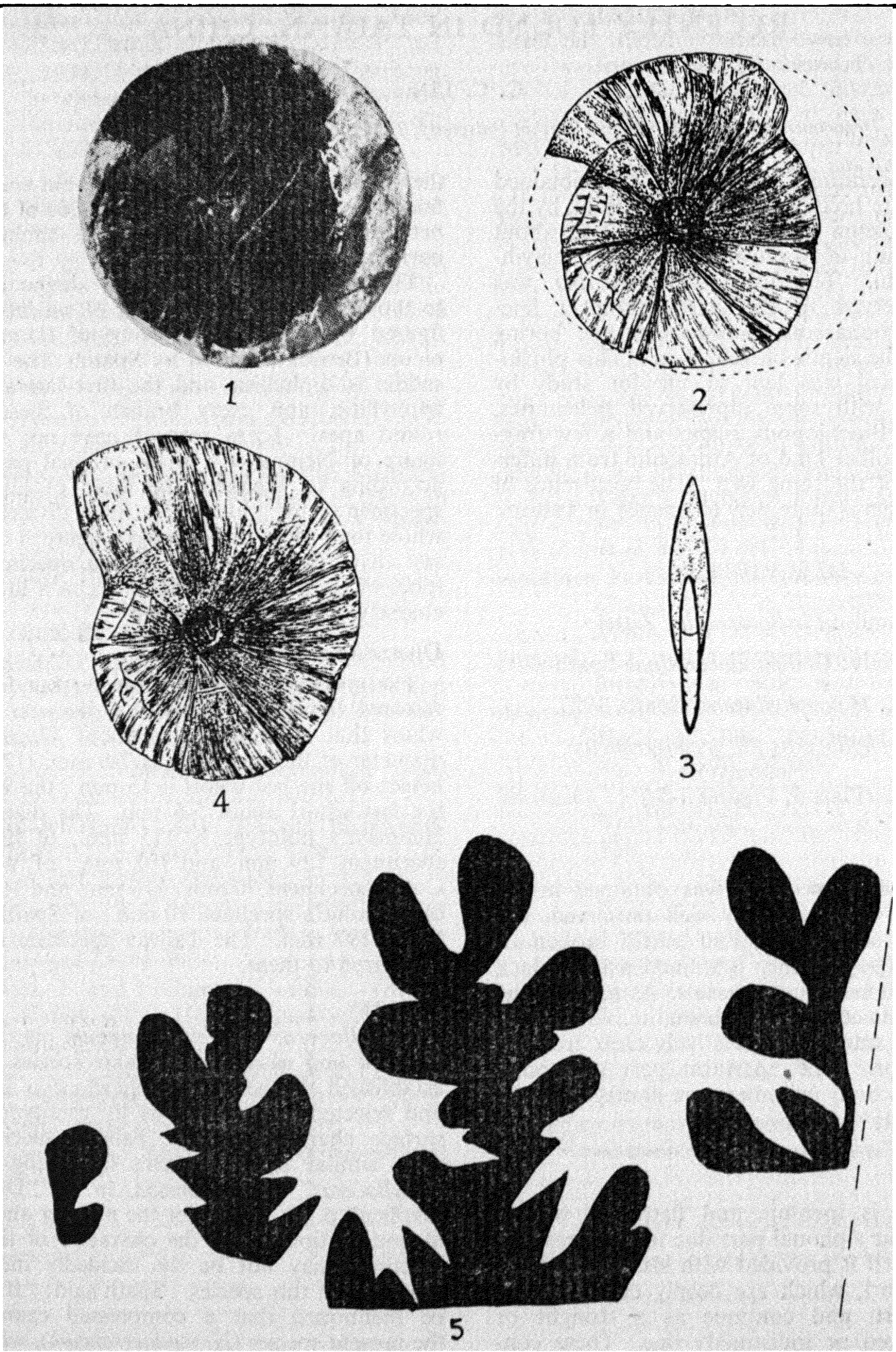

Plate 1.—Jurassic Ammonite from Taiwan.

Beds of Fakirwadi. Since there occur transitions to *H. polyolcum* already in the Callovian, it will be seen that a new specific name for the forms intermediate between *H. mediterraneum* and *H. polyolcum* (in the number of constrictions) would not even be of stratigraphical value." And it is difficult to separate immature examples of *H. polyolcum* from *H. mediterraneum* only by their constrictions. Anyway the number and shape of constrictions of the Taiwan specimen are somewhat different with the others, and more similar to the constrictions of *Calliphylloceras* aff. *demidorffi* (Rousseau) from bed No. 6 of Khera Hill, and of the immature specimen of *H.* aff. *polyolcum* from Katrol Beds, Kimmeridgian, of Fakirwadi; both were figured by Spath.

The suture lines of the Taiwan specimen agree typically with those of *H. mediterraneum* figured by Waagen and some of *H.* aff. *polyolcum*, figured by Spath, the external saddle being diphyllitic, the first lateral saddle triphyllitic and the second and third (?) ones also diphyllitic. Suture lines of *H.* aff. *polyolcum* of Pl. VI, fig. 2e and Pl. VII, fig. 5 in Spath's monograph agree most with those of our specimen.

Although Spath gave the name "H. aff. *polyolcum*" to the thirty-five specimens of *Hocophylloceras* from the Kimmeridgian Katrol Series of Cutch, I believe some of them should be included in *H. mediterraneum* from his description and figures. So my specific range of *H. mediterraneum* is somewhat wider than according to the opinion of Spath and includes Spath's *H. mediterraneum* from Callovian Chari Series and some of his *H.* aff. *polyolcum* from Kimmeridgian Katrol Series of the Cutch Region.

As there remain some questions: such as, number and shape of constrictions or separation of *mediterraneum* and aff. *polyolcum*, etc. I propose temporarily the name of *H.* aff. *mediterraneum* for the Taiwan specimen.

LOCALITY

As already mentioned in the introduction, this *Holcophylloceras* aff. *mediterraneum* was obtained from a depth of 1691.8 m from the boring core of PK No. 2 Well, sunk by China Pepteleum Corporation, during Feb. 14 to June 13 this year (1957), at two kilometer south of Ssuhu near Peikang town, Chiayihsien.

GEOLOGICAL AGE

H. mediterraneum is one of the most common Ammonites in the Tethys province including Uhlig's "Mediterran-Kaukasisches Reich" and "Himalajisches Reich", etc., in Jurassic Paleogeography. In Europe this species has a very large vertical distribution, and ranges from Bathonian up to the uppermost Jurassic. (Prinz, 1904, said this species begins already in the Lower Bajocian.)

In the "Himalajisches Reich" this species occurs abundantly in the Callovian anceps zone of the Chari Group and the Kimmeridgian Katrol Beds.

ACKNOWLEDGEMENT

Thanks are due to the authorities of the China Petroleum Corporation for giving me the opportunity to study the first specimen of a Jurassic fossil from Taiwan.

REFERENCES

Koken, Ernst, 1896, *Die Leitfossilien*, Leipzig.

Spath, L.H., 1927, Revision of the Jurassic Cephalopod Fauna off Katch (Kachh), *Pal. Ind., New Ser.* **9** (2): 60.

Op. Cit. (2), Pl. VII, fig. 8 (*Calliphylloceras* aff. *demidoffi*) and Fig. 5 (*Holcophylloceras* aff. *polyolcum*).

Waagen, William, 1937, Jurassic Fauna of Cutch, vol. I, The Cephalopoda, *Pal. Ind.*, **9**: (1-4).

Uhlig, I, 1911, Die marine Reiche des Jura und der Unterkreide, *Mitt. Wien Geol. Ges.* **4**.

EXPLANATION OF PLATE

Holcophylloceras aff. *mediterraneum* (Neumayr)

Figures 1 and 2. Deformed specimen, preserved in boring core. Side view 1/1.

Figure 3. Front view. 1/1.

Figure 4. Restored figure. 1/1.

Figure 5. Suture line, largely magnified.

THE JURASSIC OF JAPAN AND ITS BEARING ON THE CORRELATION

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In Japan the Jurassic was the transitional period between the Triassic Akiyoshi and Cretaceous Sakawa orogeny, and her palaeogeography is highly complicated. In the *Akiyoshi folded mountains* on the continental side there was a series of basins along the boundary between the Sangun metamorphosed zone and the Yamaguchi folded zone (See map). These basins were separated from the Pacific Ocean by the so-called *Eo-Nippon Cordillera* which is the embryonic geanticline of the growing Sakawa mountains. Such a great variability of geographic import is indicated by the tremendous variation of sediments in facies and thickness and the fossils therein. The Jurassic stratigraphy and paleontology of Japan were greatly improved in recent years with the result that the Jurassic areas are now classifiable as follows:

I. *The chain of basins in the Akiyoshi hinterland*, where the nerito-paralic sediments were accumulated to a great thickness.

Ia. *The Kuruma, Iwamuro and Yamaoku basins* (8,9 and 3 in map respectively) prolific in Rhaeto-Liassic plants and various pelecypods of which the latter show that the three basins were confluent. The Kuruma series measures several thousand meters in thickness and yields Liassic ammonites in three beds. (According to Kobayashi, Konishi, Ta. Kimura, Sato, Hayami.).

Ib. *The Tetori, Kuzuryu, Jinzu and Furukawa areas* (4, 5, 6, 7). The Tetori series there has been considered Upper or Middle Jurassic, but with the find of the Omichidani flora containing Dicotyledonous plants it is known now to consist of the Limnic Akaiwa formation of Middle Cretaceous age, the paralic Itoshiro formation of Upper Jurassic to Lower Cretaceous and the Middle (?) and Upper Jurassic Kuzuryu formation, mostly neritic. They are separated by local disconformities. The so-called Tetori flora is contained in the Itoshiro and Kuzuryu formations. The thickness of the Jurassic part is about 1,000 m. (Kobayashi, Kawai, Maeda, *et al.*)

Ic. *The Toyora and Toyonishi basins* (2, 1). The Toyora series of the former basin consists of marine sediments of about 1,000 meters thickness in an embayment which reveals a cycle of sedimentation from Hettangian to Callovian. It is unconformably overlain by the paralic Toyonishi series on the west side which is an orogenic type of sediment (Matsumoto and Ono.)

II. *The northern marginal depressions of the Eo-Nippon Cordillera.* In the southern Kitakami mountains are two synclines which were narrow parallel embayments. The Jurassic strip of Soma on the eastern foothills of the Abukuma mountains belong to the epiric sea of the Pacific Ocean.

IIa. *The Shizukawa embayment* comprising the Shizukawa, Hashiura and Mizunuma areas (11, 12, 13). There exist most stages from Hettangian to Tithonian, but the sequence is interrupted by one or two disconformities. The total thickness is about 1,000 m. where the Lias occupies only 150 m. or so. (Matsumoto, Ono, Mori, and Sato).

IIb. *The Ojika embayment* including the Ojika peninsula and Karakuwa area (14, 15) where the sedimentation was commenced after Aelenian. Nevertheless the thickness attains more than 1,500 m. (Onuki, Oyama, Fukada, Sato).

IIc. *The Jurassic strip of Soma* (16). Although the base is unexposed, the Middle and Upper Jurassic formations attain more than 1,500 m. The major part belongs to the shallow open-sea facies and a reef-limestone layer is intercalated. (To. Kimura, Masatani, Tamura).

III. *Geosynclines.* While there was vigorous volcanism in the Yezo geosyncline in Hokkaido in the Jurassic and early Cretaceous periods, it is imperceptible in the Shimanto geosyncline from the Kwanto region to South Kyushu.

IIIa. *The near-shore zone of the Shimanto geosyncline* where the Torinosu series containing bioherms is extensive and disconformably overlies the Sambosan group which is mostly Permo-Triassic. At a few places, however, Lower or Middle Jurassic brachiopods are found near the top. The Torinosu series is about 500 m. thick at the type locality in the Sakawa basin. (18, To. Kimura).

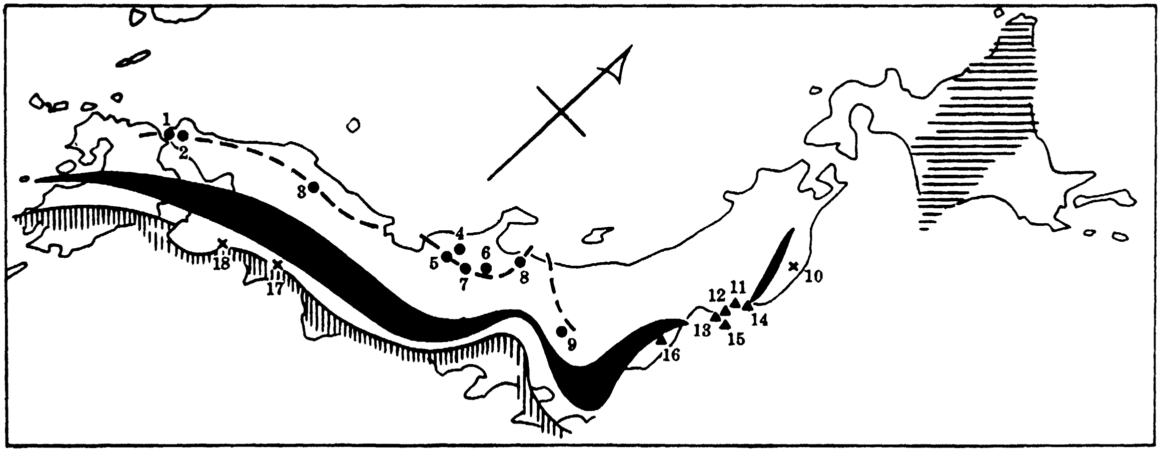
IIIb. *The off-shore zone of the Shimanto geosyncline.* The Shimanto group is an unbroken series from Lower Cretaceous to Triassic or Permian. It is mostly composed of unfossiliferous bathyal sediments. The Nishigawa division containing the Torinosu limestone is undoubtedly Upper Jurassic. (Kobayashi, To. Kimura, Ichikawa).

IIIc. *The marginal zone of the Yezo geosyncline.* The Iwaizumi formation (10) in the northern Kitakami mountains is 570 m. thick and composed of conglomerate, sandstone, clayslate, schalstein and biohermic limestone containing the Torinosu limestone fauna. (Onuki).

IIId. *The axial zone of the Yezo geosyncline* in Central Hokkaido where the Sorachi formation with the Albio-Aptian *Orbitolina* limestone in the lower part. As it is called "*Schalstein formation*," its leading components are andesitic and basaltic tuffs, tuffaceous sandstone, siliceous slate and Radiolarian chert. The inclusion of the Torinosu limestone warrants that a part is Upper Jurassic.

If the Sorachi, Shimanto and Sambosan groups are excluded, the base of the Jurassic is well marked. On the contrary there are some passage beds toward the Cretaceous.

Because the meta-orogeny of the Akiyoshi cycle did not cease, the Lias of the Kuruma basin is astonishingly thick. Subsequently the Liassic basins (Ia) were emerged and new ones (Ib) brought to being in Central Japan by the Hida disturbance. Its influence was reduced in the western area (Ic) where, however, the Toyora and Toyonishi series are separated by the discordance of the early Oga phase. In marked contrast to the Toyora cycle of sedimentation, the facies is changeable vertically as well as horizontally and sometimes local discordances are met with in the paralic Toyonishi series. These aspects on the hole demonstrate the crustal unstability in the *Oga prelude* of the Sakawa orogeny.



Index Map to the Jurassic Areas in Japan.

I. Chains of basins in Akiyoshi hinterland.
  Broken line: Boundary between Sangun metamorphosed zone and Yamaguchi folded zone of Akiyoshi folded mountains.
  Ia. Kuruma (8), Iwamuro (4), and Yamaoku (3) basins.
  Ib. Tetori (4), Kuzuryu (5), Jinzu (6) and Furukawa (7) areas.
  Ic. Toyora (2) and Toyonishi (1) basins.

II. Marginal depressions of Eo-Nippon Cordillera.
  Black: Eo-Nippon Cordillera.
  IIa. Shizukawa embayment of South Kitakami; Shizukawa (11), Hashiura (12) and Mizunuma (13) areas.
  IIb. Ojika embayment of South Kitakami; Karakuwa (14) and Ojika (15) areas.
  IIc. Jurassic strip of Soma (16).

III. Yezo-Shimanto geosyncline.
  IIIa. Near-shore zone of Shimanto geosyncline; Sakawa (18) and Sakuradani (17) areas.
  IIIb. Off-shore zone of Shimanto geosyncline (Vertical lines).
  IIIc. Marginal zone of Yezo geosyncline; Iwaizumi area (10).
  IIId. Azial zone of Yezo geosyncline (Horizontal lines).

The growth of the depressions in the southern Kitakami and Soma areas (II) and the increase in the rate of sedimentation from Lias to Malm indicate that the axial culmination of Eo-Nippon was accelerated and its embryonic folding was developing through the Jurassic period. The Torinosu series is comparatively thin, because the Torinosu zone (IIIa) was distant from the Eo-Nippon Cordillera. If the Radiolarian cherts in the Sichota Alins and the lower Amur valley are really in part Jurassic and their development is related to submarine volcanism, they may be allied to the Sorachi facies in Hokkaido (III).

The normal marine Jurassic is extensive in the maritime province of USSR, but the Dogger is limited, probably due to the Hida emergence or disturbance. In the Sichota Alines the Middle and Upper Jurassic containing *Trigonia costata* and *Myophorella imbricata* is said to overly the Lias clino-unconformably. Because various inocerami occur commonly and extensively in the province and also in the Akiyoshi basins and the southern Kitakami region (I, IIa-b), their comparative study is of prime importance for the stratigraphic correlation.

Recently the Lias of Japan was zonated as shown in the table. Each basin or column bears its own individuality, but in Japan the Aalenian is more properly combined with the subjacent than the superjacent formation. No ammonite represents lower Hettangian, lower Sinemurian or lower Pliensbachian. Broadly speaking, the Liassic fauna is intimately related to those of the southwestern Pacific, but boreal *Amaltheus* is coexistent with the Tethyran *Canavaria* in the Domerian of the Kunuma basin. The Aalenian of the Mae-Sot region, West Thailand, is linked with that of Alaska through the southern Kitakami by common occurrences of *Tmetoceras*. (Sato).

Bajocian *Stephanoceras* cfr. *plicatissimum* from the Karakuwa series (IIb) is one of the a few Middle Jurassic ammonites in Japan (Sato). Her Upper Jurassic fauna comprises quite a variety of Perisphinctids in addition to some oppelids and others. It is noteworthy that the inflow of cold water into the Kuzuryu and Shizukawa basins in the Callovian epoch is proven by the discovery of *Kepplerites* (*Seymourites*) (Kobayashi).

The Liassic pelecypod fauna in Japan comprises about 145 forms (or species plus varieties) in 54 genera, of which 37 forms in 24 genera occur in the Shizukawa series (1), 68 forms in 32 genera in the Kuruma series (2) and 46 forms in 29 genera in the Toyora series. Among them 2 forms and 14 genera are common between (1) and (2), 4 forms and 11 genera between (2) and (3) and 0.5 form and 6 genera between (3) and (1) where aff. or cfr. is counted 0.5. The weak affinity among these faunas depends more on ecology and endemism than time-difference. While certain species in the Toyora fauna are almost identical with lower Liassic ones in Europe serveral new genera indicate strong individualities of the Shizukawa and Kuruma faunas. Cyrenoids common in the Shizukawa and Kuruma series have attracted attention of conchologists because of their archaeism. They are, however, probably not true cyrenids, but marine members of the Cyprinidae (Hayami). The corbiculid fauna of the Tetori series may be the oldest non-marine one in Japan (Kobayashi and Suzuki).

Some 35 Trigonian species in 11 genera are known from the Jurassic of Japan (Kobayashi, Mori and Tamura). *Geratrigonia*, for example, is a Liassic indigenous genus. *Nipponitrigonia* is another in the Jurassic and Lower Cretaceous, but distributed as far as the Philippines. *Vaugonia* as a genus is cosmopolitan in the Jurassic, reaching its acme in Dogger, but in Japan it flourished more in the Lias than later. *Oistotrigonia* was considered a Cretaceous member of the Myophorellinae, but its progenitor appears in Japan already in Malm. In the southern Pacific on the contrary it occurs in Senonian. Thus one must be cautious for distant correlation by means of Trigonian genera.

Many Trigonian species in Japan are limited to one or a few closely set areas. There are, however, some having wide distribution. *Linotrigonia toyamai* is a guide fossil of the Torinosu series. *Myophorella obsoleta* occurs in the Malm of the South Kitakami and in the middle Shimanto formation of Shikoku. *M. orientalis* (i.e., *Trigonia formosa* by Shimizu, non Lycett) is described from the upper Malm of the south Kitakami, Soma and Kuzuryu in Japan and reported to occur also in Ussuri. In Mindoro, Philippines, it is found associated with *Latitrigonia*, *Nipponitrigonia* and *Rutitrigonia*, the generic assemblage suggesting the Jurasso-Cretaceous passage for the Trigonian sandstone of Amaga, Mindoro. *Trigonia molengràffi* from West Borneo is probably Upper Jurassic, instead of Cretaceous, because it is intimately related to *Myophorella crenulata* from the Malm of Soma (Kobayashi).

Jurassic brachiopids from Shikoku island comprise 16 species in 10 genera including

CORRELATION OF THE LIASSIC FORMATIONS IN JAPAN (SATO)

Toyora Series (Matsumoto & Ono)	Kuruma Series	Shizukawa Series	Age	
Uh Hammatoceras Dumortieria	Mizukami-dani Beds	Hh Hammatoceras Hyperlioceras Tmetoceras	Aalenian	
Ub Haugia	Otaki-dani Beds	Hl Leioceras? Tmetoceras Harpoceras	Toarcian	
Up Pseudolioceras, Chartronia	Crammoceratid			
Ni Dactylioceras	Hammatoceratid			
Nh Hildoceras, Dactylioceras Harpoceras, Peronoceras Brodceras, Protogrammoceras	Shina-dani	Hiatus		
Ng Protogrammoceras Murleyiceras, Harpoceras Harpoceratoides, Brodieia Dactylioceras, Hildoceras	Beds			
Nf Fontanelliceras, Arieticeras Fuciniceras, Paltarpites Protogrammoceras	Teradani Beds Amaltheus Canavaria		Pliensbachian	Domerian
Hiatus	(Deroceras) Negoya-dani Beds			Carixian
	Kitamata-dani Beds	Ha Arnioceras	Sinemurian	
Upper Higashi-Nagano Beds Arietites	Jodogani	Hi		
Rhacophyllites Lower Higashi-Nagano Beds	Beds	Nss Yebisites Nsh	Hettang.	

Up, b,h: Lower Utano Beds
Nf-i : Nishi-Nakayama Beds

Hi, a and Hl, h: Lower and Upper Hosoura Beds
Nsh, ss : Niranohama Beds

Burmirhynchia, *Kallirhynchia*, *Parmirhynchia*, *Zeilleria*, *Terebratulina* and so forth. The Miyakodani, Naradani and Torinosu faunules in the table can be dated respectively as Lias, Dogger and Malm. They are on the whole related to the faunas in the Tethyan province, especially of the Shan State, Cutch and Attock districts (Tokuyama).

Genera/Species	Rhynchonelloids	Terebratulloids	Total
Torinosu; Malm	2/2(3)	4 (1)/5(5)	6 (1)/8(8)
Naradani; Dogger	2/2(1)	4 (1)/4(4)	6 (1)/6(5)
Miyakodani; Lias	2/2	2/2	4/4
Total (n. gen. or n.sp.)	4/7(4)	6/11(9)	10(2)/18(13)

The Torinosu series is in the time-range from Callovian to Tithonian as determined by the following fossils:

1. *Horioceras mitodense*, *Hecticoceras* sp, *Sigaloceras* sp. *Properisphinctes* aff. *bernensis* - - - Callovian and lower Oxfordian
2. *Lithacoceras tarodense* - - - Uppermost Oxfordian to lower Kimmeridgian
3. *Ataxioceras kurisakense*, *Aulacosphinctoides steigeri* - - - Kimmeridgian
4. *Pseudosaccocoma japonica* - - - Tithonian

Beside these there are *Pseudocyclamina*, *Milleporidium* and many other warm water inhabitants (Hanzawa, Eguchi), showing affinities to the Tethyan fauna. In view of not only the development of the southern members, but also the inclusion of the definitely northern elements, the Jurassic of Japan is found to be a key point for interprovincial correlation.

Finally, it is noted that all marine faunas in Japan are so similar in the late Triassic period that no barrier is recognizable between the inner and outer side, while the Jurassic ones are quite different between the two sides, the facts showing the appearance of the Eo-Nippon Cordillera. Due to the development by the Sakawa orogeny, the difference became by far greater in the Cretaceous period when the non-marine red formation was extensively developed on the inner side.

For the recent advancements in the stratigraphy of the other systems, see the following papers:

Fujimoto, H., 1952, The fusulinid Zones in the Japanese Carboniferous. *Cr. 3e Congr. Strat. Geol. Carbon. Heerlen, 1951, Vol. 1.*

Hayasaka, I. and Minato, M., 1952, Carboniferous Formations in the Japanese Islands. *Ibid. Vol. 1.*

Ichikawa, K., 1956, Triassic Biochronology of Japan. *Eight Pacif. Sci. Congr. Philippines, 1953, Proc. Vol. 2.*

Ikebe, N., 1956, Cenozoic Geohistory of Japan. *Ibid. Vol. 2.*

Kobayashi, T., 1952, Late Palaeozoic and Triassic Palaeogeography of Eastern Asia and its Relation to the Floral Evolution. *C. R. 3e Congr. Strat. Géol. Carbon. Heerlen, 1951, Vol. 1.*

——, 1956, The Triassic Akiyoshi Orogeny. *Geotektonisches Symposium zu Ehren von Hans Stille.*

Matsumoto, T., *et al.*, 1954, The Cretaceous System in the Japanese Islands. *Japan. Soc. for Prom. Sci. Tokyo.*

Asano and Toriyama's papers in this publication.

RECENT ADVANCES IN THE CORRELATION OF NEW ZEALAND CRETACEOUS SEDIMENTS

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This paper summarizes the main advances in Cretaceous stratigraphy made in New Zealand since 1953. *Inoceramus* has been found to be widespread in New Zealand upper and middle Cretaceous sediments. Many of the species have short ranges and are useful for local and overseas correlation. The existing stratigraphy has been revised and several new stage divisions proposed. The section at Coverham Clarence Valley, previously considered the type for the middle Cretaceous, proved to be complexly deformed and stratigraphically misleading. New type sections have been proposed. The new divisions probably provide a substantially continuous sequence from the base of the Tertiary down to the Aptian or Neocomian. In the Raukumara Peninsula the Taitai Sandstone was considered to have been thrust over upper Cretaceous sediments for many miles, but the supposed upper Cretaceous sediments are actually lower Cretaceous and probably older than the Taitai Sandstone, and there is no stratigraphic evidence for the overthrust.

HISTORY OF RECENT STUDIES

During the last five years many New Zealand Cretaceous sections have been re-examined and considerable stratigraphic changes made. A preliminary chart showing the proposed new divisions was published in the abstracts of the XX International Geological Congress (Wellman, 1956) and full descriptions of the proposed new divisions are in the press.

Correlation is mainly based on *Inoceramus* which is widely distributed and occurs in a variety of sediments. Ammonites are so rare as to be useless for local correlation. Foraminifera are most important in the uppermost Cretaceous. Four of the five *Inoceramus* species already described—*I. porrectus*, *I. pacificus*, and *I. australis*, all of Woods, 1917, and *I. bicorrugatus* Marwick 1926 are widespread in New Zealand. *I. concentricus* Park. is known in New Zealand from Coverham in the lower Clarence Valley only. Ten new species have been recognized of which seven are widely distributed. The new species are being described and will be referred to here by the initial letter of their proposed specific name.

The stratigraphic revision started on the east coast of the North Island where the following *Inoceramus* sequence was established in several sections:-

I. australis and *I. pacificus*
I. sp. O
I. bicorrugatus
I. sp. R.

The two species that occur together at the top of the sequence were originally described from Amuri Bluff (Woods 1917) in the lower part of the type section of the Piripauan Stage (Thomson 1917), and date the upper part of the east coast sections as Piripauan. The species below had been collected at various times from or near what was considered to be the type section for the New Zealand middle Cretaceous at Coverham in the Clarence Valley, South Island (Thomson, 1919), but the succession at Coverham did not match that established on the east coast of the North Island.

This was found (Wellman 1955) to be due to complex folding and faulting that had produced an extremely misleading section considered by Thomson (1919) to be stratigraphically continuous. The true sequence at Coverham is identical with that established on the east coast, but with the addition of older fossiliferous beds with *Inoceramus porrectus* Woods, *Aucellina euglypha* Woods, *Turrilites*, and *Inoceramus concentricus* Park. on which the whole section had been dated as Albian to Cenomanian by Woods in 1917. Finlay and Marwick based their Clarence Series on the Coverham section and considered it Albian in 1947.

The Clarence Series was restricted by Wellman in 1955 to the older beds with the fossils described by Woods, and a new time-stratigraphic division—the Raukumara Series—proposed for the beds between the base of the Piripauan and the top of the restricted Clarence Series. The Raukumara Series is divided into three stages—Arowhanan, Mangaotanean, and Teratan—on the basis of *Inoceramus*.

It was found by Mr. N. de B. Hornibrook of the New Zealand Geological Survey (in Wellman, 1955) that the east coast beds with *I. pacificus* contain foraminifera that more closely resemble those of the Raukumara Series than they do those that had been considered typical of the Piripauan through South Island correlation from Amuri Bluff to Waipara River.

The importance of Foraminifera for the division of the uppermost Cretaceous and basal Tertiary had been established by Finlay on the east coast of the North Island (Finlay and Marwick, 1947), but the virtual absence of foraminifera from the type Piripauan had made it difficult for him to relate the deeper water foraminiferal sediments of the east coast with the shelf sandstones with abundant Mollusca, on which the Piripauan had been based. Correlation was indirect and partly based on lithologic correlation. The discovery of the deeper water east coast sequence with *I. pacificus* and *I. australis* made correlation with the type Piripauan possible. As it was known that *I. pacificus* and *I. australis* are confined to the older part of the type Piripauan section at Amuri Bluff, the foraminiferal fauna on which correlation with the Piripauan had been based evidently represents the younger part of the Piripauan only. Subdivision of the Piripauan became necessary. "Piripauan" was retained as the stage name for the lower part with the key fossils *I. australis* and *I. pacificus* and "Haumurian" proposed as the stage name for the upper part. The type section at Amuri Bluff was retained as the type for the two stages, the boundary being taken at the bottom of the Black Grit of McKay (1877 p. 178)

The difficulty of correlating stages defined on Mollusca with those defined on Foraminifera has recently caused a further modification of the New Zealand uppermost Cretaceous time-stratigraphic divisions. The Mata Series was introduced by Finlay and Marwick in 1947 to include the Piripauan (now Piripauan and Haumurian) and the younger Teurian, and Wangaloan stages. The type locality for the Teurian, at Te Uri Stream in Hawkes Bay, North Island, is part of a sequence that extends up from the Haumurian through the Teurian to include the type localities of the four stages of the Dannevirke Series (Paleocene and lower Eocene). These stages are without Mollusca and the divisions are based entirely on Foraminifera. The Wangaloan (Finlay and Marwick, 1937) is a geographically isolated stage based on shallow water Mollusca and is without Foraminifera, the type locality being in the South Island 20 miles south of Dunedin. It has recently been suggested by Harrington and Hornibrook (1957) that the Wangaloan is probably the equivalent of either the Teurian stage or of one of the lower stages of the Dannevirke Series, and that it should be abandoned as part of the New Zealand stage sequence because of its poor stratigraphic definition as compared with the continuous sequence of stages based on the Te Uri Stream section.

With the additions and modifications outlined above, the New Zealand Cretaceous succession is now well established down to the base of the Raukumara Series, that is, down to about the base of the Senonian.

The pre-Senonian succession is somewhat less certain. The Coverham section, although moderately fossiliferous, is too strongly deformed to be useful. Better sections are known from the east coast of the North Island, several of which extend down to dark massive sandstone of probable Aptian age and are overlain by Raukumara beds. The best section at present known is in the upper valley of Motu River and extends eastwards for one mile from Motu Falls. It has been made the type for three of the four stage divisions of the Clarence Series.

Dark unfossiliferous sandstone at the base of the Motu Section can be correlated with reasonable certainty with sandstone 15 miles south-west at Koranga from which Aptian fossils were described by Marwick in 1939. The Koranga Sandstone underlies fossiliferous Clarence beds and overlies greywacke that unfortunately is unfossiliferous. The inferior position of the Aptian Koranga Sandstone to Clarence Series is thus reasonably well established, but it is difficult to determine the exact stratigraphic position of the *Inoceramus concentricus* bearing beds of Coverham on which the Coverian Stage is based, because *I. concentricus* appears to be absent from Koranga and Motu Falls and the lowest diagnostic fossils in the Motu Section—*I.* sp. K—appears to be absent from Coverham.

The pre-Clarence sequence is even less certain. At Coverham the Coverian Stage overlies the Wharfe Sandstone which in turn overlies dark crushed mudstone with a poorly preserved flat *Inoceramus* (*I.* sp. W). At Pahaoa River in the southern part of the east coast of the North Island dark massive sandstone similar to that at Motu Falls and Koranga overlies dark crushed mudstone with an *Inoceramus* that is poorly preserved but apparently identical with that below the Wharfe Sandstone (per. comm. Mr. J.B. Waterhouse). At Tapuwaeroa Valley in the northern part of the east coast a dark massive unfossiliferous sandstone — named the Taitai Sandstone by Ongley and Macpherson in 1926 — forms prominent cliffs at the top of Mt. Taitai and at the top of several nearby mountains. The sandstone is surrounded and probably underlain by dark crushed mudstone with a flat *Inoceramus* similar to that at Coverham and Pahaoa River. The dark crushed mudstone- named Mokoiwi Mudstone from Mokoiwi Stream in Tapuwaeroa Valley — is unfortunately not present below the fossiliferous sandstone at Koranga with which the Taitai Sandstone had been correlated by Finlay and Marwick (1940). The stratigraphic relation between the two pre-Clarence fossiliferous formations — the Mokoiwi Mudstone and the Koranga Sandstone — is probably not yet clearly enough established to warrant their being used as the basis of stage divisions as was proposed by Wellman in 1956. The two stages were grouped together under the Urewera Series (Wellman, 1956). Dr. C.A. Fleming has since drawn the attention of the writer to the original use of Taitai by McKay in 1887 as a formation name that in terms of the present day nomenclature includes both Mokoiwi Mudstone and Taitai Sandstone. It thus seems best to abandon the Urewera Series and to replace it by Taitai Series, the name being used in a time-stratigraphic sense for Cretaceous beds of pre-Clarence age, and in particular for the Koranga Sandstone, the Mokoiwi Mudstone, and their fossiliferous correlatives.

DESCRIPTION OF STAGES

The revised list of the stages and series for the Cretaceous of New Zealand, and their probable relation to the International Divisions, is shown by the table on page 271. The mapping symbols shown below the stage names are based on the initial letter of the series and stage name, and follow the system used by Finlay and Marwick in their revision of the Cretaceous and Tertiary stages in 1947. The symbol "U" is proposed for the Taitai Series to distinguish it from the upper Miocene Taranaki Series. The table also shows the sequence of *Inoceramus* species, and the stages in which Ammonites and some of the more important of the other Mollusca are found.

By far the greatest number of New Zealand Ammonites are from the upper Cretaceous of Northland and were described by Marshall in 1926. All Marshall's specimens were found in loose concretions on coastal beaches, and are considered to have been derived from concretions in alternating sandstones and shales (Mason 1953: 350) that are now classed as Haumurian. Ammonite-bearing concretions were found by Mason (1953) within a conglomerate of Haumurian or Teurian age near Hokianga. The Hokianga ammonites are evidently older than the conglomerate in which they are found and it is possible that some of the Northland Ammonites described by Marshall are derived from conglomerate and that some may be older than Haumurian. Only two of the Northland Ammonites are shown in the table. Concretions with Ammonites and *Inoceramus* are known at a few places on the East Coast of the North Island in conglomerate of about the same age as that at Hokianga. The concretions contain Clarence and Raukumara as well as Haumurian fossils and the east coast conglomerate must represent an important erosion interval.

Most of the pre-Piripauan Ammonites were recently identified by Mr. C. W. Wright of London, full descriptions being in the press.

A brief description of the lithology and thickness of the Cretaceous stages, and of the more important fossils used for overseas correlation is given below.

MATA SERIES (Danian to Campanian).

The Mata Series is now considered to contain three stages, the Teurian, the Haumurian, and the Piripauan.

The upper Mata stage — the Teurian — was originally defined by Finlay and Marwick in 1947 and has recently been redefined by Hornibrook and Harrington (1957) to include beds that were previously considered Wangaloan. It contains a high Cretaceous micro-fauna, is overlain by the Waipawan Stage with a Paleocene micro-fauna, and is considered to be Danian in age. As originally defined at Te Uri Stream, Hawkes Bay, it consists of 175 feet of dark calcareous siltstone; as redefined by Hornibrook and Harrington at Waipawa it included 250 ft of dark siltstone overlain by 100 ft of black siltstone. The stage is widely distributed and occurs in all the New Zealand Cretaceous districts. The Teurian contains foraminifera that are considered to be Danian (Hornibrook and Harrington, p. 666).

The type Haumurian includes the Sulphur Sand (500 ft) and the Black Grit (25 ft) of the Amuri Bluff Section. Haumurian sediments are widely distributed and include the Sulphur Sand, Whangai Shale, and Tapuwaeroa Beds — facies that range from shelf sands to redeposited sediments. The shelf sands are up to 600 ft thick and the redeposited sediments as much as 5,000 ft thick. The Whangai Shale contains Maestrichtian foraminifera (Hornibrook and Harriangton, 1957). The Haumurian contains the youngest Ammonites, Belemnites, and *Inoceramus* known in New Zealand. Some of the Ammonites are widely distributed Maestrichtian forms, and the Haumurian is considered to be Maestrichtian in age.

The type Piripauan includes 400 ft of richly fossiliferous concretionary sandstone in the lower part of the Amuri Bluff Section (Woods 1917). At most other places it is well sorted carbonaceous medium grained sandstone with few fossils except the two key species of *Inoceramus*—*I. pacificus*, and *I. australis*. Its thickness ranges from 10 ft to 1,000 ft. *Inoceramus australis* appears to be related to *I. balticus* Joh. Bohm, that is widely distributed in the Campanian of Europe.

RAUKUMARA SERIES (Santonian and Coniacian).

The three stages of the Raukumara Series, the Teratan, Mangaotanean, and Arowhanan are exposed in sequence at their type localities at Mangaotane River and its tributary Te Reta Stream, Raukumara Peninsula.

The Teratan—the upper stage—consists of about 2,000 ft. of massive siltstone with calcareous concretions that contain the key Inoceramus species *I.* sp. N and *I.* sp. O. It is overlain by Piripauan sandstone whith *I. pacificus* and *I. australis*.

The Mangaotanean Stage consists of massive siltstone about 700 ft. thick with the key fossil *I. bicorrugatus* (Marwick).

The Arowhanan consists of similar siltstone with interbedded bands of redeposited sandstone in its lower part. It is marked by the presence of the *Inoceramus* sp. R., an extremely large form, and rests conformably on the upper stage of the Clarence Series.

The three Raukumara Stages are widely distributed and occur in Northland, in the north-east of the South Island, and in the East Coast of the North Island. At Raukumara Peninsula—the north-eastern part of the North Island east coast—the three stages progressively change northwards from thin shelf deposits through massive siltstone to redeposited sediments at least 5,000 ft. thick. Macrofossils, except *Inoceramus*, are extremely rare except in coarse shelf sediments at a few places and have not yet been described. The two *Inoceramus* species of the upper stage—*I.* sp. N and *I.* sp. O. are probably related to *I. lobatus* and *I. lingua* Goldf. *I. lingua* is recorded by Seitz (1956) from the upper Santonian and lower Campanian of Germany. No related overseas forms are known for the key species of the Mangaotanean and Arowhanan stages.

The ages of the three Raukumara Stages are largely based on their stratigraphic relations to the better dated stages above and below.

CLARENCE SERIES (Turonian to Albian).

The type section for the upper three stages of the Clarence Series—the Ngaterian, Motuan and Urutawan—is a continuous sequence near the Motu Falls in the upper Valley of Motu River at Raukumara Peninsula.

The Ngaterian, the upper of the three stages, consists of about 2,000 ft of dark mudstone with numerous bands of redeposited sandstone. The key fossils *I. porrectus I.* sp. H. and *I.* sp. F. occur in the upper part of the stage directly below Arowhanan siltstone with *I.* sp. R.

The Motuan is about 1,500 ft thick and is lithologically similar to the Ngaterian. It contains *I.* sp. I. in its upper part and *I.* sp. U. and *Aucellina euglypha* in its lower part.

The Urutawan is about 3,000 ft thick and is composed of compacted mudstone with thin bands of *Inoceramus* limestone. Bands of redeposited sandstone occur near the top. It contains three bands with the key fossil *I.* sp. K.

The lowest and fourth stage of the Clarence Series is known with certainty only at Coverham in the lower Clarence Valley. It consists of blue-grey mustone with many concretionary bands and contains moderately abundant *I. concentricus* and rare *Turrilites*.

The Clarence Series is known from a single locality in Northland and from many places in the east coast of the North Island and in the north-east of the South Island. It is more compacted than the Raukumara Series and at most places is thicker, more strongly deformed, and with fewer fossils.

The fossils of the Clarence Series are more easily correlated with those outside New Zealand than are those of the Raukumara Series. At Port Awanui *I. porrectus* was found in a derived boulder with an *Otoscaphites* that suggests correlation with the upper Turonian of England (Wright, in press). *I.* sp. I. of the Motuan resembles the widespread lower Turonian *I. labiatus*.

The Ngaterian and upper Motuan are thus considered to be Turonian in age. The lower Motuan contains a few ammonites that suggest a Cenomanian age (Wright, in press). The key fossil of the Urutawan resembles *I. crippsi* Mant. of the English Cenomanian. The Coverian is considered Albian on the basis of *Inoceramus concentricus* and *Tusrilites*.

	INTERNATIONAL DIVISIONS		N.Z. Sereis	N.Z. Stage & Symbol	INOCERAMUS	AMMONITES	OTHER FOSSILS
UPPER CRETACEOUS	DANIAN		MATA	TEURIAN Mt	None	None	Defined by foraminifera
	MAESTRICHTIAN			HAUMURIAN Mh	*I.*sp.M	*Vertebrites murdochi* *Diplomoceras* cf. *cylindraceum* *Maorites cumshewaensis*, etc.	*Lahillia* *Ostrea lapillicola* *Conchothyra parasitica*
	CAMPANIAN	SENONIAN		PIRIPAUAN Mp	*I.australis* *I.pacificus*	*Kossmaticeras haumuriensis* *Baculites* cf. *vagina*	*Trigonia pseudocaudata* *Trigonia hanetiana*
			RAUKUMARA	TERATAN Rt	*I.*sp. N *I.*sp. O	*Gaudryceras* sp.	
	SANTONIAN			MANGAOTANEAN Rm	*I. bicorrugatus*		(Not yet described)
	CONIACIAN			AROWHANAN Ra	*I.* sp. R		*Trigonia meridiana* *Trigonia glyptica*
	TURONIAN		CLARENCE	NGATERIAN Cn	*I.*sp F *I.porrectus* *I.striatus* *I.*sp. H	*Gaudryceras subsacya* *Hyphantoceras* cf. *reussianum* *Otoscaphites* sp.	
	CENOMANIAN			MOTUAN Cm	*I.*sp. I *I.*sp. U	*Puzosia* sp. *Pachydesmoceras* sp. *Wellmanites zelandicus*	*Aucellina* sp. *Aucellina euglypha* *Aucellina* cf. *gryphaeoides*
				URUTAWAN Cu	*I.*sp. k		
LOWER CRETACEOUS	ALBIAN			COVERIAN Cc	*I.concentricus* *I.*sp. Z	*Turrilites circumtaeniatus* ?*Myloceras* sp.	?*Aucellina* cf.*gryphaeoides*
	APTIAN		TAITAI	(KORANGA-SANDSTONE) Uk	fragments only		*Macoyella magnata* *Aucellina* aff. *pavlowi* *Dicranodonta* sp. *Aucellina* cf. *aptiensis*
	NEOCOMIAN			(MOKOIWI MUDSTONE) Um	*I.*sp. W		

TAITAI SERIES (Aptian and ?Neocomian).

The Taitai Series is extremely thick and fossils are rare. At most places it is strongly compacted and highly deformed. It is represented by two fossiliferous formations, the Koranga Sandstone and the Mokoiwi Mudstone. The Koranga Sandstone contains a moderately large fauna but with fragments of Inoceramus only. An Aptian age is suggested by *Maccoyella magnata*, and by the occurrence together of *Aucellina* and *Dicronodonta* (per. comm. Dr. C.A. Fleming). The Koranga Sandstone is a fairly distinctive formation composed of massive dark sandstone with interbedded bands of igneous conglomerate. Similar but unfossiliferous sandstone and conglomerate that have long been correlated with the Koranga Sandstone are best described as Taitai Sandstone (Ongley and Macpherson, 1926), the type locality being at Tapuwaeroa Valley 60 miles north-east of Koranga. The Mokoiwi mudstone probably underlies the Taitai Sandstone and contains *Inoceramus* sp. W. for which no overseas correlative is known. The reported presence of *Globigerina* makes it likely that the Mokoiwi Mudstone is not older than upper Neocomian.

The Mokoiwi Mudstone is crushed and easily eroded and appears to be less compacted and younger than it actually is. It was confused by Ongley and Macpherson (1928) with much younger mudstone and grits that they named the Tapuwaeroa Series and which are now known to be part of the Haumurian Stage. A major thrust was postulated by Ongley (1930) to explain the position of the Taitai Sandstone above the supposedly younger mudstone. Although the relation of the Taitai Sandstone to the Mokoiwi mudstone is not definitely established there is no evidence for the thrust.

The Taitai Sandstone and Mokoiwi Mudstone crop out at several places on the east coast of the North Island. They appear to grade westward into thick undifferentiated "greywacke and argillite" that possibly includes the Neocomian and may pass down without major unconformity into the upper Jurassic.

REFERENCES

Finlay, H.J. and Marwick, J., 1937, The Wangaloan and Associated Molluscan Faunas of Kaitangata Green Island Subdivision. *N.Z. Geol. Surv. Pal. Bull.* **15**.

Finlay, H.J. and Marwick, J., 1940, The Divisions of the Upper Cretaceous and Tertiary in New Zealand. *Trans. Roy. Soc. N.Z.* **70**: 77-135.

Finlay, H.J. and Marwick, J., 1947, New Divisions of the New Zealand Upper Cretaceous and Tertiary. *N.Z. J. Sci. Tech. B* **28** (4): 228-36.

Hornibrook, N. de B. and Harrington, H.J., 1957, The Status of the Wangaloan Stage. *N.Z. J. Sci. Tech.* B **38** (6): 655-70.

McKay, A., 1887, On the Geology of East Auckland and the Northern District of Hawkes Bay. *N.Z. Geol. Surv. Rep. Geol. Explor.* 1886-87, **18**: 182-219.

Marshall, P., 1924, The Upper Cretaceous Ammonites of New Zealand. *Trans. N.Z. Inst.* **56**: 129-210.

Marwick, J., 1926, Cretaceous Fossils from Waiapu Subdivision. *N. Z. J. Sci. Tech.* **8**: 379-82.

Marwick, J., 1939, *Maccoyella* and *Aucellina* in the Taitai Series. *Trans. Roy. Soc. N.Z.* **68** (4).

Ongley, M., 1930, Taitai Overthrust, Raukumara Peninsula. *N.Z. J. Sci. Tech.* **11**: 376-82.

Ongley, M. and Macpherson, E.O., 1928, The Geology of the Waiapu Subdivision, Raukumara Division. *N.Z. Geol. Surv. Bull.* (*n.s.*) **30**.

Thomson, J.A., 1917, Diastrophic and other Considerations in Classification. *Trans. Z.N. Inst.* **49**: 337-413.

Thomson, J.A. 1919, The Geology of the Middle Clarence and the Ure Valleys, East Marlborough, New Zealand. *Trans. N.Z. Inst.* **51**: 289-349.

Wellman, H.W., 1955, A Revision of the Type Clarentian Section at Coverham, Clarence Valley, S. 35. *Trans. roy. Soc. N.Z.* **83** (1): 93-118.

Wellman, H.W., 1956, The Cretaceous of New Zealand. *XX Congreso Geol. Internac., Mexico*, 1956. *Resumenes de los Trabajos Presentados*, 351-2.

Woods, H., 1917, The Cretaceous Faunas of the North-eastern Part of the South Island of New Zealand. *N.Z. Geol. Surv. Pal. Bull.* **4**.

Wright, C.W. (in press), Some Cretaceous Ammonites from New Zealand. *Trans. Roy. Soc. N.Z.*

A COMPARISON OF TERTIARY FLORAL DEVELOPMENT IN JAPAN AND WESTERN NORTH AMERICA

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The older Tertiary floras of Japan have a more temperate aspect than those of western North America at the same latitude. Along with the common conifers, *Metasequoia*, *Glyptostrobus* and *Sequoia*, there is a large and varied group of deciduous angiosperms in such families as *Juglandaceae*, *Betulaceae*, *Fagaceae*. *Ulmaceae* and *Aceraceae*, whose modern members are now characteristic of middle latitudes in the northern hemisphere. This assemblage, both of the past and the present, is known as the Arcto-Tertiary Geoflora *(1)*. By contrast the Eocene floras of Oregon and northern California are made up largely of broad-leafed evergreens in the *Dilleniaceae*, *Euphorbiaceae*, *Lauraceae*, *Moraceae* and *Sabiaceae*; a palm, *Sabalites*, is locally abundant, and cycads are recorded though not common; conifers are rare or absent. Living forests of similar composition are restricted to lower latitudes, where the climate is free from frost. They and their Tertiary predecessors are known as the Neotropical-Tertiary Geoflora in America, and as the Paleotropical-Tertiary Geoflora in Eurasia *(1)*. Although palms and members of the tropical families above listed may be present in the Eocene floras of Hokkaido and northern Honshu, as recently listed by Endo, Huzicka and Tanai *(2)* representation of the Paleotropical - Tertiary Geoflora in northern Japan is always in a minority. Only when we study an Eocene flora from the Takashima coal field of northwestern Kyushu, at the latitude of San Diego, California, do we find an assemblage which suggests subtropical climate. To the ferns, *Sabal* and *Nelumbium* reported by Kryshtofovich *(3)* may be added *Glyptostrobus* and leaves of evergreen oaks and laurels recently collected by Endo and the senior author, which suggest a forest with the same climatic requirements as those from the Oregon Eocene. There is indicated a latitudinal zoning of vegetation from Hokkaido to Kyushu, similar to that on the western coast of North America during Early Tertiary time; but in America the corresponding forests were more than 10 degrees farther north, between southeastern Alaska and Oregon. Such differences in position of major climatic zones and vegetation on opposite sides of the Pacific are to be expected if air and water circulation during the Eocene was like that of today, and if the continents had essentially their present positions. This type of evidence appears to refute hypotheses involving continental drift or changes in the axis of rotation of the earth during later geologic time, as previously pointed out *(4)*.

Little change in generic composition is apparent between the Eocene and Oligocene floras of Japan as listed by Yabe and Endo *(4)*, and more recently studied by the senior author (see Table 1). This stability is in marked contrast to modifications in floristic composition which may be noted in western North America during this interval, involving a southward migration of the Neotropical-Tertiary Geoflora and the incoming from the north of the Arcto-Tertiary Geoflora. While the same Holarctic center must have been the source of this geoflora on both sides of the Pacific *(5)*, its arrival in Oregon and northern California was delayed until the end of the Oligocene because of milder climate there during Early Tertiary time. These southward shifts of geofloras were in response to a general trend toward lower temperature which is apparent throughout the world during the Tertiary period. Their more pronounced expression in western America than in eastern Asia appears to have resulted from fundamental differences in the tectonic history of the two continents, as will be discussed below. By the end of the Oligocene, the vegetation of Oregon was much like that of Japan, as shown in Table 1.

Table 1.
Occurrence of Common Tertiary Genera in Japan and Western North America.

	Japan				Oregon and northern California			
	Eocene	Oligocene	Miocene	Pliocene	Eocene	Oligocene	Miocene	Pliocene
Aecto-Tertiary Genera								
Glyptostrobus	x	x	x	x	x		x	
Metasequoia	x	x	x	x		x	x	
Taxodium	x	x				x	x	
Salix	x	x	x	x	x	x	x	x
Juglans	x	x	x	x		x	x	x
Alnus	x	x	x	x		x	x	x
Betula	x	x	x	x		x	x	
Carpinus	x	x	x	x		x	x	x
Castancea	x	x	x	x		x	x	x
Fagus	x	x	x	x		x	x	
Quercus	x	x	x	x	x	x	x	x
Ulmus	x	x	x	x		x	x	x
Zelkova	x	x	x	x		x	x	x
Cercidiphyllum	x	x	x	x		x	x	
Liquidambar	x		x	x	x	x	x	x
Platanus	x	x	x		x	x	x	x
Acer	x	x	x	x	x	x	x	x
Paleotropical and Neotropical-Tertiary Genera								
Sabalites	x	x	x		x			
Ficus	x	x	x		x			
Magnolia	x	x	x	x	x	x	x	
Cinnamomum	x	x	x	x	x			
Meliosma	x	x	x	x	x			
Marlea	x	x	x	x	x	x		

Almost the same degree of conservatism may be noted in the Miocene vegetation on the western side of the Pacific, with close generic and even some specific resemblance to the conifers and hardwoods which dominated the Eocene and Oligocene forests there. Close similarity in composition between floras of this age in Japan and western North America continued. By Pliocene time however, differences again appear as a result of greater climatic changes in America. It is not correct to indicate that the Pliocene floras of Japan, so fully known from the studies of Miki *(6)* and Okutsu *(7)* remained unchanged, for they lost most of their Paleotropical-Tertiary members, and several Arcto-Tertiary genera including *Taxodium* and *Platanus* became extinct. There is evidence of climatic fluctuations which temporarily restricted this forest, as was also the case in California. But *Metasequoia* and its typical associates continued to be common, and a majority of these Arcto-Tertiary trees are still living in Japan though *Metasequoia* did not survive the epoch. By contrast, many members of the Arcto-Tertiary Geoflora, including *Metasequoia*, disappeared from western North America at the end of the Miocene, and Pliocene forests were greatly restricted except along the coastal borders. In addition to some hardier genera of the Arcto-Tertiary Geoflora, there were small trees and shrubs of the Madro-Tertiary Geoflora which came in from the south and east. This Pliocene type of vegetation, as studied by Axelrod *(8)*, still characterizes wide areas covered by chaparral and grassland.

Our comparison of Tertiary vegetation on opposite sides of the northern Pacific Basin has shown wide differences in composition, succession and distribution which can best be explained by referring to the geologic history of the continents involved. Assuming that North America had its present position on the eastern side of the Pacific Basin during Eocene time, it would be expected that the forests from California northward would have been more affected by marine climatic influences than those at the same latitude on the western side; their more tropical character is therefore consistent with the assumption that Asia and North America have through the Tertiary held essentially the same position with reference to the Pacific Ocean that they hold today. Gradual emergence of North America since the Eocene has accentuated the effects of a world-wide trend toward lower temperature. With the southward shifting of the Neotropical-Tertiary Geoflora, the Arcto-Tertiary Geoflora became dominant in Oregon at the end of the Oligocene. Orogeny which culminated in the up-building of the Cascade Range and the Sierra Nevada during the Miocene and Pliocene has brought continental climate to the Columbia Plateau and the Great Basin; Late Tertiary changes in ocean circulation, not necessarily related to diastrophism, have shifted the rainfall regime from summer to winter, and have greatly reduced the area in which the summer-wet Arcto-Tertiary Geoflora can survive, resulting in a wide expansion of the Madro-Tertiary Geoflora which is well suited to a cool, dry climate. The history of Tertiary vegetation in North America is a record of progressive change on an emerging continent.

By contrast, the post-Eocene history of eastern Asia has been one of submergence, as shown by the paleogeographic maps of Watanabe *(9)* and Otuka *(10)*, and by the field observations of the junior author. Here the moderating influence of the sea appears to have offset the trend toward climatic extremes so manifest in some other parts of the world, for the vegetation of Japan changed much less during post-Eocene time than in western North America. A majority of the characteristic Arcto-Tertiary genera lived throughout the Tertiary in northern Japan, but only during the middle of the period is there comparable stability in the forests of Oregon and California. Even in the Pliocene, when many of their Paleotropical-Tertiary members disappeared, the temperate forests of Japan remained largely unaltered. This conservatism was long ago noted by Kryshtofovich *(11)*.

Although the major changes which characterize the Tertiary floras of North America are lacking in Japan, there are many detailed differences in floral composition which make possible the separation of Japanese floras on the basis of their age. But for the reason above suggested, and doubtless as a result of other geographic causes, the living forests of Japan and adjacent China have retained their Tertiary aspect, and may be supposed to reflect the climate and other environmental features of the past. This region will continue to provide information essential to any sound interpretation of the history of plants, and to our understanding of modern forest distribution in the northern hemisphere.

REFERENCES

(1) Chaney, R.W., Miocene floras of the Columbia Plateau. *Carnegie Inst. Wash. Pub.* In press.

(2) Endo, S.K. Huzi ka and T. Tanai, 1956, Palaeogene floras in Japan. Issued in mimeographed form.

(3) Kryshtofovich, A., 1918, Two forms and a palm from the Tertiary of the Takashima coal mines in the Province of Hizen. *Jour. Geol. Soc. Tokyo*, **25**: 1-5.

(4) Chaney, R.W., 1940, Tertiary forests and continental history. *Bull. Geol. Soc. Am.* **51**: 481-486.

(5) Chaney, R.W., 1947, Tertiary centers and migration routes. Encl. Mon. **17**: 144-146.

(6) Miki, S., 1941, The clay or lignite beds flora in Japan with special reference to the *Pinus trifolia* beds in Central Hondo. *Jap. Jour. Bot.* **11**: 237-303.

(7) Okutsu, H., 1955, On the stratigraphy and paleobotany of the Cenozoic plant beds of the Sendai area. *Sci. Repts. Tohoku Univ.*, 2nd ser., **26**: 1-114.

(8) Axelrod, D.I., 1950, Studies in Late Tertiary paleobotany. *Carnegie Inst. Wash. Pub.* **590**: 1-323.

(9) Watanabe, K., 1938, Tertiary palaeogeography of Japan. *Jour. Geog.* **50** (594): 351-372 (an abstract in English).

(10) Otuka, Y., 1939, Tertiary crustal deformations in Japan (with short remarks on Tertiary palaeogeography). Jubilee Pub. in Commemoration of Prof. H. Yabe's 60th Birthday.: 481-519.

(11) Kryshtofovich, A., 1920, A new fossil palm and some other plants of the Tertiary Japan. *Jour. Geol. Soc. Tokyo*, **37**: 1-20.

A COMPARISON OF THE FAUNA OF THE PORONAI FORMATION OF JAPAN WITH WEST AMERICAN MIDDLE TERTIARY FAUNAS

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Comparison of specimens of marine mollusca (twenty three species) from the Poronai formation of Hokkaido, Japan, with specimens of West American Tertiary species shows the greatest similarity to be with species from the Blakeley formation of Washington and Poul Creek formation of Alaska. Over half of these species vary from very close to moderately close to the American species. Whether or not this relationship indicates a like age or similarity of depositional facies cannot be certainly determined at present. Because the Japanese species show little resemblance to species of West American formations younger than the Blakeley and the Poul Creek, it is suggested that the relationship may indicate similar age.

The Japanese and the most similar West American species are: *Acila picturata* (Yokoyama) and *A. gettysburgensis* var. *alaskensis* (Clark) from the Poul Creek formation; *Yoldia laudabilis* Yokoyama and *Y. olympiana* Clark from the Blakeley formation; *Y. tokunagai* Yokoyama and *Y. blakeleyensis* Durham from the Blakeley formation; *Y. watasei* Kanehara and *Y. chehalisensis* Tegland (not Arnold) from the Blakeley formation; *Y.* cf. *thraciaeformis* Storer and *Y.* cf. *olympiana* Clark of Tegland from the Blakeley formation; *Nemocardium ezoense* Takeda and *N. griphus* Keen from the Astoria formation; *Thyasira bisecta* Conrad of Takeda and *T. bisecta* Conrad from the Blakeley formation; *Macoma asagaiensis* Makiyama and *M. lorenzoensis* var. *arnoldi* Tegland from the Blakeley formation *M. sejugata* (Yokoyama) and *M.* cf. *secta* Clark from the Poul Creek formation; *Turritella poronaiensis* Takeda with *T. porterensis* from the Lincoln formation and *T.* cf. *porterensis* Clark from the Poul Creek formation (according to F.S. MacNeil, 1957); *Neptunea ezoana* Takeda and *Ancistrolepis teglandae* Weaver (= *A. clarki* Tegland, non Meek) from the Blackeley formation.

No specimens of the other species of Takeda's 1953 list of seventy species have been available for comparison.

Suggested Correlation of the Middle Tertiary Formations of the Selected Areas of the North Pacific.

Geologic Age		Hokkaido	Alaska	Washington	Oregon	West American Standards (Megafossil)
Miocene	low.	Kawabata fm. (lower)	↑ ? Yakataga fm.	Astoria fm.	Astoria fm.	Temblor
		Takino-ué fm.			Nye fm.	Vaqueros
			?			
Oligocene	up.	Momijiyama fm. Poronai fm.	Poul Creek fm.	Blakeley fm.	Yaquina fm.	Blakeley
			?			
	low.	Ishikari gr.		Lincoln fm.	Toledo fm.	Lincoln
Eocene	up.	(upper and middle)		Keasey fm.		Keasey
			Kulthieth fm.	Cowlitz fm.	?	Tejon

FORAMINIFERAL CORRELATION IN THE JAPANESE PALEOGENE

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INTRODUCTION

During the past several years, many Foraminifera samples from the Tertiary formations of Japan were studied by K. Asano and S. Murata. The study has arrived at the point able to summarize the sequences of Foraminifera assemblages in the Paleogene formations of Hokkaido, Kyushu and the Joban coal-field, the three main areas of the Japanese Paleogene deposits.

To ascertain the geographical extent to which Japanese Paleogene sequences here described can be traced, more knowledge should be accumulated, inasmuch as a little is known about succession of Paleogene Foraminifera assemblages in the Circum-Pacific region, except the West Coast of North America where numbers of foraminiferal zones and stages have been proposed to classify the Eocene and Oligocene formations. Nevertheless, presence of several characteristic elements which are common to both Japanese and American sequences inclines the writer to believe the possibility of trans-Pacific correlation of Paleogene formations by means of Foraminifera.

ISHIKARI AND KUSHIRO COAL-FIELDS, HOKKAIDO

The Poronai shale is the typical marine Paleogene formation of the Ishikari Coal-field, Hokkaido. The shale unconformably overlies the Ishikari group which is mainly composed of the coal bearing formations, and includes other fresh, brackish or marine deposits. The Poronai shale predominantly consists of grey coloured, massive, compact mudstone from its base to top with a thickness of more than 1,200 m. Being monotonous in lithology, the formation is difficult to subdivide by lithologic criteria, despite that subdivision is needed for exploration of the underlying coal-measures of the Ishikari group. Attempts to subdivide the formation by macrofossil zones have only been successful in limited areas; and an Oligocene age of the formation has been suggested by many authors chiefly upon molluscan evidence.

Foraminifera are the most common fossils in the Poronai shale, and the writer has proposed the following four foraminiferal zonules in the formation from studies of three type sections, Hobetsu, Ikushunbetsu and Sorachi. They are, in descending order:

Plectofrondicularia packardi zonule
Bulimina ezoensis zonule
Cornuspiroides oinomikadoi zonule
Nonion sorachiense-Ammobaculites akabiraensis zonule

The *N. sorachiense - A. akabiraensis* zonule occupies the lower part of the Poronai of the southern district (Hobetsu) of the Ishikari coal-field, and is also found in the marine members of the Ishikari group.

The *Cornuspiroides oinomikadoi* zonule occupies the lower part of the Poronai of the central district (Miruto) of the Ishikari coal-field; and the Shitakara formation of the Kushiro coal-field.

The *Bulimina ezoensis*, and *Plectofrondicularia packardi* zonules are developed in the upper part of the Poronai of the Ishikari coal-field; and the Charo and Nuibetsu formations of the Kushiro coal-field.

It is therefore considered that the Poronai must have been accumulated by successive transgressions from the south to the north of the field from the sequence of the foraminiferal zonules.

Plectofrondicularia packardi, and *Bulimina ezoensis* zonules may be correlated partly, if not completely, with the Gaviota, Tumey and Wagonwheel formations of California, and with the Keasey and Bastendorf formations of Oregon, because of the occurrences of the following characteristic species:

Plectofrondicularia packardi Cushman and Schenck
Pl. *packardi multilineata* Cushman and Simonson
Pl. *gracilis* Smith
Bulimina schwageri Yokoyama
Cassidulina globosa Hantken

Hence, the geologic age of these two zonules is unquestionably equivalent to that of the Refugian stage of California, lower Oligocene.

The *Cornuspiroides oinomikadoi* zonule, which is characterized by the larger specimens of *C.*

oinomikadoi Hanzawa and Asano (attaining up to 5 mm in diameter), is a good index horizon of the Ishikari and Kushiro coal-fields.

The *Nonion sorachiense* - *Ammobaculites akabiraensis* zonule is characterized by *A. Akabiraensis* Asano, *Nonion sorachiense* Asano, *Plectina poronaiensis* Asano, and *Cyclammina pacifica* Beck. The zonule may be correlated with the parts of Cowlitz formation of Oregon (upper Eocene) from the foraminiferal evidence.

AMAKUSA, TAKASHIMA, KARATSU, CHIKUHO COAL-FIELDS, KYUSHU

Paleogene formations of Kyushu are developed successively from Amakusa in the south to the Chikuho coal-field in the north. They are, in descending order (after T. Nagao):

Ashiya group
Otsuji group
Sakasegawa group
Hondo group
Miroku group

The Fukami and Shiratake formations of the Miroku group are characterized by *Nummulites amakusaensis* Yabe and Hanzawa. According to Hanzawa, *N. amakusaensis* is more primitive in shell structure than a Lutetian species *N. boninensis* Hanzawa from the Ogasawara (Bonin) islands; therefore the Miroku group is older than Lutetian in age.

The Kyoragi formation of the Hondo group overlies conformably the Shiratake formation of Miroku group, and contains, the following characteristic species:

Globorotalia cf. *wilcoxensis* Cushman and Ponton
Globigerina triloculinoides Plummer
Cyclammina tani Ishizaki
Quinqueloculina cf. *imperialis* Hanna and Hanna
Q. cf. *weaveri* Rau

Occurrences of numbers of new species are also noticeable. The *Globorotalia wilcoxensis* zone has been widely known in the lower Eocene of the Gulf Coast of North America; and in the Middle East of Asia, the zone ranges from the Ypresian to Lutetian. Considering the planktonic nature of the characteristic species of this zone, the Kyoragi formation can be correlated with the Wilcox stage of the Gulf Coast.

The overlying Sakasegawa shale, a typical formation of the Sakasegawa group, contains many characteristic Foraminifera. The following four zonules are at present distinguished in the formation:

Plectofrondicularia packardi zonule
Plectina poronaiensis zonule
Plectofrondicularia nogataensis zonule
Hemicristellaria sandersi zonule

The *Plectofrondicularia packardi* zonule corresponds to that of the Poronai shale, Hokkaido and is believed to be equivalent of the Refugian stage in California.

Characteristics of the *Hemicristellaria sandersi* zonule show similarities with those of the Eocene Cowlitz formation of Oregon and Washington. Hence, it is safe to believe that the Sakasegawa shale ranges in time from the late Eocene to the early Oligocene.

Planktonic Foraminifera are fairly common throughout the Sakasegawa shale, and are apparently different from those of the Kyoragi. They are:

Globigerina eocenica Terquem
Globigerina ouachitaensis sensilis Bandy
Globigerina cf. *dissimilis* Cushman and Bermudez.

For the Otsuji group, the Iojima Foraminifera faunule from the Takashima coal-field is most typical. In the faunule, following new species (MS) are common: *Elphidium iojimaense*, *Gaudryina kishimaensis*, *Pseudononion kishimaense*, *Gyroidina iojimaensis*, *Hanzawaia sumitomoi*, *Bulimina yabei* and *Vaginulina karatsuensis*.

Elphidium iojimaense and *Bulimina yabei* are known to occur in the Shimokine formation of the Rumoi coal-field, Hokkaido, and the Shimokine is in turn correlated with the Asagai formation of the Joban coal-field by the common occurrences of *Trochammina asagaiensis* Asano and *Elphidium yumotoense* Asano. Thus, the Iojima formation may be correlated with the Shimokine and the Asagai formations, the geologic age of the latter was once discussed by Asano, referring to the Zemorrian stage of California.

The Ashiya group, the uppermost Paleogene of Kyushu, is subdivided in two foraminiferal zonules containing the Kishima faunule and the Sari faunule. Most of the species of the Kishima faunule, the lower one, extend their ranges from the Iojima faunule and is considered to be upper Oligocene. But Miocene elements of Foraminifera of Japan, such as *Nonion pompilioides* (Fichtel and Moll), *Planulina nipponica* Asano, *Trochammina nobensis* Asano, *Nodosaria longiscata* d'Orbigny and *Glandulina laevigata* d'Ornigny first appear in the Sari faunule of the Ahsiya formation.

JOBAN COAL-FIELD, FUKUSHIMA PREFECTURE

As it was previously reported by Asano, the Asagai formation, a typical Paleogene marine member of the Joban Coal-field, is characterized by the common occurrences of *Trochammina asagaiensis* Asano, *Elphidium asagaiense* Asano and *Elphidium yumotoense* Asano. With the close relation of these Foraminifera species to those of the Vaqueros formation in the Simi Valley, California, age equivalence of the Asagai to the Zemorrian stage of California was inferred.

The above statements are summarized in the following table.

Foraminiferal Correlation of the Japanese Paleogene.

	Kyushu				Fukushima	Hokkaido			
	Amakusa	Takashima	Karatsu	Chikuho	Joban	Ishikari	Kushiro	Rumoi	
Miocene			Ashiya Hatatsu Yukiaino Honeishi Sari	Ashiya Jimbara Honeishi Norimatsu					
Oligocene	~~~~~ Sakasegawa	~~~~~~ Iojima ~~~~~~ ~~~~~~ Okinoshima	Kishima ~~~~~~ (Kyuragi)	Orio ~~~~~~ (Otsuji) (Nogata)	~~~~~ Shirasaka Asagai (Iwaki)	~~~~ Poronai	Nuibetsu Charo (Shiakubetsu) Shitakara (Yubetsu)	~~~~~ Tappu Shimokine ~~~~~	Asano 7
Eocene	Hondo Miroku	(Takashima)				(Ishikari)			

( ) .... Non-marine or no Foraminifera.

~~~~ .... Unconformity.
~~~~

LOWER EOCENE PHOSPHATIZED GLOBIGERINA OOZE FROM SYLVANIA GUYOT, MARSHALL ISLANDS

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(Abstract)

The Scripps Institution of Oceanography-U.S. Navy Electronics Laboratory Mid-Pacific Expeditions of 1950 took a number of dredge hauls on the top of Sylvania Guyot, the seamount adjacent to Bikini Atoll, Marshall Islands. Sylvania has a very flat top at about 705 fathoms and is connected to Bikini by a saddle at a depth of 790 fathoms; the adjacent sea floor is deeper than 2500 fathoms.

In three of these dredge hauls fossil Foraminifera have been found in the cracks and pockets inside tuff breccia or altered lava boulders which were convered on the outside by ferromanganese crusts. In all of these deposits the material was an ancient calcareous ooze formed by the planktonic foraminiferal fauna of the time; in two deposits the calcareous material was almost completely phosphatized.

In the dredge haul from Mid-Pacific Station 43-A the tuff breccia contained cracks filled with a phosphatized fauna of earliest Eocene age dominated by *Globorotalia velascoensis* and *G.* aragonensis; the nearest faunal affinity of this assemblage, the oldest in the Northern Marshall Islands, is with similar occurring faunas from the Mid-Pacific Mountains about 1000 miles to the east and with faunas from the Paleocene and Eocene deposits of the Tampico Embayment region of Mexico.

In the dredge haul from Mid-Pacific Station MP 43-D and MP 43-DD the fossil planktonic fauna was from the Miocene. The material from MP 43-D is correlated with the *Globigerinatella insueta* zone of the Carribbean; the material is of about the same age as that found on Saipan.

The new evidence from Sylvania fits well into that previously determined and indicates the probability that in Late Cretaceous or earliest Tertiary time Sylvania was eroded to a flat bank; Bikini at this time was probably a younger and higher feature which had been little eroded. Fast subsidence in Late Cretaceous or Early Tertiary left Sylvania as a relatively deeply submerged flat bank while Bikini was at or above the surface. Subsequent submergence was relatively slow so that a great reef grew on Bikini while planktonic Foraminifera were being deposited on the top of Sylvania.

It may be very significant in the geologic history of north-central Pacific Basin that roughly the same events were transpiring at about the same time in the Bikini-Sylvania area, in the Mid-Pacific Mountains to the east, and at Eniwetok to the west.

EVIDENCE OF TERTIARY IN THE ISLAND OF BANGKA (INDONESIA)

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(Abstract)

During the author's stay in Bangka as Head and Chief-geologist of the Exploration Department of the "Bangka Tin Mines" (Perusahaan Negara Tambang Timah Bangka) investigations and screening was carried out of pre-war rock-material and lists of borings drilled for the "Bangka Tin Mines" in order to come to a re-valuation of ore-reserves for the Company. An important geological fact hitherto unpublished was found and it is worth to be mentioned here because it is for the first time that definite evidence of a Tertiary sediment in the Indonesian part of the Tin-Belt has been delivered.

In samples of borings drilled on the righthand bank of the river Menduk, 1, 5 kms. south and 0,5 km. east of the hamlet of Airpandan (West-coast of Bangka) pebbles of fossiliferous marly clay in layers of fine sand were found at a depth of 15 to 20 metres by the mining-engineer A. van der Burg in January 1939.

Determination of the smaller foraminifera by the micropalaeontologist H.E. Thalmann proved an approximately Pliocene age and the pebbles are certainly not older than Late-Neogene. The following foraminifera were recognized:

Rotalia conoides d'Orb.
Spiroloculina cf. *striata* d'Orb.
Triloculina rotundata d'Orb.
Textularia cf. *gibbosa* d'Orb.

The pebbles of fossiliferous marly clay were found in layers of fine sand containing small quantities of tin-ore and deposited discordant on the sandstone-bedrock of presumably Upper Triassic age. Stratigraphic correlation with similar deposits from Southern Sumatra is discussed.

THE USE OF CALCAREOUS ALGAE IN CORRELATING CENOZOIC DEPOSITS OF THE WESTERN PACIFIC AREA†

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Fossil calcareous algae occur abundantly in many of the marine Cenozoic deposits of the tropical Pacific region. They are especially abundant in reefs and associated deposits but occur also in other shallow water marine sediments.

Mention is made of the occurrence of algae, "Nullipores", "Lithothamnia", and Halimeda in many geological reports and papers, but relatively few are actually described.

During the last 10 years the author has collected and studied fossil and Recent calcareous algae from numerous islands of the western Pacific and has studied collections from the East Indies, Japan, and Hawaii. He has also studied the algae obtained in the deep cores drilled in the reefs of Funafuti, Kita-Daito-Jima, Bikini, and Eniwetok. These studies have given him an opportunity to become acquainted with algal floras ranging in age from Eocene to Recent and from a number of quite widely separated localities. It has been found that in general the ancient floras of calcareous algae resembled the Recent ones in several respects: (1) the floras consist mainly of a relatively small number of widely distributed forms, (2) all the calcareous algae have belonged to the green or red groups, and (3) a majority of the genera have been the same from the Eocene to the Recent.[1]

Throughout the Cenozoic calcareous algae have been locally abundant, and have contributed considerably in building limestones and reefs.

CALCAREOUS ALGAE

The calcareous algae are those algae which have developed the ability to secrete or deposit calcium carbonate within and around the plant tissue. This may be accomplished in a number of ways: (1) lime may be secreted within and between the cell walls (as among the red coralline algae), (2) a calcification of the tissue may start at the outside and gradually progress inward until some of the older parts of the plant are well calcified (as in the Recent *Halimeda* and among many ancient members of the family *Codiaceae*), (3) lime may be precipitated around the plant or portions of it, forming a more or less complete mold (as with many of the *Dasycladaceae*), (4) lime may be precipitated in and around a plant, colony, or felt-like growth of fine algal threads, forming quite solid but very porous calcareous masses (particularly among some of the lower types of green and blue-green algae).

Calcareous algae appear in the geologic record far back in geologic time (middle Proterozoic) and have been at least locally important at various times and places ever since.

CLASSIFICATION OF CALCAREOUS ALGAE

Algae have been separated by botanists into a number of major divisions or phyla on the basis of the color (pigmentation) of the living plants. Some members of four of these phyla have developed the ability to secrete or deposit lime.

Table 1 shows a classification for fossil algae and the basic characteristics of the most important groups.

Only three of these groups occur in any abundance in the Cenozoic rocks of the Western Pacific. These are the red Coralline algae, and members of two families of green algae — the *Halimeda* among the *Codiaceae* and some of the *Dasycladaceae*. The classification of these is shown on Table 2, and the names of the more common genera are given.

All of these algae can be useful to the geologist in supplying ecological data, but the crustose corallines are the only ones which can be used for correlating and dating rocks at the present time. The dasycladaceans have good possibilities and have been used in central Europe and the Mediterranean region. For the Pacific area we do not yet have sufficient data on them. *Halimeda* probably could be used where entire loose

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† Publication authorized by the Director, U.S. Geological Survey.

[1] However, the common widespread Recent genera *Porolithon* and *Goniolithon* have not been found in rocks older than Tertiary g. and are not abundantly represented before the Pleistocene.

segments are available. The genus is easily recognized in thin sections, but species can rarely be differentiated, hence cannot be used for dating rocks.

DISTRIBUTION

The coralline algae of the tropical Pacific form a small group of rather highly specialized plants. At a given locality they are usually represented by a large number of individuals belonging to a small number of genera and species. The common species have a wide geographic distribution, extending from the Red Sea, across the Indian Ocean, through the East Indies and widely over the western Pacific, some extending over to Hawaii. The greatest variety appears to occur in and around the East Indies.

The fossil assemblages studied to date appear to belong to two quite typical groups apparently separated largely by latitude (and water temperature): (1) a temperate flora from Japan and Okinawa (material studied mainly Pliocene to Recent), and (2) the tropical flora from the Marshalls, Mariannas, Carolines, Palau, Fiji and the East Indies. Taiwan and the southern Ryukyus are in between as far as the fossils of the late Tertiary and Pleistocene indicate, but had the tropical flora during the Eocene.

POSSIBILITIES OF ALGAE FOR CORRELATION

So far the author's work on fossil algae from the western Pacific has been largely identification and description of material from beds of known age (dated by Foraminifera). Collections have been studied from a number of widely separated islands. No material of Oligocene age has been received, and the only Pliocene specimens studied came from Okinawa (see Table 3). Each collection studied has revealed some new species, but a pattern is beginning to appear. No Eocene

Table 1.
Classification of Fossil Algae.

Class	Family or order	Characteristic Structures
Rhodophyta (red algae)	*Corallinaceae*	Rows of closely packed cells rectangular in section. Spore cases or conceptacles.
	Solenoporaceae	Rows of closely packed cells with polygonal cross section. Cross partitions present though frequently very thin.
Phaeophyta (brown algae)	*Laminariales* and others (?)	Corded strands of parallel threads (as in framework of *Archimedes* Hall). Frondese types.
Chlorophyta (green algae)	*Codiaceae*	Small tubes loosely arranged so as to form segmented stems. Tubes round in cross section and branching.
	Dasycladaceae	A central stalk, preserved as a tube or bulb, surrounded by tufts of stems or branches, preserved as knobs or brushlike protuberances.
	Charophyta	Highly developed small bushy plants. Fossils usually consist of calcified, heavily ribbed, spherical oogonia and the whorled branches which bear them.
Cyanophyta (possibly Chlorophyta)	*Porostromata*	Small tubes so loosely arranged as not to compress each other. No cross partitions visible.
Cyanophyta (blue-green algae)	*Spongiostromata*	Cellular structure seldom preserved. The $CaCO_3$ is deposited as crusts on the outside of the colony or cell, or between the tissues, not in the cell wall. Classified on the basis of growth habit and form of the colony.

Table 2.

Classification of Cenozoic Calcareous Algae of the Western Pacific.

Phylum	Family & Subfamily	Common Genera
Rhodophyceae (Red algae)	*Corallinaceae* 1-*Crustose Corallines* *(Melobesieae)*	*Archaeolithothamnium* *Lithothamnium* *Mesophyllum* *Lithophyllum* *Porolithon* *Goniolithon* *Lithoporella* *Melobesia* *Dermatolithon*
	2-*Articulated Corallines* *(Corallineae)*	*Corallina* *Amphiroa* *Jania* *Arthrocardia*
Chlorophyceae (Green algae)	*Codiaceae*	*Halimeda*
	Dasycladaceae	*Bornetella* *Cymapolia* *Acetabularia*

Table 3.

Age and Geographic Distribution of Collections Studied.

	East Indies	Funafuti	Lau, Fiji	Palau	Guam	Saipan	Bikini	Eniwetok	Ishigaki	Okinawa	Kita-Daito-Jima
Recent	x	x	x	x	x	x	x	x		x	x
Pleistocene	x	?	x	x	x	x	x	x	x	x	x
Pliocene										x	?
Miocene	x		x	x	x	x	x	x			
Oligocene						?					
Eocene	x				x	x		x	x		

species have been found in the Miocene, and only two questionably determined Miocene forms extend up into the Pleistocene. Pleistocene and Recent cannot be separated, and the one Pliocene collection studied is very similar to Pleistocene and Recent.

It is interesting to note that the Eocene flora is surprisingly homogeneous in all the areas studied, and it contains a number of forms which are specifically identical or very closely related to species which have been described from the Mediterranean Region. The composition and known distribution of this flora is shown graphically as Table 4. Future work probably will add to the area in which the flora is known to occur. The Miocene flora also has links with the Mediterranean, but it is not so closely connected as the Eocene flora. Charts showing the known distribution of fossil species described from the Western Pacific will be published in the author's forthcoming report on the algae from the Eniwetok, Funafuti, and Kita-Daito-Jima cores.

Table 4.
Geographical Distribution of Eocene Coralline Algae Found in the Western Pacific.

Genus and Species	Eniwetok	Ishigashi	Saipan	India	Egypt	Somali	Algeria	Spain	Italy	Yugoslavia	Panama
Archaeolithothamnium											
A. cf. A. *chamorrosum* Johnson		x	x								
A. *dalloni* Lemoine	x	x					x				
A. cf. A. *hemchandri* Rao	x			x							
A. *nummuliticum* (Gümbel) Rothpletz	x	x		x	x	x	x	x	x	x	
A. *oulianovi* Pfender	x		x				x	x			
A. aff. A. *saipanensum* Johnson	x	x									
A. cf. A. *sociabile* Lemoine	x						x				
Lithophyllum											
L. cf. *lingusticum* Airoldi	x					x					
Lithothamnium											
L. cf. L. *abraidi* Lemoine	x	x	x				x		x		
L. *crisputhallum* Johnson	x		x								
L. *kumbecrustum* Johnson	x		x								
L. cf. *moreti* Lemoine		x					x				
L. *tapachaum* Johnson		x	x								
Mesophyllum											
M. *robustus* Johnson	x	x									
M. *vaughanii* (Howe) Lemoine		x									x
Corallina											
C. *prisca* Johnson	x		x								

Madame Lemoine's work (1939) has shown that the crustose coralline algae can be used in correlating strata in the region around the western Mediterranean. The studies completed and in progress have convinced the author that they have similar possibilities for use in stratigraphic correlation, not only in the Western Pacific region, but over a much more extensive area embracing much of southeastern Asia.

REFERENCES

Foslie, M.H. and Printz, H., 1929, contributions to a Monograph of the Lithothamnia. *Det Kongl. Norske Vid. Selsk. Museet.* Monograph 60 pp., 75 pl.

Ishijima, W., 1954, Cenozoic Coralline Algae from the Western Pacific. Tokyo, Yuhodo Company, Tokyo, 87 pp., 69 pl.

Johnson, J. Harlan, 1954, An Introduction to the Study of Rock Building Algae and Algal Limestones. *Colorado School of Mines Quart.* **49** (2): 117 pp., 62 pl. (April).

———, 1954, Fossil Calcareous Algae from Bikini Atoll. *U.S. Geol. Survey Prof. Paper* **260-M,** 537-545.

———, 1957, Fossil Calcareous Algae from Saipan, *U.S. Geol. Survey Prof. Paper* **280-E** pl. 25 (in press).

———, 1958, Fossil Calcareous Algae from the Eniwetok, Funafuti and Kita-Daito-Jima Drill Holes. *U.S. Geol. Survey Prof. Paper* **260-W** (in press).

Johnson, J. Harlan and Ferris, B.J., 1949, Tertiary Coralline Algae from the Dutch East Indies, *Jour. Paleontology,* **23** (2) : 193-198, pls, 37-39, March).

———, 1950, Tertiary and Pleistocene Coralline Algae from Lau, Fiji, *Bernice P. Bishop Museum Bulletin* **201** : 27 pp. 9 pls.

Lemoine, Mme. P., 1939, Les Algues Calcaires Fossiles de L' Algerie. *Mat. Carte Géol. de L'Algerie,* 1mc Series, **9**: 128 pp., 3 pls., 80 figs.

Lignac-Crutterink, L.H., 1943, Some Tertiary Corallinaceae of the Malaysian Archipelago. *Verh. Geologisch-Mijnbouwkundig Genootschap voor Nederland en Koloniën.* Geol. Ser., **13**:283-297, 2 pl. (Dec.).

Sripada, Rao K., 1943, Fossil Algae from Assam: 1-The Corallinaceae. *Proc. Nat. L'Acad. Sciences, India,* **13** (5): 265-299.

Weber van Bosse, Mrs. and Foslie, M.H., 1904, The Corallinaceae of the Siboga Expedition. *Siboga Exp. Mono.* **61**: 110 pp., 16 pl., Leyden, Holland.

A REVISION OF THE STRATIGRAPHICAL SEQUENCE OF THE LANGKAWI ISLANDS, FEDERATION OF MALAYA†

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INTRODUCTION

The Langkawi Islands lie some 20 miles off the coast of Perlis, in northwest Malaya and were first visited by Mr. J.B. Scrivenor, then Director of the Geological Survey, F.M.S., in 1919 and again in 1920. In 1922 Mr. E.S. Willbourn, Assistant Geologist, obtained further information. In all approximately 6 weeks were spent on field investigations. Scrivenor and Willbourn published, in a joint paper (1923), a preliminary account of the geology together with a sketch geological map.

Scrivenor was faced with the difficult task of plotting his data on a poorly surveyed outline of the islands: many of the place names were wrongly sited. Nevertheless, a relatively accurate sketch map indicating the distribution and structure of the rocks was produced on the scale of half an inch to a mile. Most of the geological details were obtained from the superbly exposed coastal sections, but some of the inland geological boundaries proved to be less accurate. During the latter half of 1956 more detailed mapping of the Islands was carried out on a scale of 2.56 inches to a mile, using a United States Army map prepared from aerial photographs.

In revising the original map by Scrivenor and Willbourn the geology of the area has been more closely studied and a number of interesting fossil localities have been discovered. As well as the information that has come to light in re-mapping the Langkawi Islands, other material has been collected in 1955 and 1956 during the course of field-work carried out by the writer in Perlis and northern Kedah and as a member of the joint team of Thai and Malayan geologists responsible for the reconnaissance survey of the Thai Islands which lie to the north of the Langkawi Group. The evidence now accumulated shows that the conclusions of Scrivenor and Willbourn cannot be upheld regarding, firstly, the age assignments given to the sedimentary rocks and, secondly, some of the stratigraphical detail. Sufficient evidence has now been obtained to make a revision of the stratigraphy imperative. Such a reassessment will also call for a review of the probable evolution of the Malayan Arc and the general palaeogeography of the region.

ORIGINAL INTERPRETATION

This section discusses briefly the findings of Scrivenor and Willbourn, and their interpretation of the geology of Langkawi in the light of what was known at the time about the geology of other parts of Malaya. The main stratigraphical succession is set out in their paper (1923, p. 339). Apart from an attempt to correlate them with beds of known age established on the mainland, little information is given about the age of the rocks. Scrivenor (1931) suggested that more accurate determinations could be made as the identification of fossil collections from Perlis and other parts of Malaya progressed.

The stratigraphical sequence given by Scrivenor and Willbourn is as follows:—

Group A Youngest:	quartzite and shale
Group B	5,000 feet of limestone with a middle series of shale and a little quartzite.
Group C Oldest:	5,000 feet of quartzite and shale with a few thin beds of siliceous limestone.

Additional information given is that 'the limestone of group B is very clearly distinguished from the quartzite and shale of A and C but no unconformity has been noted between the three groups .... B is conformable to C and some evidence has been seen that A is conformable to B'.

This succession has been confirmed except for the quartzite and shale formation (Group A) said to be lying conformably above the limestone group. It has now been established that the beds

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at Tanjong Timun, and on Pulau Tebuyi, Pulau Tuba, and nearby islands which on Scrivenor and Willbourn's map appear as Triassic, are, in fact, a southwesterly continuation of a formation of shale, phyllite, and quartzite interbedded with the main limestone on Pulau Timun and extending from Tanjong Timun to the north coast of that island. With the removal of Scrivenor's group A the revised sequence, using carefully measured, selected sections, can be summarized briefly as follows:—

Younger: Setul Formation*	7,500 feet or more of massively bedded limestone and marble. At least two thin lenses of quartzite and shale occupy some 600 feet of the upper part of the sequence.
Older: Machinchang Formation*	4,300 feet or more of well-bedded guartzite, siltstone, and shale.

* New name

The accompanying map (Fig. 1) shows the distribution of these rock types, while the diagrammatic section (Fig. 2) shows the general structure of the islands. The lower quartzite and shale occupy in general the western half of the islands and dip to the east at gentle angle under the limestone; the limestone forms the rugged tracts of land in the eastern part of the group. The sediments are disturbed and metamorphosed by a number of granite bosses on Pulau Langkawi, Pulau Dayang Bunting, and Pulau Tuba. When comparing the revised map with the old it will be noticed that, adjoining the limestone exposures near the south point of Pulau Dayang Bunting, Scrivenor and Willbourn mapped an isolated area of quatzite and shale, an extension of which forms the little island of Pulau Batang a mile off-shore. In view of the lithology and structure of these beds they are now believed to belong to the thick lower quartzite and shale sequence. Their presence so far to the east of the main outcrop is explained by an anticlinal flexure affecting the rocks at this point.

Considering again Scrivenor and Willbourn's original succession, it is instructive to trace the evidence that led to the age allocations given to the groups A, B, and C. The only fossils recorded during the early investigations were found in the quartzite and shale of group C, and in the limestone lying immediately over the passage beds between B and C. The quartzite and shale in places showed some obscure markings which were thought to represent the casts of worm burrows. Univalve molluscan shells, bryozoans and other remains were noted on Pulau Jong (Pulau Kora), and crinoid stems were seen on Pulau Singha Kechil. No collection was made for purposes of identification on account of the relatively poor state of preservation of the specimens. Scrivenor and Willbourn wrote:

> 'Although the limestone is almost certainly Carboniferous, judging from the age of the limestone on the mainland not very far removed, and although the fossils found do not afford evidence against this view there seems little prospect of obtaining a large fauna from these rocks.
>
> 'There can be little or no doubt that the limestone is part of the Carboniferous Limestone Formation that is found in Sumatra, the Malay Peninsula, Indo-China and Burma.
>
> 'The shale and quartzite underlying the limestone conformably may be equivalent to the sandy lower beds of the Middle Carboniferous of Eastern Yunnan, where this period began with shallow water conditions. There is no evidence that they are older than Carboniferous (Devonian).
>
> 'The shale and quartzite overlying the limestone conformably is also a shallow water phase of the Carboniferous. On the mainland chert is found with quartzite above limestone and in younger strata still (Triassic to Jurassic).'

In 1926 Willbourn published an account of the geology of Kedah and Perlis. In Perlis he recognized a limestone with a thick sequence of quartzite and shale lying conformably under it. The limestone here and on Langkawi was regarded as equivalent, the underlying quartzite and shale in Perlis being correlated with the rocks of group C on Langkawi. Fossil remains were found in the passage beds between quartzite and limestone on the Perlis-Thailand Frontier near Bukit Mata Ayer. A collection was described by R.B. Newton (1926) and the assemblage found to include:

Fusulina cf. *granum-avenae* (Roemer)
Doliolina cf. *lepida* (Schwager)
Myropora (?)
Chaetetes sp.
Stenopora sp.
A Cyathophylloid coral
Cyathocrinus
Fenestella cf. *retiformis* (Schlotheim)
Schizodus sp.
Pleurophorus sp.

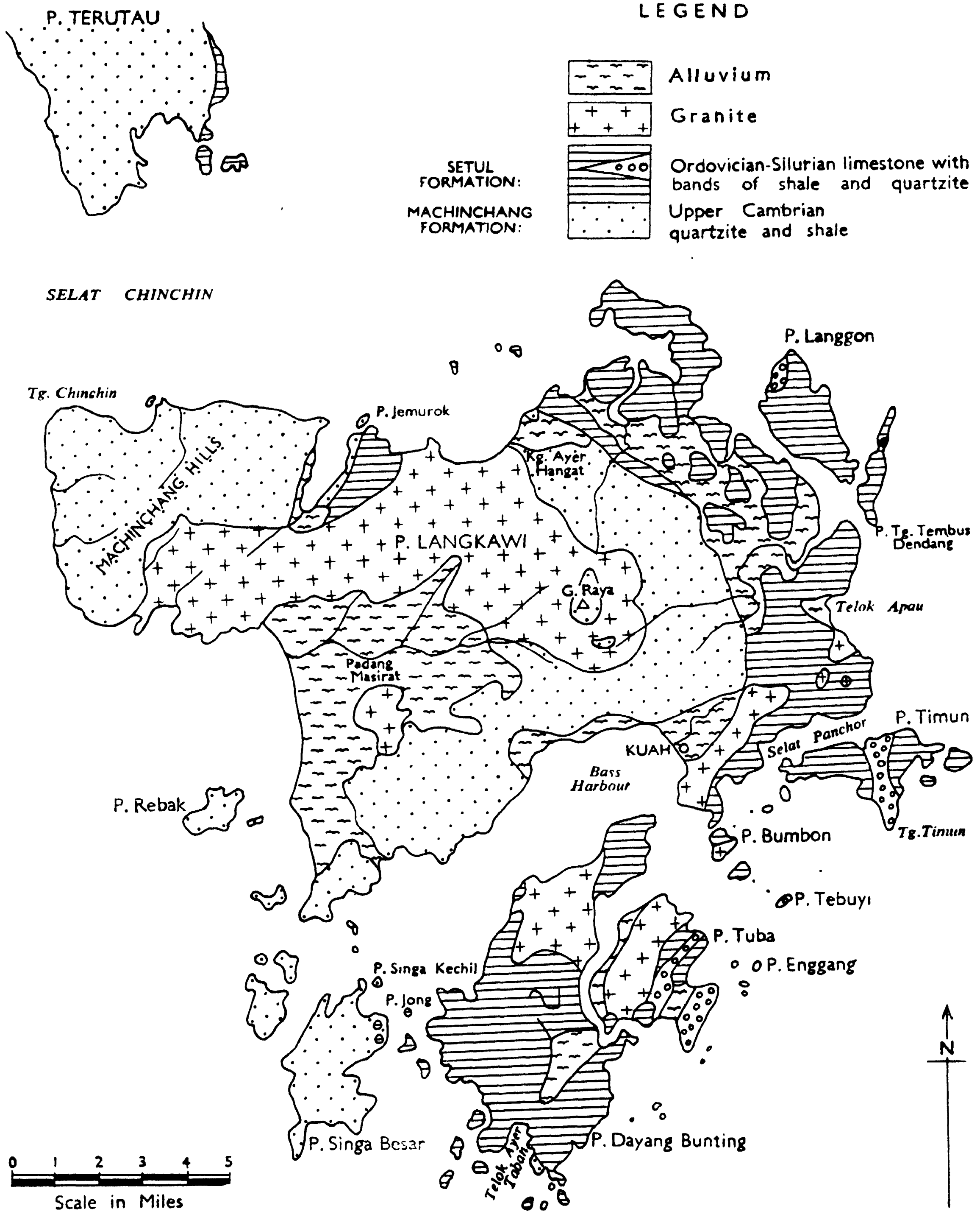

Fig. 1. — Sketch map illustrating the revised geology of the Langkawi Islands.

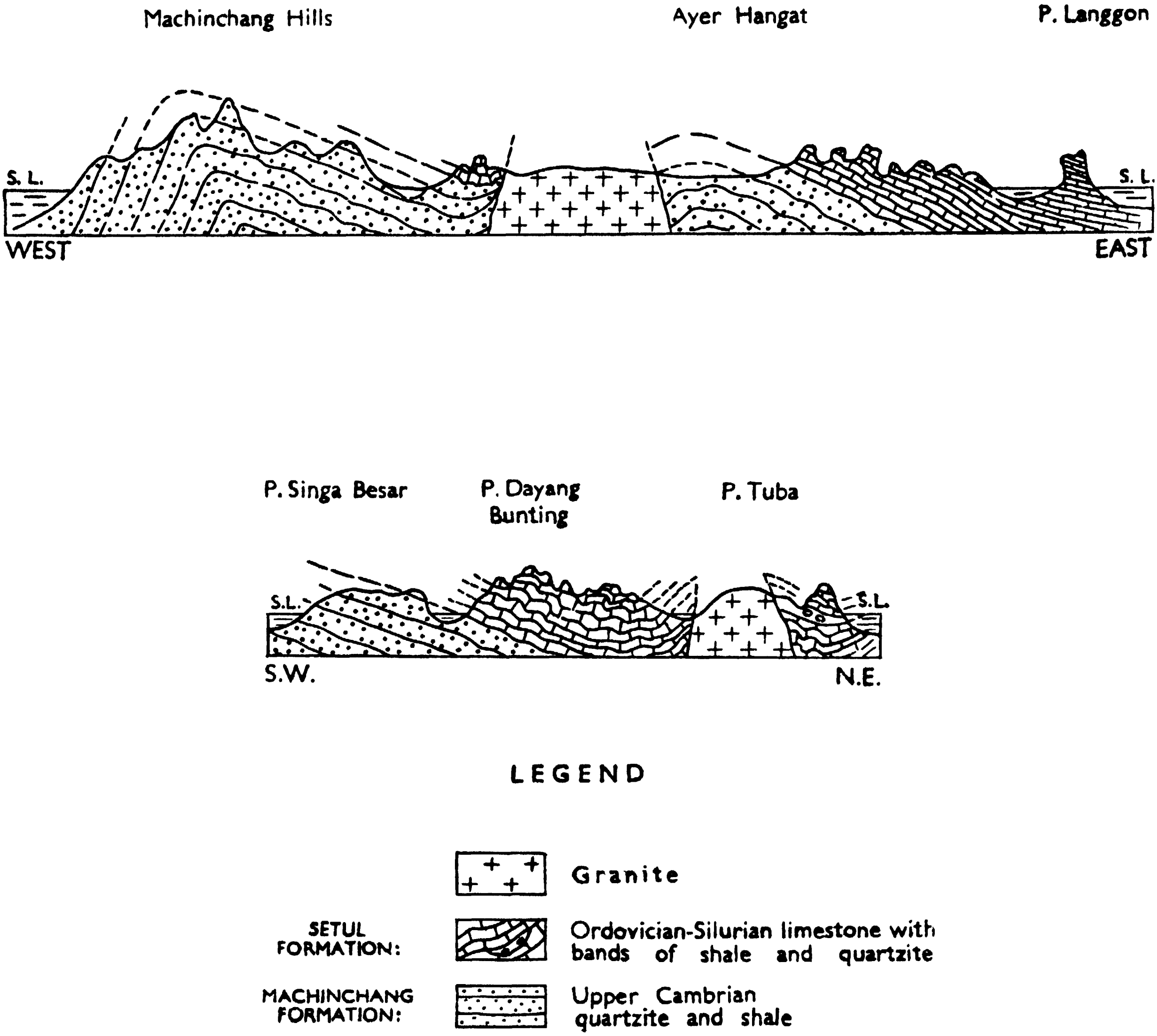

Fig. 2. — Diagrammatic sections across the Langkawi Islands illustrating the structure.

Due to the abundance of *Fusulina* the age was put at late Carboniferous or Permo-Carboniferous (Ouralian). Small lamellibranch valves were also found in shale near Kuala Nerang in Kedah. These were described by Newton (1925) as *Halobia* and given a Triassic age. It was therefore concluded that a quartzite and shale formation overlay as well as underlay the limestone, and that the upper formation extended into the Triassic.

Scrivenor (1931) summarized the picture in his 'Geology of Malaya'. He considered further evidence arising from the discovery of fossiliferous silty beds outcropping near Phattalung in Thailand. These beds bear some resemblance to the sediments underlying the limestone in Perlis and in fact would appear to represent a northerly continuation along the strike of the Perlis beds. Cowper-Reed (1920) described the fauna and lists the following fossils:

Pronorites aff. *cyclolobus* (Phill)
Pleurotomaria aff. *conica* (Phill)
Euomphalus cf. *subcircularis* (Mansuy)
Helminthochiton cf. *priscus* (Munster)
Parallelodon aff. *corrugatus* (De Kon)
Edmondia sp.
Posidonomya Becheri var. *siamensis* (Bronn Sp. nov.)

Pseudomusium cf. *pratense* (Von Koenen)
Aviculopecten cf. *denistria* (Sandb)
Athyris subtilita (Hall)
Camarophoria
Productus concentricus (Sarres-Kays)
Productus laevipunctatus (Sarres)
Chonetes rectispina (Von Kuenen)
Chonetes buchiana (De Kon)
Proetus cf. *coddonensis* (Woods)
Phillipsia aff. *silesiaca* (Scupin)
Cladochonus michelini (Edw. & Haime)

It was concluded that the fauna was closely related to the Culm Fauna (Lower Carboniferous) of Europe to the extent that some of the species seemed identical or closely comparable with types occurring in Southwest England. The sequence at Langkawi was therefore regarded as:-

Group A — Quartzite and shale: age Trias.
Group B — Limestone: age Permo-Carboniferous.
Group C — Quartzite and shale: age Carboniferous.

REASSESSMENT

It became necessary to review the early work of correlation when the existence of two limestone formations of different ages in Perlis was recognized. Detailed investigations in that state by the writer in 1955 and 1956 showed two widely separated limestone formations divided by a sequence of quartzite, siltstone, and mudstone. The upper one of these is the limestone established as Permo-Carboniferous by Willbourn; but it is only the lower and much older formation which is represented in Langkawi. It is a remarkable coincidence that both limestone formations are underlain conformably by closely similar sequences of arenaceous and argillaceous deposits. Fossil collections made in Perlis, Langkawi, and on some Thai Islands to the north of the Langkawi group, have shown that the lower limestone is, in fact, of general Ordovician age extending in time probably as late as Middle Silurian. The underlying quartzite and shale of western Langkawi represent deposition which took place late in the Cambrian period.

The older limestone of western Perlis extends north into Thailand, and one of the few fossils which so far has been identified from this series, is an Orthoceratid-like cephalopod from Thung Song. It has been recognized as belonging to the genus *Armenoceras* of Middle Ordovician age by G.A. Cooper of the Smithsonian Institute.

ORDOVICIAN AND SILURIAN LINESTONE ON LANGKAWI (SETUL FORMATION)

The limestone on Langkawi has yielded a plentiful and varied suite of often well-preserved organisms. On the islands of Pulau Langgon and Palau Tanjong Tembus Dendang, along the northwest and adjoining stretches of the coast, the limestone cliffs are continually being attacked by the sea, and this wave action has often etched the less resistant calcareous matrix surrounding the purer crystalline material which replaces the organisms and has revealed beautifully preserved specimens. The fossiliferous horizons are restricted and indeed great thicknesses of rock are barren of remains. Southwards towards Pulau Timun fossils become more rare. Here closer folding and proximity to granite intrusion have transformed the limestone into a soft and sometimes sugary marble. Distorted fossil remains can occasionally be recognized on the roofs of sea-caves, while, at intervals along the east coast of Pulau Dayang Bunting, marble formations carrying fibrous-looking diopside and tremolite also show bodies with indistinct outlines which can only be interpreted as the remnants of organic structures. The limestone lying immediately above the lower quartzite and shale on Pulau Singha Besar, on Pulau Singha Kechil, and on the nearby island stack of Pulau Jong, is dark and finely crystalline; it frequently yields moderately preserved remains.

A large selection of the limestone fauna is at present under identification and should, after detailed inspection, provide a long list of Ordovician and probably Silurian fossils. The commonest organism in the northeast Langkawi Islands around Pulau Tanjong Tembus Dendang and, in fact, throughout most of the limestone succession, is a plani-spiralled gastropod varying from a minute size to as large as 3 or 4 inches in diameter. There appear to be several different varieties of this creature depending on shell ornamentation and structure. Long, helicoidally-spiralled gastropods are also common on Pulau Langgon and these are well seen in association with horn-shaped, coral-like structures on the craggy southern tip of the island. Brachiopods of varying genera and two or three different types of primitive, orthoconic cephalopods, one of which is probably the *Armenoceras* already identified from the limestone at Thung Song, occur in profusion at certain points. A preliminary report on the brachiopods by the British Museum names the following organisms:

Fig. 3. — Fragmentary Saukid Trilobites from the late Upper Cambrian Quartzites of Pulau Terutau.

A *strophomenoid*
Schizophoria sp.
An *orthid*

These are said to represent a general Ordovician or Silurian age. The discoid gastropods seem to be the forms which most strongly resist the forces of metamorphism and usually it is only the distorted remains of these creatures which can be seen in the Pulau Timun region. Bryozoans, crinoid ossicles and brachiopods appear to be the commonest kind of organisms in the lowest horizons of the limestone around Pulau Singha Besar. Other fossils collected from the limestone of Langkawi are of a problematical nature and possibly belong to the phylum *Porifera* and others to the class *Stromatoporoidea* of the *Coelenterata.*

ORDOVICIAN AND SILURIAN ARGILLACEOUS AND ARENACEOUS BEDS ON LANGKAWI (SETUL FORMATION)

It is within the sandy and muddy phases which spanned the intervals between the main stages of calcareous deposition that the most interesting fossils and most important time indices appear. Black flagstone occurs interbedded with dark, fine-grained, and thinly-bedded siliceous material represent the non-calcareous phase of deposition on Pulau Tanjong Tembus Dendang in the northeast Langkawi Islands. These beds occupy a low saddle between hills of limestone and reach some 200 feet in thickness. Superficially they appear to have a complicated relationship with the limestone that lies above them to the north and below them to the south of the island: the limestone is thickly bedded and dips constantly at a gentle angle to the northeast; in contrast the flaggy and cherty beds are tightly folded into a series of sharp anticlines and synclines. However, close examination shows that the sequence is wholly conformable, the zone of folding probably arising by virtue of non-competence of the closely bedded non-calcareous deposits between the more competent limestone.

The flagstone on the east shore near the bottom of the sequence has yielded numerous biserial and other graptolites. Although the material is in a comparatively poor state of preservation, some very useful information has been obtained from an examination of the fauna. A representative collection has been inspected by Dr. H.W. Ball of the British Museum in co-operation with Dr. I. Strachan of Birmingham University and Professor O.M.B. Bulman of the Sedgwick Museum, Cambridge. The following organisms are listed:

A *diplograptid*
Climacograptus sp.
Climacograptus cf. *rectangularis*
Monograptus 2 spp.

Dr. Ball in his report comments that although the material is poorly preserved the assemblage indicates at least a Lower Silurian (Llandovery) age. The diplograptid in the opinion of Professor Bulman is either Glyptograptus or an Orthograptus of calcaratus type. He adds that the Glyptograptus which has rather an Ordovician 'look' about it is probably a new species; nothing in the Lower Silurian being comparable with it. Of the two species of Monograptus one has a small curved rhabdosome while the other, according to Professor Bulman, has long slender stipes and may be something in the nature of concinnus or regularis.

In late 1956 further graptolite-bearing strata were discovered on Pulau Langgon about a mile and a half to the west of the Pulau Tanjong Tembus Dendang locality. Pulau Langgon is composed mainly of limestone, but the section exposed along the west coast reveals two shaly and sandy bands in the limestone sequence. The lower band, possibly 200 feet thick, is composed of closely bedded black brittle shaly material. Graptolites occur, often profusely, along lamination planes and appear to be similar to those on Pulau Tanjong Tembus Dendang so that the two horizons are possibly equivalent. Fortunately, the Langgon specimens are better preserved than the others. Dr. Ball has provided the following list of genera:

Climacograptus spp.
Orthograptus sp.

He adds that the material is again too poorly preserved to allow specific identification, and both the genera recorded range from Middle Ordovician to Lower Silurian. That this horizon is indeed Lower Silurian is proved by the presence of a further thickness of shaly beds with subsidiary quartzite lying conformably above and separated from it by possibly 200 ft. of grey limestone. The colours of these upper beds are distinct from the lower shaly band in that they are generally buff, light-grey, brown or red. One horizon appearing about the middle of the succession has yielded a single but well-preserved monograptid identified by Drs. Ball and Strachan as *M. clingani* from the Middle Llandovery. The specimen was found in association with abundant casts of small, triangular-shaped scaphopods determined as cf. conularids. The age of these two argillaceous bands is therefore fixed with some precision as Lower to Middle Llandovery. The big thickness of limestone overlying these beds and forming the northern tip of Pulau Langgon must therefore extend well into the Silurian.

The discovery of graptolites on Langkawi is of considerable interest since these organisms have not been recorded previously from this part of the world. The nearest other known locality to Malaya is in the northern Shan States of Burma where a suite of Llandovery graptolites has been mentioned by Chhibber (1934). The Burmese locality lies approximately 1,300 miles north of Langkawi.

Bands of argillaceous and arenaceous rocks occurring interbedded with the limestone are met with again on Pulau Timun, Pulau Tebuyi, Pulau Tuba, and the group of six small islands lying to the east and southeast of Tanjong Peluru on Pulau Tuba. The rocks are usually in the form of phyllite, slate, and hard metaquartzite, their metamorphism being due to the effects of folding and the nearby granite intrusion. Although a careful search has been made in the less altered sediments no organisms have been found, and it is probable that, even if they had been present originally, they would have been destroyed by diastrophism.

The age of the base of the limestone has not so far been ascertained, but the few fossils which have been collected from the rocks lying just above the passage beds on Pulau Singha Besar, and from rocks slightly higher up in the succession on Pulau Jong, should give some indication when the main change from detrital to calcareous deposition took place.

CAMBRIAN QUARTZITE AND SHALE ON LANGKAWI (MACHINCHANG FORMATION)

Passing down into the underlying thick sequence of quartzite, siltstone, flaggy rocks, and shale, the passage beds are conspicuous by their lack of preserved organic matter. The flaggy beds and siltstone forming the shore of Pulau Singha Kechil often show indistinct fucoidal impressions. Similar markings can frequently be seen on the shores of islands formed of rocks from the higher parts of the succession both in the southwest Langkawi Islands and on the north shore of Pulau Langkawi near Pulau Jemurok where, again, these beds can be seen passing up into the limestone. In addition to fucoids other material collected from these rocks include a cylindrical organism resembling a crinoid stem from Pulau Lallang and some small, poorly preserved brachiopod casts from Pulau Singha Besar and Pulau Jemurok. These latter remains have been examined and described by the British Museum as of Linguloid form but with a median ridge on the internal cast running from the umbo to the anterior of the shell. Although distinctive, these structures do not resemble any known form and they are thought to represent Inarticulate

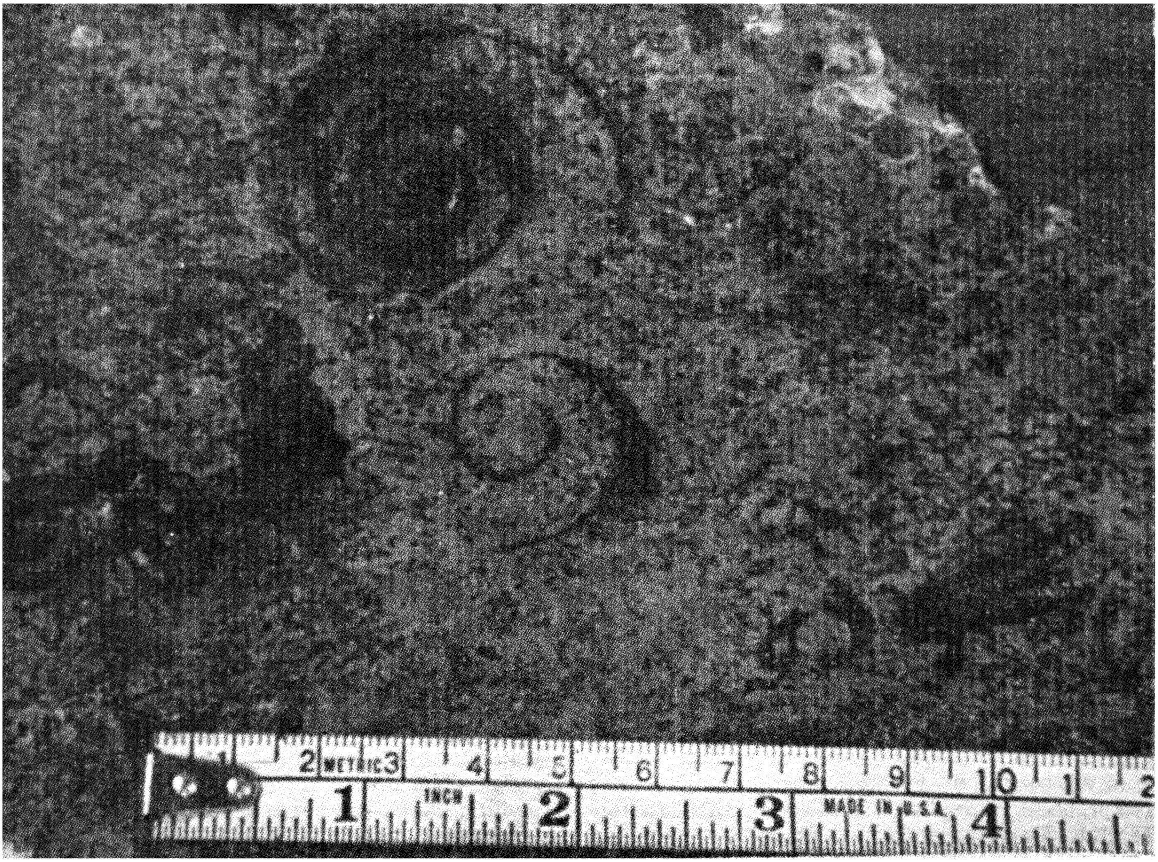

Fig. 4. — Discoid Gastropods and a Cephalopod from the Ordovician Limestone of Langkawi.

Brachiopods or primitive Terebratulids of a general Palaeozoic age. Fucoid markings similar to those on Langkawi have been described by Thai Geologists (1953) from shaly rocks exposed on Phuket Island some 100 miles to the northwest of Langkawi. Such markings have tentatively been referred to the genus *Eophyton* with a suggested Cambrian age.

The massive quartzite and shale culminate in an anticline to form the rugged Machinchang Hills of west Pulau Langkawi, and the strike of these beds can be followed northwards over Selat Chinchin to the Thai island of Pulau Terutau about 4 miles from Langkawi. There the quartzite is predominant; it is softer and coarser, and shows well-developed cross-bedding features indicating a shallow environment of deposition. The sandy beds can be seen passing up into limestone on the south and east shores of Pulau Terutau as on Langkawi. At two localities on West Terutau speckled red and yellow, thickly bedded sandstone yielded an abundance of quite well-preserved, though very fragmentary trilobites and associated brachiopod casts. On the southern coastal section some passage beds rich in a similar suite of remains were also found. Professor Teiichi Kobayashi of the Geological Institute, University of Tokyo has made an examination of the fauna at the request of the Royal Thai Department of Mines. He names the following list of organisms:

Apheoorthis (?) Sp.
Brachiopod gen. et sp. indt.
Pagodia thaiensis Kobayashi, sp. nov.
'*Eosaukia*' *buravasi* Kobayshi, sp. nov.
Coosia-like cranidium, gen. et sp. indt.
3 kinds of free cheek, gen. et sp. indt.
2 kinds of pygidia, gen. et sp. indt.

Due to the fragmentary nature of the remains Professor Kobayashi remarks that most of the forms are not suitable for accurate taxonomy, but the three trilobites and the brachiopod to which names have been applied prove that the beds are of Upper Cambrian age. The presence of Saukid trilobites permits a still further narrowing of the limits to the late Upper Cambrian, since with the sole exception of one Eosaukid from Kueichou, Saukids are all late Upper Cambrian. A report on the material from the same localities by the British Museum mentions that the brachiopods include forms similar to *Eoorthis* and *Billingsella.* With this information a reliable date can now be inferred for the lower formation of sediments on Langkawi. The bottom of the succession does not appear and the lowest beds exposed are probably those forming the southern point of Pulau Singha Besar. No fossils have been found there, and similarly the fauna from Terutau is more or less restricted to the upper parts of the exposed sequence; consequently it is not known whether the beds are entirely of late Upper Cambrian age or whether the lower parts of the succession include earlier parts of the Cambrian. However, on lithological and structural grounds the sediments appear to have accumulated very rapidly, so that the age defined by the Terutau fauna probably covers the whole of the exposed sequence.

CARBONIFEROUS QUARTZITE AND SHALE EAST OF LANGKAWI

Before concluding it is of interest to note that an assemblage of Carboniferous fossils was collected from Pulau Panjang, a Thai island lying between Langkawi and the mainland. The fossiliferous strata are exposed on the shore and include brown and grey shale, mudstone, and quartzite. They occupy a position in a synclinal trough trending north-south between the limestone of Langkawi and the Setul Boundary Range of Perlis. Dark-grey siltstone is present on the island of Pulau Tengah to the west of Pulau Terutau and the Langkawi Group and appears to occupy a corresponding position to the Pulau Panjang beds in a syncline on the west side of the Machinchang anticline. These beds have provided an interesting fauna determined by the British Museum as:

cf. *Marginirugus*
A *spiriferid*
Dielasma sp.
Worthenia aff. *orientalis* (Roemer)

The age is considered as probably Carboniferous. The report adds that the spiriferid is a member of the subfamily *Reticularinae* and is reminiscent of both *Reticularia* and *Phricodothyris.* The productid is comparable to productellids and is possibly a new genus. Scrivenor was therefore correct in placing a quartzite and shale formation on top of the limestone. The presence of these beds on the Langkawi group proper cannot be confirmed, but it is probable that they form the sea-floor at no great distance to the east of the islands. Their age is not Triassic but Carboniferous and they are equivalent to the beds underlying the upper limestone of Perlis.

REVISED STRATIGRAPHICAL TABLE FOR LANGKAWI

The revised form of the stratigraphical table representing the generalized sequence of the sedimentary rocks of Langkawi can now be summarized as follows:

Formation	Age	Description
Setul Formation	Ordovician extending into the Middle Silurian or even later	7,500 feet plus of massively bedded limestone and marble. The rock is richly fossiliferous at certain levels, the fauna being an assemblage of Ordovician and Silurian organisms including the cephalopod *Armenoceras*, discoidally and helicoidally-spiralled gastropods, corals, brachiopods, and bryozoans. The formation can be divided into two main calcareous phases separated by small thicknesses of shale and quartzite. A lower flaggy band has yielded *Climacograptus* in association with *Monograptus* indicating a lower Silurian (Llandovery) age. An upper shaly band contains *Monograptus clingani* of Middle Llandovery age: this is capped by a further big thickness of limestone.
Machinchang Formation	Late Upper Cambrian	4,500 feet or more of well-bedded quartzite, siltstone, shale and flaggy rocks showing little variation in their development. A shallow-water formation containing few fossils on Langkawi, but with Eosaukids and other related trilobites occurring in association with primitive Orthids on Pulau Terutau.

CORRELATION OF THE LANGKAWI SEQUENCE WITH THE LOWER PALAEOZOIC OF NEIGHBOURING COUNTRIES AND ITS IMPLICATIONS ON PALAEOGEOGRAPHICAL RECONSTRUCTION

With the establishment of Cambrian, Ordovician, and Silurian strata in Malaya it becomes necessary to discuss the relationship of these beds with deposits in neighbouring countries which are known to contain definite Lower Palaeozoic fossils. Previous work has necessarily had to commence with the Lower Carboniferous or late Devonian which, until now, represented the oldest known period to which the rocks of Malaya were thought to belong. Scrivenor in an appendix in Chhibber (1934) remarks on the conspicuous gap then apparently existing between the stratigraphical records of Malaya and Burma. The absence of any beds older than carboniferous was explained by the presence of land in Malaya during those times, with the consequence that no record remained.

Brief descriptions follow regarding the deposits of Lower Palaeozoic age which to date have been described in the countries adjacent to and in close proximity to Malaya. First though, with regard to Malaya, it should be noted that no Lower Palaeozoic deposits apart from the Langkawi occurrences have so far been discovered, and it seems true to say that the possibility of doing so in the future is remote.

INDONESIA

Van Bemmelen (1949) has dealt with the geological record of the East Indies in some detail. The oldest known sediments which have been conclusively dated come from the Snow Mountain Range of New Guinea where limestone boulders have yielded *Halysites wallichii* Reed proving an Upper Silurian age. It is certain though that these beds are related to the circum-Australia mountain system and not to the Himalaya-Peninsula belt.

The oldest known rocks of the Sunda region are of Lower Devonian age. The Danau formation of east-central Borneo has yielded *Clathrodiction* and *Heliolites*.

THAILAND

Until very recently only sparse geological information has been forthcoming from Thailand. In a publication by the Royal Thai Department of Mines, Brown, Buravas, and others (1953) give a short summary of the stratigraphy of the country. It appears that the Lower Palaeozoic is well represented in the Peninsula. The chronological column starts with a sequence of disputable Cambrian strata—the Phuket Series of the western coast and associated islands. The presence of the problematical organism *Eophyton* in slates from Phuket Island prompted the remark 'In the absence of other fossils a Cambrian age cannot be contradicted'. Recent work by the joint Thai-Malayan team has shown that the Phuket Series may well be the northerly extension of the Upper Cambrian beds of Pulau Terutau, so that the previous temporary assignment is probably correct. However, the proof is not yet conclusive and one difficulty which remains to be overcome is that the Phuket Series in several places has been traced up to the Burmese frontier, where the equivalent beds on the further side of the border are the Mergui Series of doubtful age, but regarded as probably Carboniferous.

The Ordovician limestone of Perlis passes into Thailand as the Thung Song Series, which extends north in a broken chain of rugged hills and passes out into the Gulf of Siam near Surat on the east coast. The beds have not been definitely recognized beyond that point.

The Kanchanaburi Series of Thailand is an extensively out-cropping sequence of shale and quartzite running north from the Malayan border in Perlis through Peninsula Thailand to the northwest tip of the country. It includes beds of Silurian to Carboniferous age, although breaks in deposition possibly occur. On the island of Ko Lanta Yai, south east of Krabi, it is seen lying over the Thung Song limestone. Pteropods similar to *Tentaculites elegans* Barrande have been recovered from shale near Kanchanaburi town and suggest a Silurian age. No Devonian fossils have been found up to the present time, but the Series extends into the Carboniferous, the Phattalung fossils already referred to on page 4 coming from slate and shale of this Series.

BURMA

The Lower Palaeozoic is quite well represented in Burma and is described by Chhibber (1934). No indisputable Cambrian sediments have been mapped, but the extensive Mergui Series of Tenasserim has been favoured from time to time with a Cambrian assignment, although it is now generally regarded as Carboniferous (see pp. 184-186). From a palaeogeographical point of view it seems very likely that Cambrian rocks should exist in Burma.

The Ordovician is represented by the Naungkangyi Series and Hwe Maung Series of shale, mudstone, and limestone, both of which present a varied selection of trilobites (*Asaphus*, *Ampyx*, *Harpes*), brachiopods (*Orthis*, *Rafinisquina*, *Plectambonites*) and cystids (*Arystocystis* etc.).

Silurian strata occur in the northern and southern Shan States. The Panghsa-pye calcareous shale and mudstone yield Llandovery graptolites (*Monograptus*, *Orthograptus*, *Climacograptus*) and other fossils (*Acidaspis*, *Orthis*, etc.). Above them come sandstone with *Bilobites*, *Pentamerus*, *Phacops*, *Calymene*, etc. followed by the Zebingyi beds of limestone and shale with *Monograptus* and *Tentaculites*. This sequence can be recognized in the southern Shan States where the Zebingyi beds at Loilem yield a fauna the top of which may be Lower Devonian.

INDIA

It is sufficient to say here that extensive Cambrian, Ordovician and Silurian deposits are known from the Central Himalayas and further west from the Salt Range and Kashmir.

CONCLUSIONS ON THE PALAEOGEOGRAPHY OF THE PERIOD

The problem then is to find the equivalents of the Langkawi beds in Peninsular Thailand and to trace them northwestwards into Burma and further into Extra-peninsular India. The Upper Cambrian of Langkawi can be followed to Terutau with little change as described on page 294. The Terutau beds are probably represented northwards by the Phuket Series which passes laterally into the Mergui Series of Tenasserim. Ordovician limestones of the Malay-Thai Peninsula are represented in Burma by more muddy deposits, although thin bands of limestone are present. The graptolitic facies extends southwards from Burma in a number of phases of which at least two in the early Silurian reached as far south as Langkawi. The local type of deposition is reversed in the late Silurian and Devonian, with predominantly muddy beds in the south, and thick limestone deposits in Burma. The relationship of the Himalayan Palaeozoic to that of the Burmese region has not been demonstrated, but there is little doubt that they both represent manifestations of the same Tethyan cycle.

Such a correlation provides a guide to a revised palaeogeographical reconstruction of Southeast Asia. The presence of an immense ocean, the forerunner of the Tethys, occupying a region of the earth's surface which probably extended east

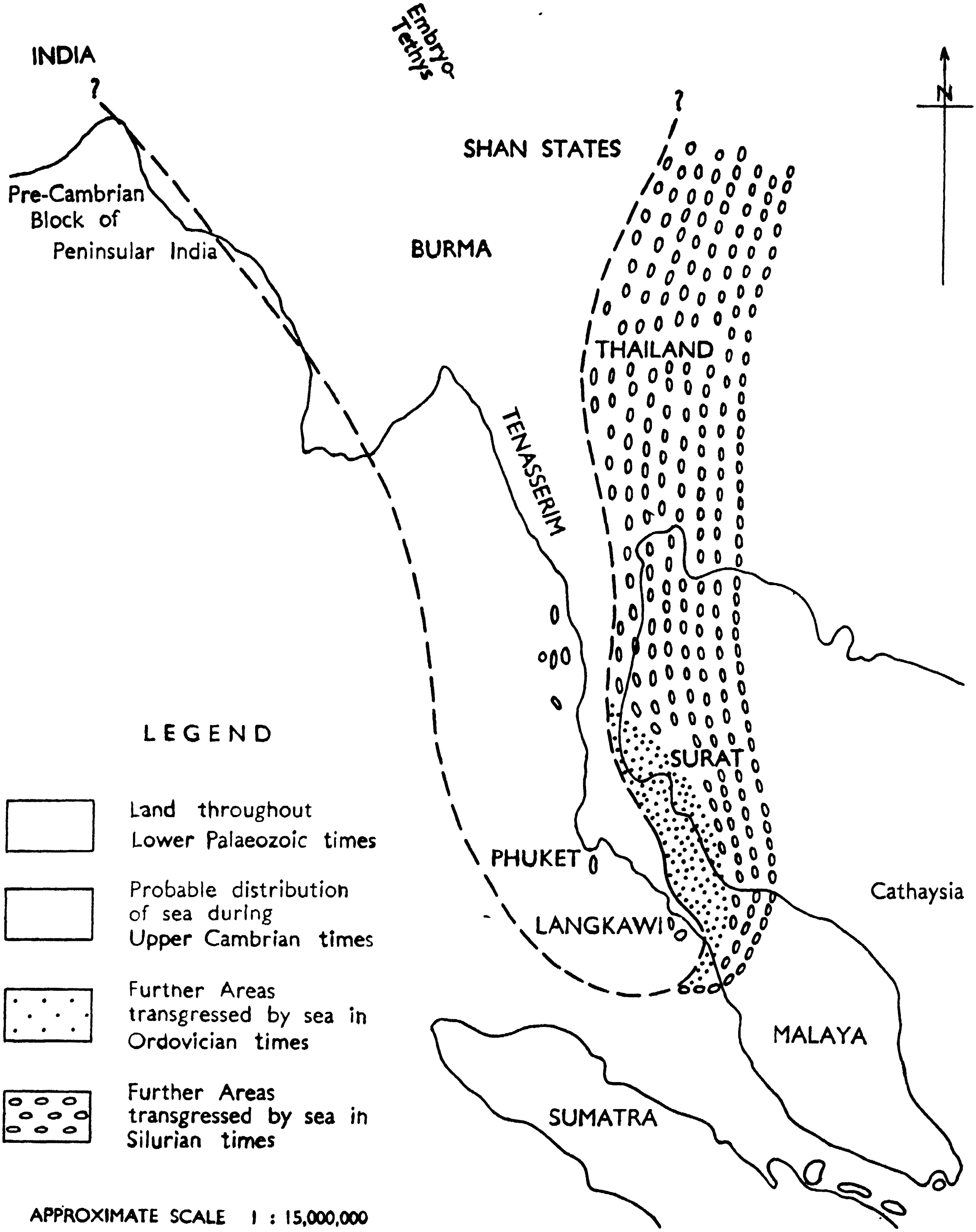

Fig. 5. — Sketch plan showing the probable distribution of land and sea during Lower Palaeozoic times.

from Europe to where the Himalayas now stand, has been well established in North India. This marine environment first became an important feature in the early Palaeozoic, and the nearly complete sequence of Cambrian, Ordovician and Silurian rocks reported from Kashmir and the Himalayas represent the deposits laid down near the southern margin of this sea. The Lower Palaeozoic cycle in Northern India shows close similarities to that of Burma, and it seems probable that the embryo-Tethys continued east in an unbroken swing to cover Upper Burma. The lateral continuity of beds which can be traced from Burma through Thailand to Malaya can be explained conveniently by a further extension of the embryo-Tethys in the form of an arm extending south to the Langkawi area.

A tentative interpretation of the palaeogeography of the peninsula during Lower Palaeozoic times is summarized on the accompanying diagram (Fig. 5). This indicates the southerly extending arm of the embryo-Tethys and demonstrates its probable growth from the time of its apparent initiation in the late Cambrian to the end of the Silurian period when drastic changes in its relative position began to take place.

The marine trough lay between two stable blocks of land to east and west. Of these the westerly block was the Pre-Cambrian mass of Peninsular India which later constituted part of the continent which has come to be termed Gondwanaland; the easterly block was the western limit of the continent of Cathaysia. The exact position of the coastline in late Cambrian times is hard to define with any precision, except in the south near Terutau where there is some evidence in the form of cross-bedding which suggests that the Cambrian sediments were derived from a landmass immediately to the northeast. The absence of further Cambrian deposits in that direction tends to confirm this hypothesis. The western limit of the sea must have been a considerable distance away from Langkawi but, as the late Cambrian of Langkawi represents the most southerly outcrop known to occur, the shore lines appear to have joined somewhere to the south of these islands.

During Ordovician and Silurian times the marine trough widened, giving rise to deposits which now occupy areas reaching far over towards the east coast of the Peninsula. A geological map of Thailand shows the Ordovician and Lower Silurian limestone extending north and east from the localities in Malaya to near Surat Thani in Thailand. The ensuing deposits of Upper Silurian and Devonian sediments cover even greater expanses of country to the east and north extending to near the Indo-Chinese frontier. This continued encroachment of Tethys produced, by the end of the Upper Palaeozoic, an extensive sea passing south over most of Malaya; with this event the palaeogeography becomes easier to define more clearly.

The Lower Palaeozoic sea can thus be visualized as forming the earliest stage in the evolution of the Malayan geosyncline. This stage is represented by the period late Cambrian to Devonian when the sea proceeded no further south than Langkawi, and most development took place towards the east. The deep geosynclinal trough proposed by Fitch (1951) became well established in the time-span Carboniferous to Trias, and represents the second stage. The final stage culminated in late Cretaceous or early Tertiary times with the rise of extensive mountain chains to form the Malaya-Indonesia Arc.

REFERENCES

Brown, G.F., Buravas, S., *et al.*, 1953, Geologic Reconnaissance of the Mineral Deposits of Thailand. *Geological Survey Memoir* **1**. Royal Thai Department of Mines, Bangkok.

Chhibber, H.L., 1934, The Geology of Burma. Macmillan & Co., Ltd., London.

Cowper-Reed, F.R., 1920, Carboniferous Fossils from Siam. *Geological Magazine*, **57**: 113-120 & 172-178.

Fitch, F.H., 1951, The Geology and Mineral Resources of the neighbourhood of Kuantan. Pahang. *Geological Survey Memoir* **6**, Geological Survey, Federation of Malaya.

Newton, R.B., 1925, On Marine Triassic Fossils from the Malayan Provinces of Kedah and Perak. *Geological Magazine*, **62**: 76-85.

————, 1926, On Fusulina and other Organisms in partially Calcareous Quartzite from near the Malayan-Siamese Frontier; *Annals and Magazine of Natural History* **17**: 49-66.

Scrivenor, J.B., 1931, The Geology of Malaya. Macmillan and Co., Ltd., London.

————, and Willbourn, E.S., 1923, The Geology of the Langkawi Islands. *Journal Malayan Branch, Royal Asiatic Society*, **1**: 338-347.

Van Bemmelen, R.W., 1949, The Geology of Indonesia, **Ia**. The Hague.

Willbourn, E.S., 1926, The Geology and Mining Industries of Kedah and Perlis. *Journal Malayan Branch, Royal Asiatic Society,* **4** : 289-232.

STRATIGRAPHY OF THAILAND

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Owing to lack of reliable topographical maps of Thailand the stratigraphy presented hereafter is almost entirely based upon fossil evidences backed up by occasional superpositions where-ever exposed. A tentative correlation with neighbouring countries' formations is also attempted, so that it may serve as a basis for future discussions and final recommendations.

CAMBRIAN

A recent discovery of Saukid trilobites and Orthid brachiopods at Tarutao Island (Cambrian$_3$ in map) finally proved that there exists a definite late Upper Cambrian formation *(1)* in the western part of the peninsula. The fossils are imbedded in a massive brown fine micaceous sandstone which has been traced to Langawi Island (Cambrian$_2$ in map) on the Malay side of the border. Trilobites are unfortunately absent over there but at Pulao Singha Besar *Eophyton* or *Planolites* with some casts of a still unidentified brachiopod were found in indurated sandy shale, enclosing occasional granite pebbles.

In every respect, the rocks are similar to rocks of the Phuket Series (Cambrian$_1$ in map) formerly described as of tentative Cambrian age *(2)*. This formation extends northward along the coast right into the southernmost tip of Burma. *Eophyton* or *Planolites* were also found in the Cambrian of southwest Yunnan (Mansuy, 1912). Thus it seems that the Upper Cambrian system of this part of the world extended down from the Yunnan Cambrian of China becoming the Chaung Magyi Series of Upper Shan States of north Burma, the Mergui Series of Lowermost Burma, the Phuket Series of Thailand, the Tarutao sandstone of south Thailand and the Langawi sandstone and shale of Malaya. At present, this Cambrian belt has not been discovered further south.

ORDOVICIAN

Lower Palaeozoic black limestone known as the Thungsong Limestone was found extending south from the mountain range east of Nakhon Si Thammarat (0_1 in map) to Satun (0_3 in map) and ending in Perlis of Malaya (0_2 in map). Cephalopods and early corals were discovered (0_1 in map) and identified as of Middle Ordovician age *(3)*. Similar layers (0_3 and 0_2 in Tarutao and Langawi Islands respectively) with gastropods, brachiopods, and a few trilobites, are lying disconformably over the Cambrian formation.

This Ordovician massive limestone formation disappears under the sea at both extremities and could not be traced anywhere inside Thailand. It is doubtful whether this can be correlated with the Mawson series of the Southern Shan States. The Ordovician of Indochina is more closely related to it.

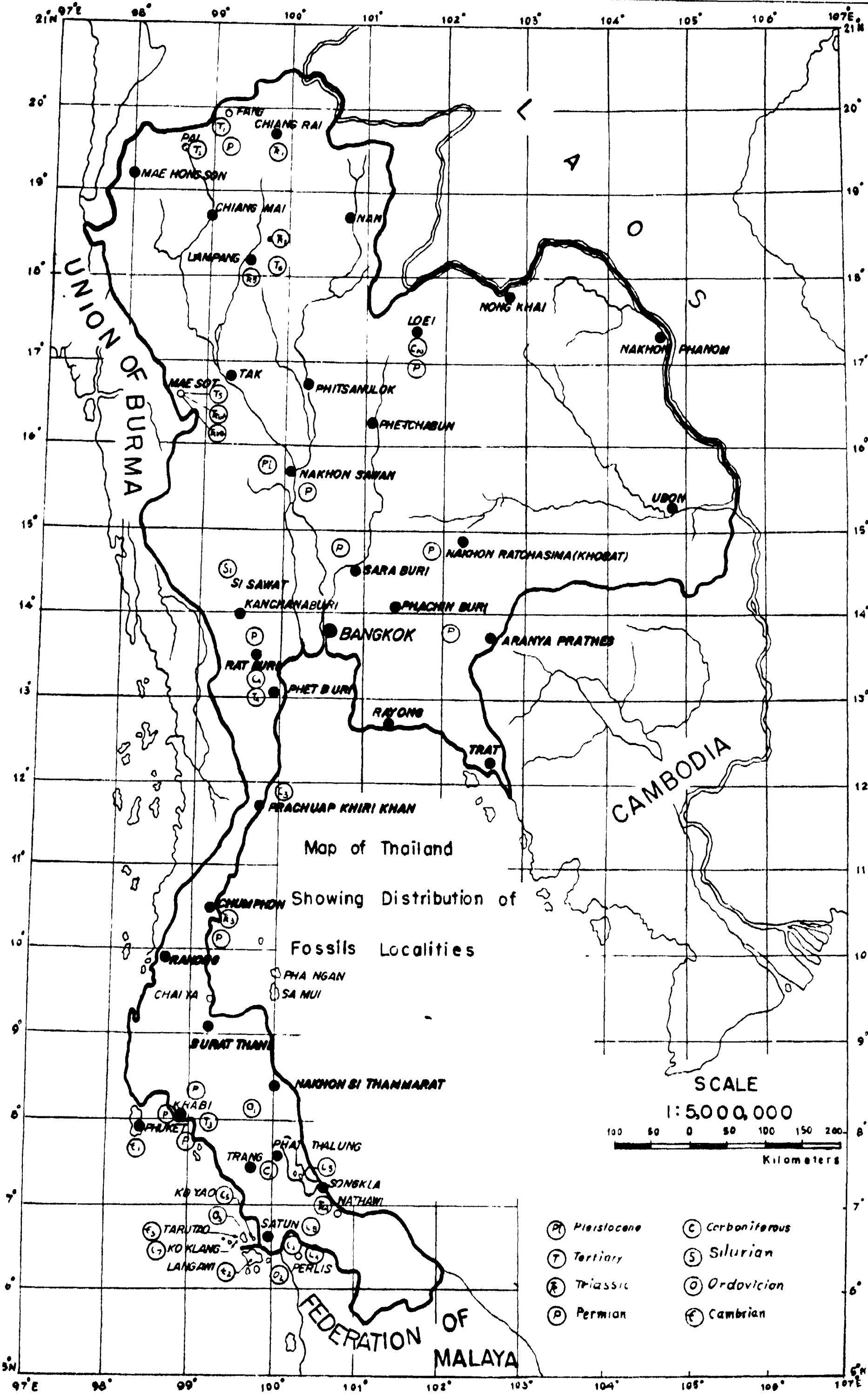
SILURIAN

The only occurrence in Thailand is at Sisawat (S_1 in map) NW of Kanchana Buri where *Tentaculites*, *Styliolina* and some unidentifiable pelecypods were found in a pinkish fine sandy shale underlying Permian limestone. The age was set as Silurian *(4)* owing to similarity with a shaly layer of the Burmese Zebingyi series although in Indochina a Tentaculites-bearing shale was ascribed a Devonian age.

It is very interesting to note here that the apparently continuous black Ordovician limestone, already mentioned, does include some shale beds (north-east tip of Langawi Island of Malaya) containing graptolites. These graptolites were originally thought to be of Caradoc age but finally reassigned a possible Lower Silurian age *(5)*. Therefore a continuous depositional period from Middle Ordovician to Middle Silurian age is indicated. The bottom of the sea during that time could have been confined to the present Thai-Malay border area because in Burma and Indochina, the Ordovician and Silurian formations were definitely differentiated.

CARBONIFEROUS

No definite Devonian fossils (except the controversial *Tentaculites*) have been found in Thailand. As there are several instances showing a disconformity between the Ordovician (possibly including Silurian) and the Carboniferous formation, there must have been a long period of



Map of Thailand Showing Distribution of Fossils Localities denudation during that period.

The first Carboniferous fossil collection was discovered at a small quarry on the Phatthalung-Trang roadside (C_1 in map) and the faunal assemblage (trilobites, ammonites, brachiopods etc.) suggested a Lower Carboniferous age *(6)*. The second locality (fusulinids etc.) in the Perlis (Malaya)—Padang Besar (Thailand) border area, (C_2 in map) is designated a Permo-Carboniferous, probably an Upper Carboniferous age *(7)*. Fenestella was found in black shale below Permian limestone at Prachuap Khiri Khan (C_3) and the same set-up repeated itself (C_9) north of Phet Buri. These faunas suggest an Upper Carboniferous age (Pennsylvanian). *Posidonomya* and a few trilobites occur in Perlis of Malaya (C_4), *Posidonomya* was found on an island in the Songkhla inland sea (C_5), trilobite pygidiums were enclosed in a red fine sandstone of Ko Yao (Pulao Panyang) southwest of Satun (C_6), *Argentiproductus (8)* abounds in dark gray shale of Ko Klang (Pulao Ta Nga) west of Tarutao Island (C_7), and a gastropod horizon cropped out at a district about half-way on the Songkhla-Perlis Highway (C_8). These are believed to be of Lower Carboniferous age (Viséan).

At Wang Saphung 20 kilometers south of Loei (C_{10}) a faunal assemblage consisting of fusulinids, gastropods, single corals, crinoid head, etc. was discovered and thought to be of Upper Carboniferous age.

These undifferentiated beds have been named the "Kanchana Buri Series" and comprise of quartzite, quartzitic sandstone, slate, indurated shale and calcareous shale with at least two bands of non-fossiliferous limestone some of which run up to 200 meters in thickness. Correlation between Thailand and Malaya is definite but although the Carboniferous at Loei continues into the Laos State and a similar bed NW of Chiang Mai continues into the Shan States in the north, correlation is quite uncertain because of the diversified nature of the Plateau Limestone of Burma and the Carboniferous beds of NW Indochina.

PERMIAN

There were numerous places in Thailand and quite a few places in Malaya where a massive limestone formation (designated "Ratburi Limestone") of considerable thickness lies above the Carboniferous beds, sometimes disconformably (southern Thailand) and sometimes unconformably (northern Thailand). Shale intercalation is found in only one place NE of Bangkok, the rest is exclusively limestone.

The lower part of this limestone (all designated P in map because of proficiency of fossil occurrences) contains *Fusulinella*, *Pseudofusulina*, *Parafusulina*, *Pseudoschwagerina*, *Schwagerina*, *Neoschwagerina*, *Verbeekina* etc. genera of forams, beside *Productus*, *Leptodus* (or *Oldhamia*) and various Permian corals especially *Sinophyllum*, and *Wentzelella*. These indicate a Lower Permian age (Sakmarian stage) *(9)*. The top limit of this limestone has not yet been defined, but at some localities Middle Permian fossils are present. Therefore this rock unit is assigned a Lower to Middle Permian age.

Consistency of lithologic nature suggests an extensive Permian sea covering Thailand completely. The Younger Plateau Limestone of Burma, the Makou Limestone of China, the Ouralo-Permian Limestone of Indochina and part of the Calcareous Series of Malaya may have been deposited at the same time.

TRIASSIC AND JURASSIC

This formation lies *unconformably* on top of the Permian limestone and is known as the Khorat Series. It consists mainly of arenaceous sediments in the lower part. The middle part varies; in some parts of the country it occurs as sandstone and shale with or without salt and in other parts it occurs as limestone and shale. The top part is limestone, rather isolated and confined and its relation with the middle part is still not clear.

Although this formation is most extensive especially in the Khorat Plateau (Northeast Thailand), where it underlies one third of the country's area, fossils are rare. Unidentifiable fragmental bones were found in situ while silicified wood and occasional *Dicotyledones of definite Triassic age* were collected from the present land surface and river gravels on the Plateau itself. Therefore, differentiation has not been possible. However, outside of the Plateau area, some occurrences of Triassic faunas were discovered intermittently and more or less definitely identified.

Myophoria, *Trigonodus* and other gastropods were the first finds ($\mathrm{T{\scriptstyle R}}_1$) in a road cutting eight kilometers south of Chiang Rai identified as definitely Triassic probably Middle Triassic *(10)* and the sandstone formation is believed to be the lowest Triassic member in Thailand. Lithologically similar sandstone beds containing *Astarte* sp. *(11)* occur at Chumphon's river mouth ($\mathrm{T_R}_3$). In the north *Halobia* or *Daonella* ($\mathrm{T_R}_2$) was found in shale further south on the same road from Chiang Rai to Lampang and the age was generally set as Triassic but later on, its presence with other index fossils (*Joannites, Balatonites* etc.) in shale and limestone at a nearby locality suggested a late Middle to Upper Triassic age *(12)* Daonella is also found in a green shale at Na Thawi south of Songkhla ($\mathrm{T_R}_4$).

A little south of Lampang ($\mathrm{T_R}_5$) and also at Mae Sot west of Tak ($\mathrm{T_R}_{6A.}$) corals identified as *Thecosmilia, Margarosmilia, Montivaltia, Conophyllia*, etc. were discovered and the age is set as late Middle to Upper Triassic *(13)*.

The foregoing beds are similar to the Napeng beds of Burma, the Trias of Yunnan, the Trias of Indochina and the Trias of Malaya. *Daonella* or *Halobia* is the common fossil.

At Mae Sot ($\mathrm{T_R}_{6B.}$), ammonites (*Erycites, Tmetoceras* and *Ludwigia*) were present in a limestone seemingly continuous with $\mathrm{T_R}_{6A.}$ As this fauna suggests an early Middle Jurassic age *(14)* there is a possibility that the Upper Triassic limestone, already mentioned, continues into Middle Jurassic time. However, as this is the only occurrence of Jurassic fossils in Thailand, more work has to be done to ascertain its position with regard to the lower two Triassic units. At present, only the Namyau beds of Burma can be considered related. Other occurrences of Jurassic beds in surrounding countries seem to be younger and greatly isolated.

TERTIARY

Except at Krabi in Peninsular Thailand the Tertiary formations are found in completely isolated intermontane basins in the northern half of the country. All fossils collected implied a late Tertiary age — not older than Miocene and probably including Lower Pleistocene as well.

From north to south, the layers of the Fang basin oil prospect (T_1) 150 Km. north of Chiang Mai contain small vertebrate bones and teeth, leaves, turtle's back plates, insects and a doubtful naticoid or viviparus gastropod suggesting a lake deposit of fresh or brackish water environment. At Pai (T_2) east of Mae Hongson, a similar viviparus specimen was found. In the present lignite mine near Lampang (T_6) insects, turtle's back plates, viviparus etc. were present and therefore the period of deposition here is considered the same as at Fang and Pai.

From the Tertiary bed of Mae Sot (oilshale bearing and named the 'Mae Sot Series' — T_5) fresh water mollusks including *Viviparus, Taia, Margarya, Oncomelania, Hydrobia* and *Stenothyra (15)* were found together with Cyprinid fishes, leaves and insects. These indicate a Pliocene or Pleistocene age.

At Phet Buri (T_4) southwest of Bangkok, three species of *terrestrial* gastropods of the same age *(16)* were discovered in a very limited deposit on top of a small hill.

At Krabi (T_3) marine gastropods of late Tertiary or possibly Pleistocene age are found in a lignite bearing formation. It is believed that at one time the Tertiary sea may have cut the Peninsular in two i.e. extending from Krabi northward to and beyond Surat Thani.

Correlation with the Tertiary of surrounding countries is difficult because of lack of definite index fossils. Perhaps the Tertiary deposits of Shan Plateau and Tenasserim of Burma and the Batu Arang Coal deposit of Malaya could be considered the same age as the various scattered deposits in Thailand because *Viviparus* or *Margarya* and fossil leaves seem to be of common occurrence.

PLEISTOCENE

Unconsolidated gravel, sand and clay formation was found resting unconformably upon older rocks in many places, sometimes several hundred meters above the general land surface. The bed dips only gently with occasional warping. Fossil wood and leaves are present but they are indeterminable. During construction of a bridge at Nakhon Sawan (P_1) fossil mammals were scooped up from a depth of 10 meters below water level. They were identified *(17)* as being parts of hippopotamus, buffalo, and elephant of Lower Pleistocene age — not unlike those from the Siwaliks of India. The nature of the containing beds is not known but quartz and quartzite gravel fills the cavities of the fossils.

At present, correlation with surrounding countries is impossible.

ANCIENT MAN'S IMPLEMENTS

Paleolithic chopping tools and other primitive implements made from river gravel of quartz, quartzite and hard siliceous slate were found in elevated river terraces just north of Chiang Mai, a little north of Lop Buri and 44 kilometers northwest of Kanchana Buri. Neolithic finds were present in at least 40 localities. They are rather scattered in the north from Phet Buri up, but in Peninsular Thailand there are two definite trends, one starting at Chaiya south to Krabi and the other south from Nakhon Si Thammarat to Satun. Southeast of those the neolithic artifacts are rather scattered but extend southward into Malaya and a communistic mode of living upon stream or river banks is apparent.

Only animal bones are met with because in every place where human or human-like remains were discovered, they were all cremated so that the owner's spirit will be able to re-incarnate somewhere and somehow! This is quite a set back to the tracing of migration routes of prehistoric man in this part of the world.

There is a definite gap between Phet Buri and Surat Thani and further south in which no record of either Paleolithic or Neolithic artifacts were ever recorded. It is believed that the migration route could have been effected either southward or northward along that stretch of rising sandy beach east of the Peninsula.

Animal bones had been found with the artifacts at a place about halfway between Sukho Thai and Tak (foreleg bone of a mountain goat) and also at a place a little south of Surat (unidentifiable).

There is still a great controversy between historians and archeologists whether migration of ancient man in Thailand was from south to north, from north to south, or both.

LIST OF EXAMINERS OF FOSSILS

(All personal communications except when publications are mentioned).

(1) Prof. T. Kobayashi, 1956, Geological Institute, University of Tokyo, Japan.

(2) Dr. H. Duncan, 1949, U.S. Geological Survey, U.S.A.

(3) Dr. G.A. Cooper, 1956, Smithsonian Institution, U.S. National Museum, U.S.A.

(4) Dr. G.A. Cooper, 1946,
Dr. H. Duncan, 1949,

(5) Dr. R. J. Ross, Jr., 1956, U.S. Geological Survey, U.S.A.
Prof. O. M. B. Bulman, 1956-1957, Sedgwick Museum, University of Cambridge, England.
Dr. H.W. Ball, 1957, British Museum (Natural History), England.
Dr. I. Strachan, 1957, Birmingham University, England.

(6) Dr. F.R. Cowper Reed, 1920, Carboniferous fossils from Siam: *Geol. Mag.*, **57**: 113-120, 172-178.

(7) Dr. R.B. Newton, 1926, Annals and Mag. *Nat. History*, *9th ser.*, **17** : 49-64.

(8) Dr. Mackenzie Gordon, Jr., 1956, U.S. Geological Survey, U.S.A.

(9) Prof. Carl. O. Dunber, 1939, Personal report on A Heim and H. Hirschi's collection.
Prof. R. Toriyama, 1944, On some Fusulinids from northern Tai: *Japan Journ. Geol. Geogr.*, **19**: nos. 1-4, pp. 243-248.
Dr. M. Minato, 1944, An Occurrences of Wentzella Subtimorica in northern Tai, *Proc. Imp. Acad. Tokyo*; **XX**.
Dr. L.G. Henbest, 1949, U.S. Geological Survey, U.S.A.
Dr. H. Duncan, 1949.
Dr. G.A. Cooper, 1949.
Dr. K. Konishi, 1953, *Trans. Proc. Palaeont. Sec. Japan, New Series*, **12** : 103-110.

(10) Dr. T.W. Stanton, 1923, Personal report on W. M. Lee's collection.

(11) Dr. R.W. Imlay, 1956, U.S. Geological Survey, U.S.A.

(12) Dr. B. Kummel, 1952 and 1954, Museum of Comparative Zoology. Harvard University, Cambridge, Mass., U.S.A.

(13) Dr. J. Wells, 1956, Cornell University, Ithaca, N.Y., U.S.A.

(14) Dr. R.W. Imlay, 1949.

(15) Dr. T.C. Yen, 1949, Smithsonian Institution, U.S. National Museum, U.S.A.

(16) Dr. T.C. Yen, 1949, Smithsonian Institution, U.S. National Museum, U.S.A.

(17) ———, 1941, British Museum of Natural History, England.

THE SUCCESSION OF NAPPES IN THE WESTERN MIOMAFFO AREA OF THE ISLAND OF TIMOR: A POSSIBLE KEY TO THE STRUCTURE OF TIMOR

P. MARKS

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During an expedition made for the Faculty of Science of the University of Indonesia in Bandung to the Western Miomaffo area in the North Central part of the Indonesian half of the island (Fig. 1), a clear picture was obtained of the succession of the overthrust units for which this island is so justly renowned. In the area, remarkable for the number and excellence of outcrops, most of the rockunits known from other parts of Timor have been recognized, vis. the:

Kekneno Formation, represented here as elsewhere by claystones and shales, often of a vivid lightblue colour, locally with intercalations of red and green coloured shales and thin bedded limestones in its upper parts; well bedded graywackes and graywacke shales, sometimes containing *Halobia* in more calcareous layers; limestones and shales in regular alternation. From top to bottom the following members have been recognized (Fig. 2):

Blue clay of varying thickness, sometimes marly, locally absent; limestones and shales, often darkcoloured, strongly folded, sometimes variegated and cherty varicoloured shales;

Well bedded graywackes, with tuffaceous components and even occasional agglomerates of volcanic origin forming the most competent

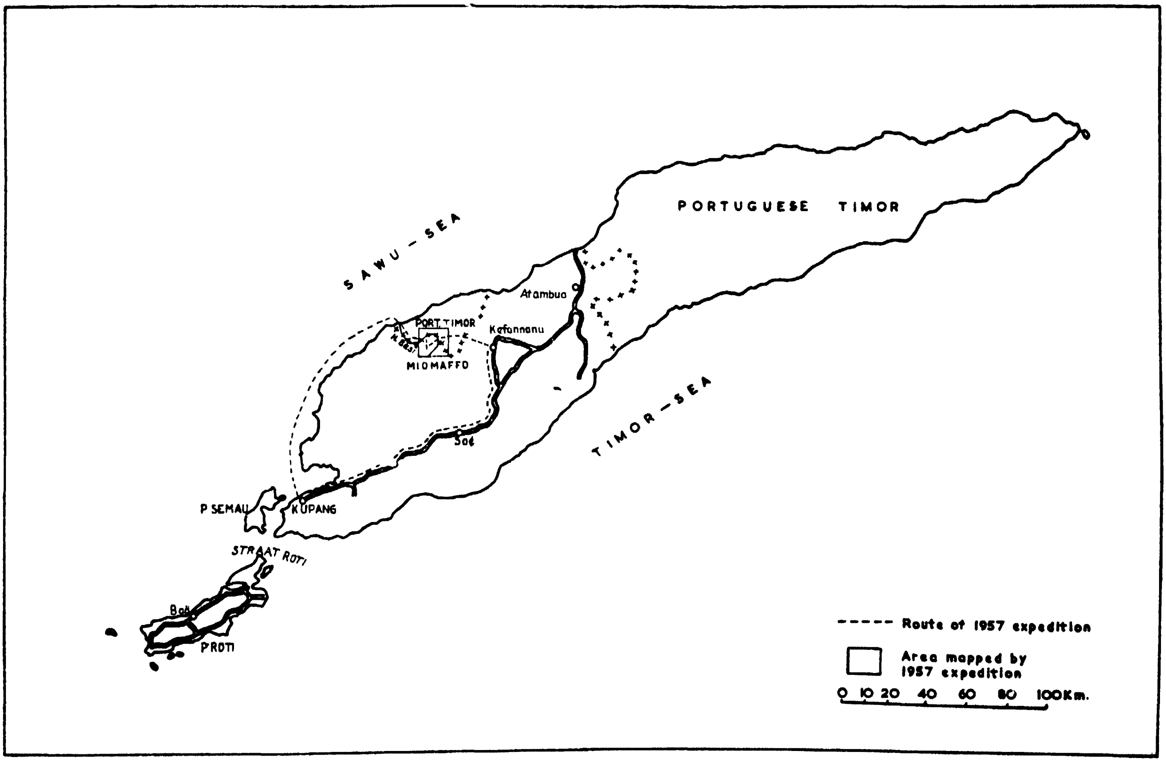

Fig. 1.

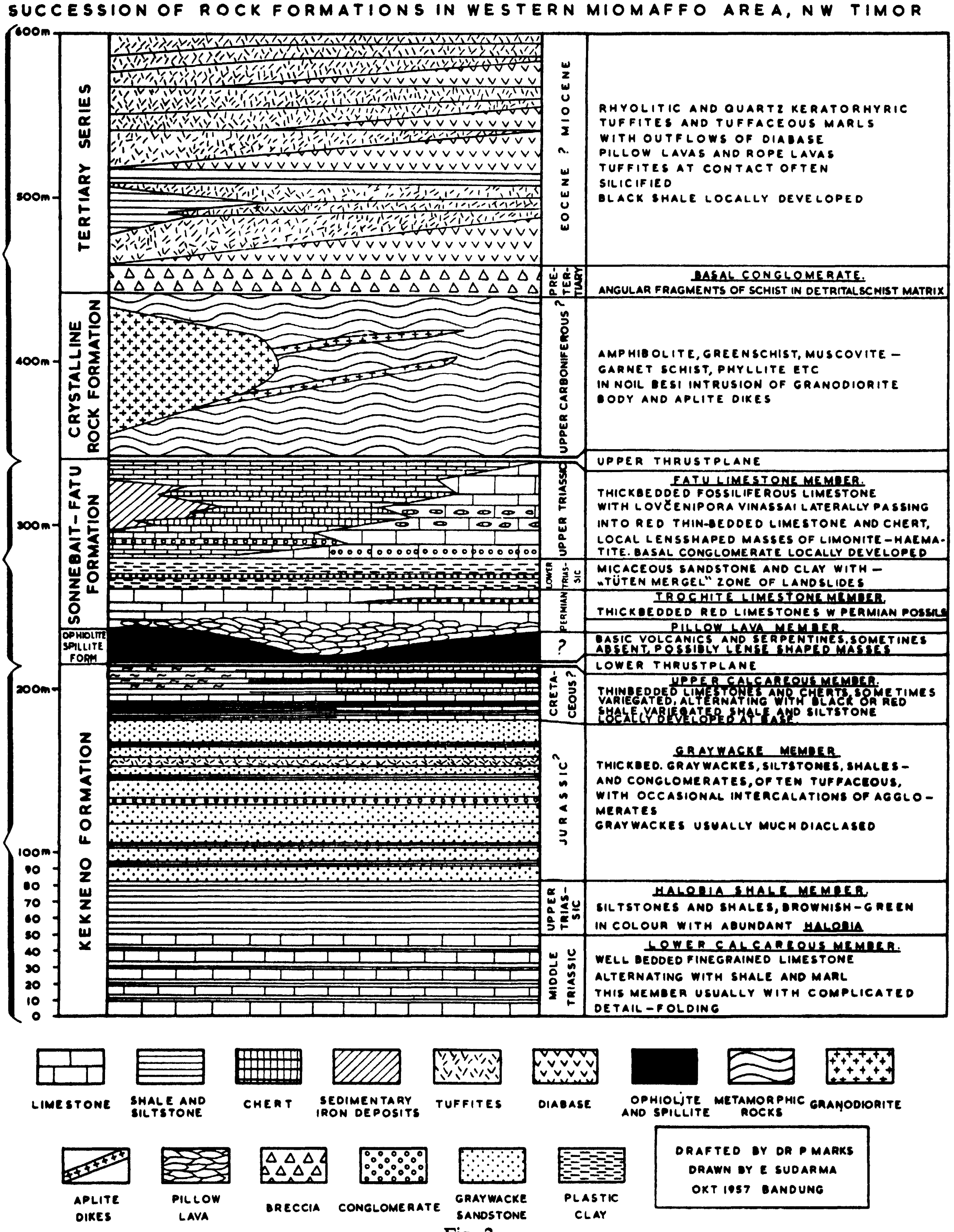
SUCCESSION OF ROCK FORMATIONS IN WESTERN MIOMAFFO AREA, NW TIMOR
600m
500m
400m
300m
200m
100m
90
80
70
60
50
40
30
20
10
0
UPPER NAPPE
LOWER NAPPE
PARA AUTOCHTHONOUS
TERTIARY SERIES
CRYSTALLINE ROCK FORMATION
SONNEBAIT-FATU FORMATION
OPHIOLITE SPILLITE FORM
KEKNENO FORMATION
EOCENE ? MIOCENE
PRE-TER-TIARY
UPPER CARBONIFEROUS ?
UPPER TRIASSIC
LOWER TRIAS-SIC
PERMIAN
?
CRETA-CEOUS?
JURASSIC?
UPPER TRIAS-SIC
MIDDLE TRIASSIC
RHYOLITIC AND QUARTZ KERATORHYRIC TUFFITES AND TUFFACEOUS MARLS WITH OUTFLOWS OF DIABASE PILLOW LAVAS AND ROPE LAVAS TUFFITES AT CONTACT OFTEN SILICIFIED
BLACK SHALE LOCALLY DEVELOPED
BASAL CONGLOMERATE.
ANGULAR FRAGMENTS OF SCHIST IN DETRITALSCHIST MATRIX
AMPHIBOLITE, GREENSCHIST, MUSCOVITE — GARNET SCHIST, PHYLLITE ETC
IN NOIL BESI INTRUSION OF GRANODIORITE BODY AND APLITE DIKES
UPPER THRUSTPLANE
FATU LIMESTONE MEMBER.
THICKBEDDED FOSSILIFEROUS LIMESTONE WITH LOVČENIPORA VINASSAI LATERALLY PASSING INTO RED THIN-BEDDED LIMESTONE AND CHERT, LOCAL LENSSHAPED MASSES OF LIMONITE-HAEMATITE. BASAL CONGLOMERATE LOCALLY DEVELOPED
MICACEOUS SANDSTONE AND CLAY WITH — „TÜTEN MERGEL" ZONE OF LANDSLIDES
TROCHITE LIMESTONE MEMBER.
THICKBEDDED RED LIMESTONES W PERMIAN FOSSILS
PILLOW LAVA MEMBER.
BASIC VOLCANICS AND SERPENTINES, SOMETINES ABSENT, POSSIBLY LENSE SHAPED MASSES
LOWER THRUSTPLANE
UPPER CALCAREOUS MEMBER.
THINBEDDED LIMESTONES AND CHERTS, SOMETIMES VARIEGATED, ALTERNATING WITH BLACK OR RED SHALE, VARIEGATED SHALE AND SILTSTONE LOCALLY DEVELOPED AT BASE.
GRAYWACKE MEMBER
THICKBED. GRAYWACKES, SILTSTONES, SHALES — AND CONGLOMERATES, OFTEN TUFFACEOUS, WITH OCCASIONAL INTERCALATIONS OF AGGLOMERATES
GRAYWACKES USUALLY MUCH DIACLASED
HALOBIA SHALE MEMBER.
SILTSTONES AND SHALES, BROWNISH-GREEN IN COLOUR WITH ABUNDANT HALOBIA
LOWER CALCAREOUS MEMBER.
WELL BEDDED FINEGRAINED LIMESTONE ALTERNATING WITH SHALE AND MARL
THIS MEMBER USUALLY WITH COMPLICATED DETAIL-FOLDING
LIMESTONE
SHALE AND SILTSTONE
CHERT
SEDIMENTARY IRON DEPOSITS
TUFFITES
DIABASE
OPHIOLITE AND SPILLITE
METAMORPHIC ROCKS
GRANODIORITE
APLITE DIKES
PILLOW LAVA
BRECCIA
CONGLOMERATE
GRAYWACKE SANDSTONE
PLASTIC CLAY
DRAFTED BY DR P MARKS
DRAWN BY E SUDARMA
OKT 1957 BANDUNG

Fig. 2.

member; Khakicoloured shales with calcareous intercalations, often containing zones with *Halobia;*

Well bedded limestones alternating with shales, usually strongly folded.

The *Sonnebait Formation*, in which the following succession could be recognized: at the base pillow lavas of basaltic composition, very often with a pronounced vesicular or amygdaloidal texture, only locally developed;

Thickbedded limestones with numerous fragments of Echinoderms, alternating with beds of conglomerates, often reddish in colour, probably Pemian in age.

Bluegray clay with intercalations of marls and muscovitic sandstone [the latter often shows curious surface markings ("Rill-marks" caused by back flowing water on wave-swept beach) while the marls are often characterized by cone-in-cone structures ("Tütenmergel")]. The clay very often contains gypsum in beautiful crystals ("swallow-tails"). Fossils have not been encountered in this member.

The upper part of the Sonnebait formation is represented by thinly bedded wine-red and variegated limestones with *Halobia* sp., which are very often siliceous (chert) and have been observed to pass laterally into almost purely ferriferous deposits on the one hand (limonite or haematite) and on the other hand into thick bedded corraligene limestones in which the chert bands of the red limestones may be recognized as layers of flint or chert, usually strongly broken and deformed. The latter development is known as the *Fatu Limestone*, as the limestone masses have often been isolated by selective erosion to form towering masses in the Timorese landscape called "Fatu" in the local language. They represent typical *bioherms* in a surroundings of otherwise mainly clastic deposition. Fossils in the Fatu (*Lovcenipora vinassai*) indicate a Triassic age.

The entire Sonnebait Formation is at best a few hundreds of meters thick, and does not represent a typical geosynclinal deposit. The depositional surroundings suggest an offshore basin with recurrent lagoonal conditions, possibly separated from the open sea by a fringe of reefs or biocherms formed by tabulate corals and hexacorals, as well as sponges and brachiopda.

This lagoon deposition was strongly influenced by the adjoining landmass, on which during triassic times a wet tropical climate and lateritic weathering may account for the red colour of the upper Sonnebait deposits, as well as for the deposition of chert and limonite which characterize this member.[1] This possibility is reinforced by the presence in one place of an alternation of coarsely crystalline pure limestones with sandstone containing silicified plantremains, which may be explained as chemical deposition in evaporating waters of a lagoon, alternating with windblown sands and plant fragments.

The Tertiary is represented in this area by black shales containing large Rotalia, intercalated in lightcoloured tuffites of probably rhyolitic composition. Locally intercalated in this succession are numerous flows of diabase often with excellent pillow-and rope structures. The texture of the flows varies from coarsely crystalline to glassy and vesicular.

The tuffites-clays are often silicified in the proximity of the diabase flows. The Tertiary (Burdigalian) age is assumed because of the similarity to fossiliferous formations known from adjoining areas (Marks, 1955). The Miocene formation sometimes disconformably overlies a formation of highly metamorphic rocks, consisting of amphibolites, greenschists, phyllonites, biotite-garnet schists, etc. and is usually separated from this formation by a distinct basal conglomerate composed of large and rather angular fragments of metamorphic rock. The disconformity, however marked, is a normal stratigraphic one, and the schist-tertiary succession has to be considered as composing a single unit.

Last but not least there occur in numerous places seemingly disconnected masses of serpentine, in close association with a usually strongly weathered and crushed basic volcanic rock. Together they form the ophiolite-spillite association of Brouwer *et al.*

In the Western Miomaffo area the following succession could be established (Fig. 3):

The *Kekneno Formation* forms the lowermost unit and quite probably represents the para-autochthonous;

Overlying this formation, and always separating it from the Sonnebait Formation, is the *Ophiolite-spillite Formation* (0-S), which is not represented

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[1] Twenhofel, W.H., 1939 Principles of Sedimentation, First edition p. 372, 373, 381, 382, 387.

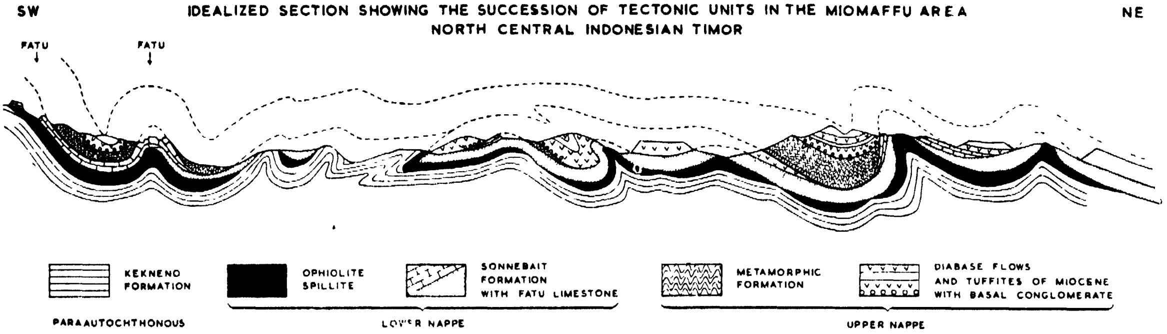

Fig. 3.

everywhere and may have been squeezed out to form a number of lense-shaped masses;

The O - S formation is always overlain by the *Sonnebait Formation* of which the *Fatu Formation* forms an integral part, in fact only represents a facies-member of the Sonnebait (Fig. 2), laterally passing into thinbedded red or variegated limestones and cherts. Together with the O - S formation the Sonnebait-Fatu Formation forms the lowermost overthrust unit or nappe. Overthrusted on this nappe is a unit composed of the metamorphic rocks, disconformably overlain by Tertiary rock, either Eocene (not represented in the Miomaffo area) or Lower Miocene, and almost invariably divided from the Sonnebait by a mylonite zone.

This schist-tertiary unit forms the second and uppermost overthrust unit in the Timor nappes, and is only represented by isolated "Klippen" or rootless masses, localized usually in steeply infolded synclines. In some areas intricate "Schuppen" structures have been formed of the schist-miocene and the sonnebait units.

The structure of the area is characterized by the occurrence of a great many parallel steeply folded, sometimes even overturned, synclines and anticlines. The synclines are characterized by the presence of upper Sonnebait, often in Fatu Facies, or even remnants of the overlying schist tertiary nappe. The anticlines often have Kekneno exposed in the core, or if erosion has not reached this formation, are characterized by ophiolite spillite, lower Sonnebait volcanics or permian limestone. The quick succession of the extremely narrow folds has given rise to the impression of a "Mega Breccia" as the true succession of the formations was not always clearly understood.

Much of the mix-up is due to the following circumstances:

1). The diabases and basalts, which in the Northwestern part of Timor occupy much of the Miocene succession, and which, especially to the North of the Mutis and in Oicusi, strongly resemble the igneous rocks of the Ophiolite spillite formation, and especially when crushed and mylonized are almost undistinguishable.

They may be separated only by their association with the lightcoloured acid tuffaceous rocks of the Miocene. Thus the "Ophiolite spillite Complex" is sometimes described as underlying the schists (although no sections have been published in which the schist is actually in direct contact with the serpentines and spillites, while numerous sections, show that the formations are separated by Fatu Limestone and/or Sonnebait) in the case of the "true" Ophiolite-spillite Formation, and as overlying the schist when in reality Miocene lavas. Especially in the Fatu Kaslioe area this succession may be observed in the maps and sections provided by De Roever.

2). A second reason is the uncritical attribution of the calcareous-cherty upper part of the Kekneno to the Sonnebait Formation. In this way the Ophiolite spillite Formation is sometimes described as overlying the Sonnebait, sometimes as being overlain by the latter formation.

A correct evaluation of the (Cretaceous?) cherts and limestones as the upper part of the Kekneno greatly reduces the number of seemingly complicated tectonic situations.

3). In the third place, the suppostion that the Fatu Limestones form a separate tectonic or stratigraphic unit has also unneccessarily complicated the tectonic interpretation.

In the area studied by the 1957 expedition, the Fatu limestones are clearly the upper member of the Sonnebait, their topographic high position often being due to their deformation into narrowly pinched anticlines, together with their greater resistance to erosion (Fig. 3, SW part of section). In fact, the schists and their autochthonous covering of Tertiary are often lying in narrow synclines completely surrounded by Fatu Limestone which distinctly dips away underneath the metamorphics. A clear example is given in fig. 15 of De Roevers publication.

Thus, the possibilities indicated by Brouwer (1942) and Van Bemmelen (1949, p. 517) are entirely confirmed, except that these authors have assumed the Fatu Limestone to overlie the metamorphie formations. The final results of the 1957 expeditions will be published in the course of 1958, and it is hoped that a more extensive application of the above described results to earlier work in Timor can be given.

REFERENCES

Roever, W.P. de, 1940, Geological Investigations in the Southwestern Moetis Region (Neth. Timor) in Geological Exped. to the lesser Sunda Islands, etc. pp. 240 ff.

Brouwer, H.A., 1942, Summary of the results of the expedition Geological Exped. to the lesser Sunda Islands etc. **4**: 345-402.

Marks, P., 1955, An occurrence of Miogypsina complanation Schlumberger in the Lalan Asu area, Timor. *Ind. Journ. Nat. Sc.* 1955: 78-80.

Waard, D. de, 1954, The second geological Timor expedition, preliminary results. *Ind. Journ. Nat. Sc.* 1954: 154-160.

STRATIGRAPHY OF WESTERN AUSTRALIA—A SUMMARY OF RECENT DISCOVERIES

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INTRODUCTION

Excellent reviews of the stratigraphy of Western Australia have been published by Teichert (1947, 1950) and Fairbridge (1953). More recently, a review that includes all the important advances in the stratigraphical knowledge of this State has been compiled by McWhae *et al.* (1957 ms.). The present summary deals particularly with the more important additions to this knowledge since 1950, and is based on the work of McWhae and his co-authors. Precambrian stratigraphy is not discussed.

The new discoveries are indicated in Fig. 1, in which the present knowledge of the stratigraphy of the intracratonic basins of the State is illustrated. The locations of these intracratonic basins are shown in Fig. 2. High-angle faults are more strongly developed than folds in the basins, as no major orogeny has affected Western Australia since Precambrian times.

The author wishes to thank the Management of West Australian Petroleum Pty. Ltd. for permission to publish this paper. Recent advances in the knowledge of the State's stratigraphy have resulted mainly from the exploration activities of this company, the Bureau of Mineral Resources (Canberra) and students and staff of the Geology Department of the University of Western Australia. The writer is deeply indebted to the geologists of these organizations for their contributions to this summary. Specific acknowledgements are given in McWhae *et al.* (1957 ms.).

STRATIGRAPHY

CAMBRIAN

Cambrian marine sediments have been known from the Bonaparte Gulf and Ord Basins for a considerable time. Both Teichert (1947, 1950) and Fairbridge (1953) have described the sequences, and more recently a comprehensive paper has been published by Traves (1955).

Marine Cambrian rocks are not known in other Western Australian basins, but an extensive development of tholeiitic basalts, agglomerates, tuffs and associated dykes occurs disconformably below the Cambrian sediments in the Bonaparte Gulf and Ord Basins. These are generally considered to be Lower Cambrian in age. They reach a thickness of 3,300 feet in the Ord Basin (Traves, 1955) and are correlated, tentatively, with similar volcanic rocks in the King Leopold Range immediately north of the Canning Basin (Guppy *et al.*, 1957).

The extensive dolerite dykes that intrude the older rocks of the State have been related to this taphrogenic period by most authors. However, recent advances in stratigraphical knowledge have shown that there are three other periods when similar suites of basic igneous rocks were formed. The first of these is probably Ordovician or Silurian in age and affects the Moora Group rocks of the Perth Basin; the second occurred probably in Triassic or Jurassic times in the northern part of the Canning Basin (the Fitzroy Basin); the third is known in the southern part of the Perth Basin where tholeiitic basalt flows are interbedded with sediments of Lower Cretaceous or uppermost Jurassic age (McWhae *et al.*, 1957 ms.).

ORDOVICIAN

Ordovician rocks were positively identified in Western Australia in 1949. Some sections are described in Fairbridge (1953), but a more detailed account is given in McWhae *et al.* (1957 ms.)

A Lower Ordovician greensand formation, the Pander Greensand, is known in the Bonaparte Gulf Basin (Traves, 1955). In the northern part of the Canning Basin a marine sequence, over 2,600 feet thick, is exposed in a very restricted area (Guppy & Öpik, 1950). It is considered to be Lower and early Middle Ordovician in age.

Logan and Chase (1956 ms.) discovered problematical fossils, which Dr. D. Hill and Dr. A.A. Öpik consider to be older Palaeozoic, in rocks formerly considered Precambrian in age, in the northern part of the Perth Basin.

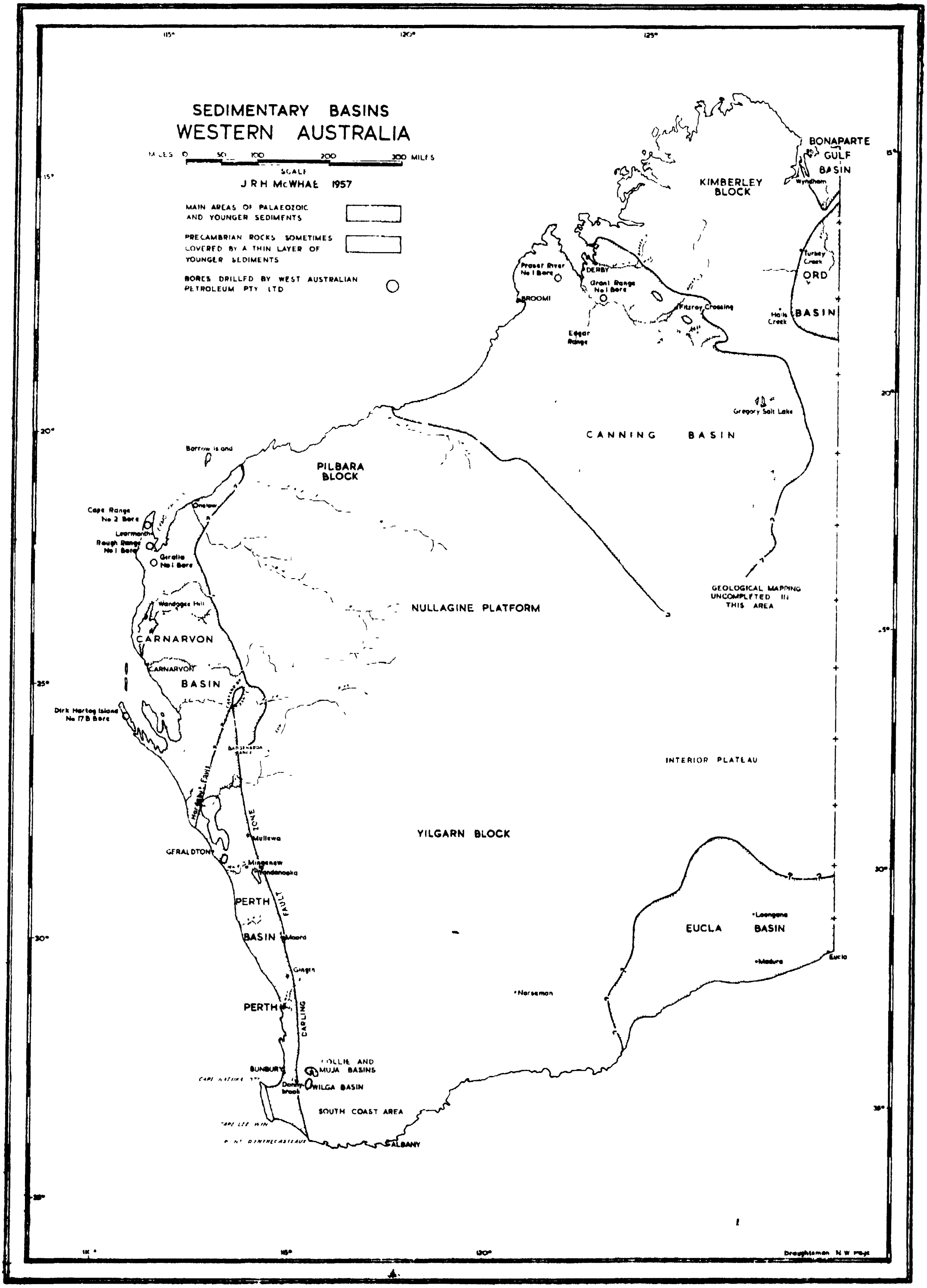
SEDIMENTARY BASINS
WESTERN AUSTRALIA
MILES 0 50 100 200 300 MILES
SCALE
J R H McWHAE 1957
MAIN AREAS OF PALAEOZOIC AND YOUNGER SEDIMENTS
PRECAMBRIAN ROCKS SOMETIMES COVERED BY A THIN LAYER OF YOUNGER SEDIMENTS
BORES DRILLED BY WEST AUSTRALIAN PETROLEUM PTY LTD
115°
120°
125°
15°
20°
25°
30°
35°
BONAPARTE GULF BASIN
Wyndham
KIMBERLEY BLOCK
Turkey Creek
ORD BASIN
Halls Creek
Fraser River No I Bore
DERBY
Grant Range No I Bore
BROOME
Fitzroy Crossing
Edgar Range
Gregory Salt Lake
CANNING BASIN
Barrow Island
PILBARA BLOCK
Onslow
Cape Range No 2 Bore
Learmonth
Rough Range No I Bore
Giralia No I Bore
GEOLOGICAL MAPPING UNCOMPLETED IN THIS AREA
NULLAGINE PLATFORM
Wandagee Hill
CARNARVON BASIN
CARNARVON
Dirk Hartog Island No 17B Bore
BANGEMALL
INTERIOR PLATEAU
Darling Fault Zone
YILGARN BLOCK
Mullewa
GERALDTON
Mingenew
Yandanooka
PERTH BASIN
Moora
Gingin
PERTH
EUCLA BASIN
Loongana
Madura
Eucla
Norseman
COLLIE AND MUJA BASINS
BUNBURY
CAPE NATURALISTE
Donnybrook
WILGA BASIN
SOUTH COAST AREA
CAPE LEEUWIN
D'ENTRECASTEAUX
ALBANY
Draughtsman N W Page

Fig. 1.

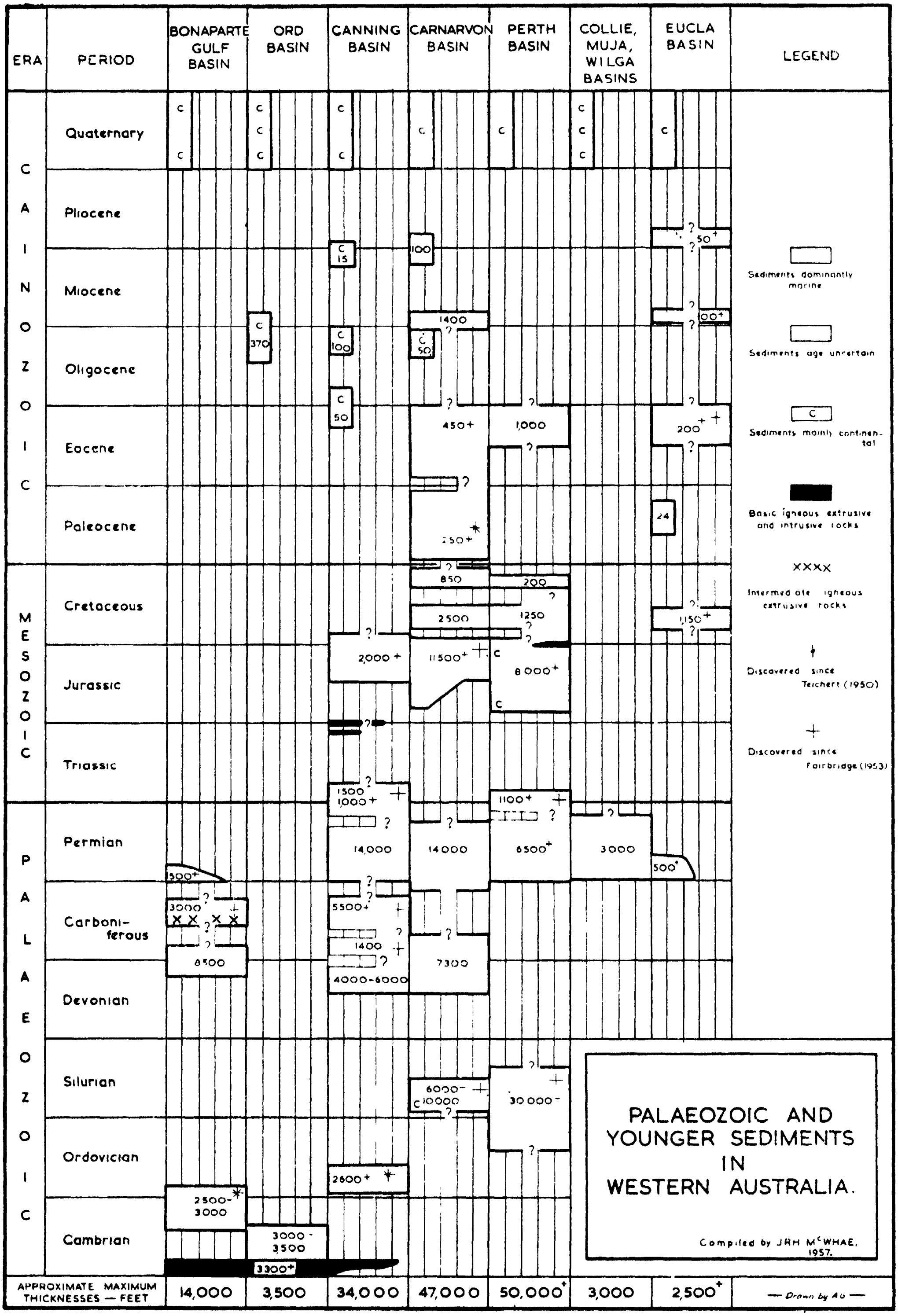
ERA
PERIOD
BONAPARTE GULF BASIN
ORD BASIN
CANNING BASIN
CARNARVON BASIN
PERTH BASIN
COLLIE, MUJA, WILGA BASINS
EUCLA BASIN
LEGEND
CAINOZOIC
MESOZOIC
PALAEOZOIC
Quaternary
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
C
50+
C 15
100
100+
1400
C 370
C 100
C 50
C 50
450+
1,000
200+
24
250+
850
200
2500
1250
150+
2,000+
11500+
8000+
1500
1,000+
1100+
14,000
14000
6500+
3000
500+
500+
3000
5500+
1400
8500
4000-6000
7300
6000-
C 10000
30 000-
2600+
2500-3000
3000-3500
3300+
Sediments dominantly marine
Sediments age uncertain
Sediments mainly continental
Basic igneous extrusive and intrusive rocks
XXXX
Intermediate igneous extrusive rocks
Discovered since Teichert (1950)
Discovered since Fairbridge (1953)
APPROXIMATE MAXIMUM THICKNESSES — FEET
14,000
3,500
34,000
47,000
50,000+
3,000
2,500+
— Drawn by A.G. —
PALAEOZOIC AND YOUNGER SEDIMENTS IN WESTERN AUSTRALIA.
Compiled by J.R.H. McWHAE, 1957.

Fig. 2.

This sequence, known as the Moora Group, is approximately 4,500 feet thick and consists of cherts, siltstones, sandstones and arkoses. It may be correlated in part with an extremely thick sequence of unfossiliferous siltstones, sandstones and conglomerates known as the Yandanooka Group. This group is developed in a huge syncline east of Yandanooka, where it attains a thickness of approximately 30,000 feet (McWhae *et al.*, 1957 ms.).

SILURIAN

Silurian rocks were unknown in Western Australia prior to 1957, when West Australian Petroleum Pty. Ltd. drilled a test well (No. 17 B) on Dirk Hartog Island in the western part of the Carnarvon Basin. Dr. B.F. and Mrs. Glenister discovered Silurian conodonts in a calcareous sequence 2,425 feet thick penetrated by this bore (McWhae *et al.*, 1957 ms.). The sequence is overlain unconformably by Cretaceous sediments, and passes downwards conformably into an arenite succession correlated with the Tumblagooda Sandstone. Besides conodonts, the fauna of the calcareous section includes nautiloids and brachiopods with Silurian affinities. The unit is considered Silurian in age by Dr. and Mrs. Glenister, and also by Dr. Öpik.

The Tumblagooda Sandstone (Clarke & Teichert, 1948) is over 3,500 feet thick in the type section in the lower part of the Murchison River, but exceeds 6,000 feet in other sections. It is regarded, tentatively, as possibly Lower Silurian in age as beds correlated with the Tumblagooda Sandstone interdigitate with the lower part of the fossiliferous, calcareous sequence in the Dirk Hartog bore. The unit consists of various sandstones, sometimes arkosic and conglomeratic, and red siltstones. Diagnostic fossils have not been found in this arenite, although tracks and worm burrows are preserved in the sediments. The tracks appear to have been made by Palaeozoic arthropods.

DEVONIAN

The Devonian sequences of the State have been described by Teichert in a number of publications. No major discoveries have been made in recent years, although additional palaeontological studies have been published and the sequences have been subdivided into a number of new formations since the publication of Teichert in 1950. Some of these are given in Fairbridge (1953), but a more up-to-date account may be found in McWhae *et al.* (1957 ms.).

Approximately 7,000 feet of Upper Devonian clastic sediments and limestones are known in the Bonaparte Gulf Basin (Traves, 1955). In the northern part of the Canning Basin, a complex reef facies 4,000 to 6,000 feet thick was deposited in Givetian to Famennian times (Guppy *et al.*, 1957; McWhae *et al.*, 1957 ms.). In the northern part of the Carnarvon Basin, clastic sediments and limestones are developed. These are largely Upper Devonian in age and attain a thickness of nearly 5,000 feet. The sequence in the Carnarvon Basin was described by Teichert (1950), and was slightly modified subsequently by Condon (1954).

CARBONIFEROUS

A number of new Carboniferous sequences have been described recently. Although Lower Carboniferous rocks were reported in the Bonaparte Gulf Basin by Teichert (1947), an additional sequence, previously regarded as Permian, has recently been dated as Upper Carboniferous by the brachiopod studies of Mr. G.A. Thomas (in McWhae *et al.*, 1957 ms.). In the northern margin of the Canning Basin (Fitzroy Basin), fossils collected from supposedly uppermost Devonian limestone were found to be Lower Carboniferous in age by Thomas (1957). This was the first discovery of Carboniferous rocks in the basin, and it was followed by the discovery of a thick sequence of mainly Upper Carboniferous rocks in the Grant Range and Fraser River bores drilled by West Australian Petroleum Pty. Ltd. in 1955 and 1956 respectively (McWhae *et al.*, 1957 ms.). Teichert (1950) summarized the Carboniferous sequence of the Carnarvon Basin. This has been modified slightly by Condon (1954).

PERMIAN

The Permian System is extremely well developed in Western Australia, and has been described in some detail by Teichert (1947), Fairbridge (1953) and especially in the *Symposium sur les séries de Gondwana* (1952) of the Nineteenth International Geological Congress. There have been few major discoveries in recent years. Upper Permian beds have been recognized recently in the Canning Basin and in the northern part of the Perth Basin. The drilling of deep oil tests in the Canning Basin demonstrated that the lowest formation of the Permian succession in that basin consists of glacial sediments more than 8,500 feet thick (McWhae *et al.*, 1957 ms.).

Lower Permian glacial sediments, consisting predominantly of marine tillites, sandstones and siltstones, are widely distributed in the State. A small thickness of approximately 500 feet occurs in the Bonaparte Gulf Basin; glacial sediments are developed over most of the Canning Basin, and are especially thick in the northern part, or Fitzroy Basin. Remnants of this unit extend southwards through the Interior Plateau into South Australia. None are known in the southern part of the Eucla Basin, but they probably underlie the Cretaceous rocks in the northern end of this basin. Thick glacial sediments occur also in the Carnarvon and Perth Basins. Glacial sediments have been recognized in the base of the Collie Basin (Fairbridge, 1952).

Marine sediments, including some euxinic siltstones and shales of Kungurian and Artinskian age, are present in the Canning, Carnarvon and Perth Basins. Upper Permian rocks were deposited in the Canning and Perth Basins only, and in both these basins deposition continued into Lower Triassic times.

The Permian sequences are over 14,000 feet thick in both the Canning and Carnarvon Basins (Guppy *et al.*, 1957; Condon, 1954) and are dominantly marine. In the Perth Basin the thickness of known Permian rocks is over 6,000 feet. These are continental in part, with some low-grade coal measures. The sediments of the small Collie, Muja and Wilga Basins are continental, and range in age from Sakmarian to possibly Kazanian. They attain a maximum thickness of 3,000 feet, and have been described by Fairbridge (1952). The State's commercial coal is situated in these basins.

TRIASSIC

Lower Triassic marine sediments have been recognized recently in both the northern part of the Canning Basin and in the northern part of the Perth Basin. The Canning Basin occurrence was discovered by Dr. R.O. Brunnschweiler in 1952, and it is described in Brunnschweiler (1954). In the Perth Basin, Lower Triassic or uppermost Permian sediments were recognized in 1956 when Dr. B. F. Glenister described the ammonoid *Xenaspis* from a core of the Geraldton Racecourse bore (McWhae *et al.*, 1957 ms.). Mr. B.E. Balme considered the plant microfossils and microplankton from these cores to be Lower Triassic in age (McWhae *et al.*, 1957 ms.). The Capel River Group, including the Donnybrook Sandstone, of the southern part of the Perth Basin is now regarded by Balme (in McWhae *et al.*, 1957 ms.) as Lower Cretaceous to Upper Jurassic and not Triassic as suggested by Teichert (1947) and Fairbridge (1953).

JURASSIC

With one notable exception, Jurassic sequences in Western Australia are relatively thin, paralic and continental deposits occurring over large areas in the Canning and Perth Basins, and in several localities in the Carnarvon Basin. In the extreme northwest of the Carnarvon Basin an exceptionally thick section of marine claystones was encountered when West Australian Petroleum Pty. Ltd. drilled Cape Range No. 2 well in 1955 (McWhae *et al.*, 1957 ms.). Various outliers of paralic Jurassic rocks were discovered recently, resting on Precambrian gneiss east of the lower Ashburton River at the north-eastern end of the Carnarvon Basin (McWhae *et al.*, 1957 ms.). In addition, regional mapping in recent years has extended the Jurassic sequence over much of the Canning Basin. The best known sequence of Jurassic rocks in the Perth Basin is exposed east of Geraldton and has been described recently by Arkell and Playford (1954). Otherwise, there have been few new discoveries in connection with Jurassic stratigraphy since the writings of Teichert (1947), Fairbridge (1953) and the 1952 *Symposium sur les séries de Gondwana* of the International Geological Congress.

In each of the three basins in which Jurassic sedimentation took place, deposition seems to have continued into Neocomian times before a general regression, accompanied by week tectonic activity, occurred.

CRETACEOUS

No major discoveries in Cretaceous stratigraphy have been made in recent years, so the accounts of the System given by Teichert (1947) and especially Fairbridge (1953) show the status of the present knowledge of Cretaceous sequences in the State.

The main Cretaceous marine transgression that commenced in Aptian or upper Neocomian times in the Carnarvon, Perth, and Eucla Basins does not appear to be represented in the Canning Basin.

In recent years, extensive exploration and drilling activities have greatly increased the knowledge of Carnarvon Basin Cretaceous stratigraphy. Drilling of test bores in the extreme north-west of the Carnarvon Basin demonstrated that the Cretaceous sequence thickened considererably in this area to attain a thickness of over 3,000 feet (McWhae *et al.*, 1957 ms.). A hiatus in deposition, probably accompanied by very weak tectonism, has been demonstrated in the sequence. Dr. M.F. Glaessner and also the Bureau of Mineral Resources micropalaeontologists Miss I. Crespin and Mr. D.J. Belford have found a break in the foraminiferal assemblage representing all of the Coniacian Stage and much of the Turonian Stage. This indicates a hiatus in deposition throughout the basin, accompanied by weak tectonism.

In the Perth Basin Lower Cretaceous marine rocks have been encountered in the bores of the Perth and Moora areas. These attain a thickness of 1,250 feet in the Perth bores. A sequence of greensand and chalk that crops out in the plateau areas of Gingin and Dandaragan has been known for more than a century. The Gingin Chalk can be correlated with thicker chalks and calcilutites in the Carnarvon Basin by means of diagnostic Foraminifera and the crinoids *Marsupites* and *Uintacrinus*. These indicate a Santonian age, and the whole sequence seems to be confined to the Upper Cretaceous.

The Eucla Basin appears to have been initiated in Lower Cretaceous times, when a thin basal conglomerate (resting on Precambrian crystalline rocks) and over 1,114 feet of shale were deposited. This sequence was encountered in bores drilled early this century at Loongana and Madura. The formations have been named Loongana Conglomerate and Madura Shale by Fairbridge (1953).

CAINOZOIC

No Tertiary sequences of any importance have been found in the State in recent years, and the account of Fairbridge (1953) includes all recent discoveries except the recognition of Eocene limestones in the Eucla Basin (Singleton, 1954; Crespin, 1956). Many years ago Tate (1879) recorded the presence of two Eocene formations in the Eucla Basin. However, this report has been overlooked by the majority of authors. In addition, the Plantagenet Beds of the South Coast Area are now regarded as Eocene in age. Quaternary deposits are predominantly continental, but include extensive aeolianites and limestones near the coast. These deposits will not be discussed in this paper, and the reader is referred to Fairbridge (1953).

Only continental and lacustrine beds were deposited in Tertiary times in the Ord and Canning Basins. These include the White Mountain Formation, a lacustrine formation consisting of cherts, siltstones, fossiliferous in the upper part. This unit is 370 feet thick (Teichert, 1947), and may be correlated approximately with similar beds in the Oakover River, Ashburton River and upper Minilya River areas. Most of these cherty, calcareous beds may have been formed in depressions approximately homochronous with the development of the main laterite sheet that is so extensively developed throughout the State. It is older than the present cycle of erosion and belongs to a time when peneplanation of Western Australia had reached an advanced stage. The laterite deposits overlie fossiliferous upper Eocene limestones and sandstones in a number of localities. No typical laterite developments overlie the Miocene limestones, so the main period of laterite formation appears to have preceded Miocene times, although it is possible that the Miocene limestones will not give rise to laterite developments.

Doubtless a number of other thin unfossiliferous arenite units are of Tertiary age. Examples are found along the north-west coast of the Canning Basin near Broome.

Marine Tertiary sequences are known in the Carnarvon, Perth and Eucla Basins. The thickest and most complete development is in the Cape Range Anticline in the extreme north-western corner of the Carnarvon Basin. Here the sequence consists of Paleocene, Eocene and lower Miocene marine calcareous rocks attaining a thickness of 2,200 feet. Possibly uppermost Oligocene and Pliocene rocks may be represented in the sequence as well.

In the Perth Basin, Middle to Upper Eocene shales over 1,000 feet thick have been recognized in the artesian bores of the Perth Metropolitan area (Parr, 1938). No other occurrences of Tertiary rocks are known in this basin. The Eucla Basin contains a sequence of limestones nearly a thousand feet thick, in which Upper Eocene and Lower Miocene Foraminifera have been identified (Tate, 1879; Singleton, 1954; Crespin, 1956). Outliers of the Eocene deposits extend far over the Precambrian crystalline rocks of the Yilgarn Block. Examples of these are the Plantagenet Beds of the South Coast Area and a sequence of fossiliferous limestones, sponge spicule rocks and dolomites in the Norseman area (Clarke, Teichert & McWhae, 1948). The latter deposits are now over 900 feet above sea-level, indicating considerable epeirogenic warping of the Precambrian Shield since Eocene times. The sequence at Norseman contains abundant sponge spicules which permit correlation with the Plantagenet Beds and the Lower Tertiary limestones of the Eucla Basin. Formerly the age of these units was considered Miocene, based on the presence in them of the nautiloid *Aturia clarkei* (Teichert, 1944). Recently, Singleton (1954) and Glaessner (1955) have given evidence that this nautiloid is probably Upper Eocene in age. Foraminifera determinations and regional lithological correlations also support an Upper Eocene age.

It is clear from these recent developments that the most extensive marine transgression of Cainozoic times took place in Upper Eocene times. Epeiric seas must have covered as much as 200,000 square miles of the southern part of the State, and extended far into South Australia. The facies is remarkably variable and includes sponge spicule rocks, sandstones, dolomites, limestones, carbonaceous siltstones and lignite (correlated with the Lower Tertiary sequence at Anglesea (Cookson, 1954) and Pidinga, in Victoria and South Australia respectively).

REFERENCES

Arkell, W.J. and Playford, P.E., 1954, The Bajocian ammonites of Western Australia. *Phil. Trans. Roy. Soc. Lond.* Ser.B, **237**: 547-605.

Brunnschweiler, R.O., 1954, Mesozoic stratigraphy and history of the Canning Desert and Fitzroy Valley, Western Australia. *J. Geol. Soc. Aust.*, **1**: 35-54.

Clarke, E. de C. and Teichert, C., 1948, Cretaceous stratigraphy of the lower Murchison River area. *J. Roy. Soc. W. Aust.* **32**: 19-47.

Clarke, E. de C., Teichert, C. and McWhae, J.R.H., 1948, Tertiary deposits near Norseman, Western Australia. *J. Roy. Soc. W. Aust.*, **32**: 85-103.

Condon, M.A., 1954, Progress report on the stratigraphy and structure of the Carnarvon Basin, Western Australia. *Aust. B.M.R.* **15**.

Cookson, I.C., 1954, The occurrence of an Older Tertiary microflora in Western Australia. *Aust. J. Sci.*, **17**: 37-38.

Crespin, I., 1956, Fossiliferous rocks from the Nullarbor Plains. *Aust. B.M.R.* **25**: 27-42.

Fairbridge, R.W., 1952, The Permian of South-Western Australia. *Cong. Int. Geol. 19th Sess. Alger.* Symposium sur les séries de Gondwana: 136-146.

Fairbridge, R.W., 1953, Stratigraphy of Australia, 2nd ed. *Univ. W. Aust.* Textbook Board.

Glaessner, M.F., 1955, Pelagic fossils (*Aturia*, penguins, whales) from the Tertiary of South Australia. *Rec. S. Aust. Mus.*, **11** (4): 353-371.

Guppy, D.J., Lindner, A.W., Rattigan, J.H. and Casey, J.N., 1957, The geology of the Fitzroy Basin, Western Australia. *Aust. B. M. R.*, Bull. **36**.

Guppy, D.J. and Öpik, A.A., 1950, Discovery of Ordovician rocks, Kimberley Division, Western Australia. *Aust. J. Sci.*, **12**: 205-206.

Logan, B.W. and Chase, R.L. St. L., 1956, ms. The geology of the Moora area and the stratigraphy of the Moora Group. *Univ. W. Aust.* Honours thesis.

Mcwhae, J.R.H., Playford, P.E., Lindner, A.W., Glenister, B.F. and Balme, B.E., 1957, ms., The Stratigraphy of Western Australia. *J. Geol. Soc. Aust.* (manuscript).

Parr, W.J., 1938, Upper Eocene Foraminifera from deep borings in King's Park, Perth, Western Australia. *J. Roy. Soc. W. Aust.*, **24**: 69-101.

Singleton, O.P., 1954, The Tertiary stratigraphy of Western Australia — A review. *Proc. Pan Indian Ocean Sci. Cong.*, sect. C: 59-65.

Tate, R., 1879, The Natural History of the country around the head of the Great Australian Bight. *J. Roy. Soc. S. Aust.*, **2**: 94-128.

Teichert, C., 1944, The genus *Aturia* in the Tertiary of Western Australia. *J. Palaeont.*, **18**: 73-82.

Teichert, C., 1947, Stratigraphy of Western Australia. *J. Proc. Roy. Soc. N.S.W.*, **80**: 81-142 and *Bull. Amer. Ass. Petrol. Geol.*, **31**: 1-70.

Teichert, C., 1950, Some recent additions to the stratigraphy of Western Australia. *Bull. Amer. Ass. Petrol. Geol.*, **34**: 1787-1794.

Thomas, G.A., 1957, Lower Carboniferous deposits in the Fitzroy Basin, Western Australia. *Aust. J. Sci.*, **19**: 160-161.

Traves, D.M., 1955, The geology of the Ord-Victoria region, Northern Australia. *Aust. B.M.R.*, Bull. **27**.

SUMMARY OF STRATIGRAPHY OF NETHERLANDS NEW GUINEA

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INTRODUCTION

The following paper is based mainly on data from the files of N.V. Nederlandsche Nieuw Guinee Petroleum Maatschappij (Dutch New Guinea Petroleum Company)[1] which has been operating in Netherlands New Guinea since 1936. Data from published literature and from the results of N.N.G.P.M.'s investigations up to 1940 have already been compiled in Van Bemmelen's "Geology of Indonesia", to which the reader is referred. It has been thought advisable to compile a new stratigraphic summary for this paper, incorporating the latest information.

The map shows the location and type of the geological surveys carried out and outlines the areas discussed.

In the chart the geologic formations occurring in each of these areas have been tabulated. In the first column a rough "utility subdivision" is shown. The second column shows the range of some pelagic foraminifera.

STRATIGRAPHY

SILURIAN

Only one rock unit at least in one part of Silurian age is known in Netherlands New Guinea, namely the *Kemoem formation* in the North Vogelkop (area IIB). It is a mainly fine clastic formation, consisting of hard phyllitic shales with subordinate quartzites. At one locality

Monograptus turriculatus (Barrande) and
Monograptus marri Perner,

have been found, indicating a Lower Silurian age.

Outside the Vogelkop, in area X, the Silurian coral *Halysites wallichi* Reed was found in limestone boulders in the Noord Oost River (Van Bemmelen 1949).

It is possible that the strongly metamorphic barren rocks occurring in the Wandamen area (area VII), especially the gneisses and mica schists of the Wandamen Peninsula also belong to the Silurian.

DEVONIAN

In quoting Keyzer (1941) Van Bemmelen reports a Devonian section in the Nassau Mountains (area IX). So far the N.N.G.P.M. geologists have not encountered rocks with Devonian fossils.

Because in area IIB the Kemoem formation is unconformably overlain by the Aifam formation (containing Upper Carboniferous brachiopods), it is possible that, at least in this area, the Devonian was a period of folding, uplift and denudation.

PERMO-CARBONIFEROUS[2]

While Silurian and Devonian rocks outcrop only in limited areas, Permo-Carboniferous rocks have a much wider distribution.

The sediments belonging to the Carboniferous and/or Permian are called *Aifam formation.* This is a generally coarse clastic formation, which, in the type locality, the North Vogelkop (area IIB), unconformably overlies the Silurian Kemoem formation. The basal part is formed by sandstones and conglomerates (approx. 600 m. thick). In its middle part it consists of calcareous sandstones and sandy limestones (approx. 1,100 m. thick). Some brachiopods have been found which have been determined as:

Neospirifer fasciger Keys
Spirifer cf. *marconi* Waagen

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[1] A partnership of B.P.M., Stanvac and Far Pacific Investments.

[2] The term Permo-Carboniferous is used here to cover the entire Carboniferous and Permian periods.

Fig. 1.

indicating an Upper Carboniferous to Permian age.

The upper part of the Aifam formation consists of predominantly black silty shales interbedded with calcareous sandstones and several coal layers. This part (approximately 750 m. thick) yielded abundant well-preserved plant remains.

The flora of the Aifam formation ranges from Upper Carboniferous to Upper Permian and may also include part of the Triassic (see Appendix I).

Outside the North Vogelkop, the Aifam formation has been found in wells in the Central Vogelkop (area IIA), in outcrops in the south coast areas (areas IX and X) and in the well Kembelangan 1 (area VII). Along the headwaters of the Otakwa and Akimeugah rivers (in areas IX and X) a thickness of 4,000 m. is attained.

TRIASSIC

Wherever the Aifam formation has been observed, a gradual change is found from its coal-bearing upper part to the red and mottled clays of the barren, locally coarse, clastic *Tipoema formation*. This change is considered to reflect the transition to a dry, desert-like climate.

The age of this formation is inferred to be Triassic from its conformable position upon the Permo-Carboniferous Aifam formation, and from the fact that, in the type area (area VII), it is overlain by Jurassic limestones of the Kembelangan formation.

JURASSO-CRETACEOUS[3]

Rocks belonging to the Jurasso-Cretaceous have a wide distribution, namely from the Tamrau Mountains (area III) as far as the south coast (area X).

In the Tamrau Mountains (area III) the black slates and phyllites with subordinate quartzites are called the *Tamrau formation*. The fossil content indicates a Middle Jurassic age.

In the lithological unit of the *Kembelangan formation*, the name of which is derived from the well Kembelangan 1 (area VII), both Jurassic and Cretaceous fossils have been found. In this well the Tipoema formation is covered by a heterogeneous complex consisting of sandstones, calcareous sandstones, claystones, marly clays and marls. Near the base of the formation, in addition to indeterminate Belemnites cf. *Grammatodon* (*Indogrammatodon*) *virgatus* (Sowerby) have been found, which might indicate an Upper Bathonian - Lower Oxfordian age.

Along the western shore of Geelvink Bay (area VIII) Callovian Ammonites have been found of the genera:

Gravesia Salfeld
cf. *Dolikephalites* Buckman and
Macrocephalites Douvillé

while from the latter genus the species *M. keeuwensis* Boehm and its varieties could be determined. A more extensive list of fossils collected in this formation near Wendesi (Windesi is in area VIII) is given by G. Boehm (1912).

In area II B the upper part of the Kembelangan formation contains a Globotruncana fauna, indicating a late Cretaceous age for this part of the formation. Below this upper part about 100 m. of sediments are found in which a limestone layer occurs containing:

Australiceras Leptum (Etheridge)
Sanmartinoceras olene Tenison Wood
and *Tropaeum* sp.

indicative of an Aptian age for this part of the formation. These Lower Cretaceous sediments overlie the Tipoema formation. A stratigraphic hiatus is therefore probable.

In well Poeragi 1 (area II A) this hiatus is larger because the Upper Cretaceous part of the Kembelangan formation lies on the Tipoema formation; further to the west, in a well near the Klamono oilfield, the Tertiary rests on the Palaeozoic Aifam formation.

Between area VII and the Moetoeri area (area IV) the upper part of the Kembelangan formation passes from sandy marls into fine-grained, more or less argillaceous limestones containing abundant pelagic foraminifera. In area IV the *Imskin formation* developed in this facies comprises, besides Upper Cretaceous, also Tertiary beds up to Tertiary *e* in age.

The preceding formations are mainly clastic and, as far as we know, deposited in elongated east-west trending basins. It is assumed that, during the pre-Tertiary, the supply of terrigenous material, if not solely, was at least mainly derived from the Australian continent to the south, which at the end of the Cretaceous had become peneplainized.

The biostratigraphy of the Palaeozoic and Mesozoic, excepting the late Cretaceous, is based on relatively rare, isolated finds of macrofossils. From the Upper Cretaceous onward, however, biostratigraphy is based upon abundantly occurring pelagic foraminifera and larger benthonic foraminifera, giving together an excellent time-stratigraphic control. Smaller benthonic foraminifera associations have been extensively used for local biostratigraphic correlation and sometimes also for ecologic interpretation.

TERTIARY

In this summary the Tertiary sediments of New Guinea have been subdivided according to the "Letter Classification" of Leupold, Umbgrove and Van der Vlerk, which is in general use for the East Indian Tertiary (for parallelization with the international nomenclature see Van Bemmelen (1949), Vol. IA, pp. 83-88).

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[3] The term Jurasso-Cretaceous is used here to cover the entire Jurassic and Cretaceous periods.

EARLY TERTIARY *a-b*

From the Etna Bay to the east (areas IX and X), sediments of early Tertiary *a-b* age are developed in the facies of the *Waripi formation*, a reefoid sequence with Bryozoa limestones, oölitic limestones and shell limestones (lumachelles).

Rocks containing:

> *Globorotalia velascoensis* (Cushman)
> *Globorotalia membranacea* (Ehrenberg),

which, according to Grimsdale (1951) indicate a Paleocene to early Eocene age, occur in the pelagic limestone of the lower part of the Imskin formation around Bintoeni Bay (area IV) and Argoeni Bay (area VIII) and must therefore also be included in the Tertiary *a-b* (early part).

On the Onin peninsula (area V A), the *Baham formation*, consisting of sandstones and marls with *Globorotalia velascoensis* (Cushman) has been deposited during this time interval.

West of area IV, early Tertiary *a-b* rocks are either absent or not identifiable due to absence of fossils.

LATE TERTIARY *a-b*

During late Tertiary *a-b* algal limestones were deposited over large parts of Netherlands New Guinea.

These limestones are almost invariably rich in *Alveolina* and/or *Lacazina.* At many localities these larger foraminifera are so conspicuous that their presence, usually recognizable with the naked eye, served to establish a separate rock unit, the *Faumai formation.*

At several localities (in areas IV and VIII) the Alveolina-Lacazina limestones of the Faumai formation grade laterally into Discocyclina-Camerina limestones with abundant pelagic foraminifera of the Globorotalia zone, and these again pass into fine -grained, slightly argillaceous limestones with pelagics only (Imskin formation).

A similar pelagic limestone facies of late Tertiary *a-b* age, the lower part of the *Onin formation*, has been found on the Onin Peninsula (in area V A).

In a small outcrop south of Sarmi (in area XI) the lower part of the *Biri formation* is of Tertiary *a-b* age.

The *Kerkberg formation* of the Waropen area (area XIII) is partly of T *a-b*, and partly of T *c-d-e* age. This formation is a shelf limestone containing in part *Biplanispira*, *Pellatispira* and *Nummulites.* This association has never been encountered elsewhere in Netherlands New Guinea.

During the Tertiary *a-b* large stable areas occurred, on which first Bryozoa and later Algae flourished. Pelagic foraminifera could apparently not penetrate into this environment. These areas are probably best visualized as extensive reef flats. In other areas where pelagic limestones were deposited, open marine conditions must have prevailed. The supply of terrigenous material during this time interval was small and consisted mainly of finegrained material.

TERTIARY *c-d-e*

During this time interval uplifts occurred locally, leading to non-deposition and probably some erosion in certain areas, while sandstones and clays were laid down in the areas bordering on the uplifts.

In area II B, north of a line from the Anggi Lakes to the Warsamson River, rocks of Tertiary *c-d-e* age are absent; at several localities in this area Tertiary *f* rocks are found overlying Tertiary *a-b* or older rocks.

Immediately south of this line a clastic formation was deposited — the *Sirga formation,* consisting of purely clastic rocks. Mixed sedimentation of clastics and limestones also took place in this area and these sediments are described as the *Ainod formation.* Both formations are of Tertiary *c-d-e* age.

On the Onin Peninsula (area V A), in the Koemawa Mountains (area V B) and in the Kaimana area (area VII) larger foraminiferal-algal-coral limestones are present, which, apart from rocks of Tertiary *c-d-e* age, also include rocks of Tertiary *a-b* and Tertiary *f* age. They have been described as the *Ogar*, *Koemawa* and *Kaimana formations.*

Furthermore, on the Onin Peninsula, the *Onin formation*, consisting mainly of pelagic limestones with intercalated larger foraminiferal limestones, is mainly of Tertiary *c-d-e* age, but also includes rocks of late Tertiary *a-b* and Tertiary *f.* It is noted that the Onin formation was deposited during the same time interval (late Tertiary *a-b* to Tertiary *f*) as the Ogar formation. This indicates a consistent difference in the depositional environment in the areas where the two formations were deposited. In the area of the Ogar formation (area V B) biohermal limestones predominate, whereas in the area of the

Onin formation (area V A) open sea marine limestones were deposited. The boundary between the Ogar and Onin formations therefore represents the boundary between the stable shelf and a basinal area from late Tertiary *a-b* into Tertiary *f* time.

The lower part of the *Darante formation* of the Sarmi area (area XI) is also of Tertiary *c-d-e* age.

In the Manokwari area (area XIII) only isolated outcrops of Tertiary *c-d-e* limestones were found.

A pelagic limestone and marl facies has been found in the subsurface of area I and has been called *Klamogoen formation*; it includes also sediments of early Tertiary *f* age.

As mentioned above, part of the Imskin formation of area IV is of Tertiary *c-d-e* age.

The shelf areas which came into existence in Tertiary *a-b* time remained relatively stable (in areas IIA, IIB, VB, VII and IX) during Tertiary *c-d-e*. In the open marine areas (areas I, VA, IV and VIII) the same type of pelagic limestone has been deposited as during Tertiary *a-b*. However, in area I and the eastern part of area IV a hiatus between the Tertiary *f* and the Upper Cretaceous was locally observed, which fact—if not due to faulting—would point to an uplift during Tertiary *c-d-e*.

During Tertiary *c-d-e* time also, the supply of terrigenous material remained small. The sands and clays of the Ainod and Sirga formations originated from the North Vogelkop (area IIB).

TERTIARY *f*

During this time interval the differentiation into stable shelves and unstable basinal areas became accentuated. While a monotonous sequence of coral limestone, the *Kais formation*, was deposited on the stable shelf, in the basinal parts pelitic sediments of great thickness accumulated.

In the typical, poorly bedded coral limestones of the Kais formation *Flosculinella bontangensis* (Rutten), *Flosculinella borneensis* (Tan Sin Hok) and various associations of larger foraminifera have been found. Within and covering the coral limestone poorly bedded limestone debris occurs. In many areas there is no lithological break between these coral limestones and those of Tertiary *c-d-e* age. Therefore local formation names have been used.

The pelitic sediments which laterally replace and partly cover the Kais formation form the *Klasafet formation*. This is a thick sequence of clays, silty or marly clays and clay shales containing floods of foraminifera. Where these pelitic sediments replace or cover calcareous beds (containing *Lepidocyclina* and/or *Miogypsina*) the boundary between Tertiary *f* and Tertiary *g-h* has for practical purposes been assumed to lie at the deepest occurrence of sandstone layers or where the clays contain plant remains.

The distinction between the Kais and Klasafet formations can be applied in the entire Vogelkop.

In the east, along the Otakwa and Akimeugah rivers (in area X) the Tertiary *f* limestone development is less consistent. Thick layers of argillaceous limestones alternate with thick beds of fine sandy to silty clays, so that it is no longer possible to make a distinction between a marly and a limestone formation. Consequently a local name has been used for these beds; the *Akimeugah formation*.

In the Sarmi area (area XI) the *Darante formation* (already mentioned under Tertiary *c-d-e*) ranges in age from Tertiary *e* to early Tertiary *f*. This formation consists of foraminiferal, reef-related and pelagic limestones and marls and is overlain and laternally replaced by the *Foein formation* (late Tertiary *e* to late Tertiary *f* or even early Tertiary *g-h*). The Foein formation consists of a marl-conglomerate-sandstone member in its lower part and a siltstone-marl member in its upper part.

In general, during the Tertiary *f* the stable shelf areas persisted, but basins developed locally in which thick, mainly fine clastic sediments were deposited, probably derived from local sources; this indicates the beginning of tectonic movements.

TERTIARY *g-h*

The boundary between the Tertiary *f* and the Tertiary *g-h* has been accepted in the Indo-Pacific area as coinciding with the highest occurrences of limestones containing Tertiary *f* fossils (*Lepidocyclina*, *Flosculinella* and *Miogypsina*).

The disappearance of these larger foraminifera may, however, be solely attributed to the disappearance of a favourable facies and does not necessarily have to coincide with the extinction of the above-mentioned genera of larger foraminifera.

Time-stratigraphy in the younger beds is now mainly based by N.N.G.P.M. on pelagic foraminifera.

During the Tertiary *g-h* the predominance of the calcareous sediments of the Tertiary *a-f* is replaced by prevalence of clastic sediments.

The sedimentation in the basins (areas I, IV, X and XI) continued uninterruptedly from Tertiary *f* into Tertiary *g-h*. Already during early Tertiary *g-h* times sedimentation spread out slowly from these basins into the subsiding neighbouring areas, leading to a progressive overlap of Tertiary *g-h* sediments on the Tertiary *f* or older rocks.

In late Tertiary *g-h* times considerable subsidence again took place in areas VI, IX, XI (partly), XII, XIII, resulting in deposition of thick sediments (several thousand metres).

It is believed that areas II B, III, V A, VII, VIII, and the northern part of areas IX and X emerged shortly after the beginning of Tertiary *g-h* time and remained above sea-level ever since.

As mentioned above, sedimentation in the basins formed in Tertiary *f* time continued uninterruptedly into Tertiary *g-h* time, but the type of sediments changed, in some areas gradually and in other areas abruptly, from argillaceous-calcareous to mainly argillaceous-arenaceous. On this change are based the distinctions between the Klasafet formation and the Klasaman formation in area I, between the Klasafet formation and the Steenkool formation in area IV, and between the Akimeugah formation and the Boeroe formation in area X.

In area I, coarse clastic sediments often accompanied by lignite beds are characteristic of the *Sele formation*.

In area II A, the *Womba formation*, consisting of a soft unconsolidated series of clays and sandy clays with lignite beds, is the equivalent of the upper part of the Sele formation.

In area V B and the western part of area VI, the *Bedidi formation*, a sandstone-shale formation with plant remains, overlaps the Ogar and Koemawa formations.

The *Sara formation* (in area VI), a sandstone-shale sequence, lies unconformably on the *Weredebe formation*. This is a thick sequence of well-bedded, coarse and fine-grained sandstones, sandy shales with intercalations of calcareous sandstones and marly shales. The Sara formation itself is partly unconformably overlain by the *Satoera formation*, which contains, in addition to the rocks found in the Sara formation, conglomeratic beds in coarse sandstones and coal beds.

The *Boeroe formation*, which in area X overlies the Akimeugah formation, spread into area IX in late Tertiary *g-h* time. Its lower part (in area X) consists of fine-grained material, but the upper part, spreading out over area IX, contains many conglomerate intercalations.

In the Sarmi area (area XI), the *Foein formation*, which, according to the content of certain pelagic foraminifera, belongs for the greater part to the Tertiary *f*, is already strongly arenaceous. The overlying *Sarmi formation* consists of massive, somewhat sandy marls, thickbedded (graywacke) sandstones and silts with intercalated conglomerates and a more clayey part at the top.

In the Waropen area (area XII), the *Nadoepoeai formation* again shows an increase in grain size from the bottom to the top. The younger *Bariwaro formation* also contains lignite beds.

In the Manokwari area (area XIII), the ***Befoor** formation* is mainly a sandy deposit with interbedded conglomerates and clays.

The lithology of the Tertiary *g-h* deposits indicates that around the Tertiary *f*/Tertiary *g-h* boundary large areas of present Netherlands New Guinea emerged and supplied the material for the early Tertiary *g-h* rocks, which were still mainly deposited in the basins already active in Tertiary *f* time. A second phase of uplifts and submergence of other parts occurred in younger Tertiary *g-h* time, resulting in enlargements of the Tertiary *f* basins and the formation of new, local basins (e.g. in areas IX, X and XIII). A third phase of uplifts finally resulted in the present configuration of Netherlands New Guinea.

REFERENCES

Van Bemmelen, R.W., 1949, The Geology of Indonesia. Vol. I A. Government Printing Office, The Hague.

Boehm, G., 1912, Unteres Callovien und Coronatenschichten zwischen Mac Cluer-Golf und Geelvink-Bai. *Nova Guinea*. **6** Geologie, (1), Leiden.

Keyzer, F.G., 1941, Fossielen van het Paleozoicum van zuidelijk Centraal Nieuw Guinea. *Hand. 28e Nat. and Geneesk. Congr. Utrecht*, 4e afd. : 271-272.

Grimsdale, T.F., 1951, Correlation, Age Determination and the Tertiary Pelagic Foraminifera. *Proceedings Third World Petroleum Congr.* The Hague 1951, Section I. Leiden.

Jongmans, W.J., 1940, Beiträge zur Kenntnis der Karbonflora von Niederländisch Neu Guinea. *Mededelingen Geologische Stichting* (Geol. Bureau, Heerlen). Jaarverslag over 1938 en 1939.

APPENDIX 1

The following plants have been determined* from the Aifam formation:

Upper Carboniferous: *Calamites suckowi* Brongniart
- cf. *Odontopteris - Neuropteris* sp.
- *Sphenophyllum* sp.

Lower Permian: *Sphenophyllum verticillatum* Schlotheim
- *Sphenophyllum* cf. *verticillatum* Schlotheim (Tryzigia form)
- *Sphenophyllum* cf. *speciosum* Royle
- *Pecopteris* (*Ptychocarpus*) *unita*
- *Pecopteris* Brongniart
- *Pecopteris* cf. *arcuata* Halle
- *Pecopteris* cf. *orientalis* Schenker *arborescens* (= *cyathea auct.*) Schlotheim
- cf. *Odontopteris* sp.
- *Glossopteris* cf. *browniana* Brongniart
- cf. *Taeniopteris* sp.

Not older than Lower Permian, younger than above assemblage:
- *Glossopteris* spp. (*retifera*, *browniana*, *indica*, *tortuosa* types)
- *Vertebraria* spp.
- *Sphenophyllum* sp.
- *Noeggerathiopsis* sp.
- cf. *Gangamopteris* sp.

Sporomorphae: Permian: *Laevigatosporites* sp.
- *Verrucosisporites* sp.
- cf. *Tuberculatosporites* sp.
- *Triquitrites* sp.
- *Pectosporites* sp.
- *Acanthotriletes* sp.
- *Cyclogranisporites* sp.
- cf. *Endosporites* sp.
- *Pityosporites* sp.
- *Platysaccus* sp.

Upper Permian-Triassic:
- *Lueckisporites* sp.
- *Pityosporites* sp.
- cf. *Nuskoisporites* sp.

Jongmans (1940) reported the following from the area of the Otakwa and Setekwa rivers (in areas IX-X):
- *Sphenophyllum verticillatum* Schlotheim
- *Pecopteris* (*Ptychocarpus*) *unita* Brongniart

- *Pecopteris* cf. *arcuata* Halle
- *Pecopteris* cf. *paucinervis* Jongmans
- *Pecopteris* cf. *orientalis* Schenker
- *Taeniopteris* cf. *taiyuanensis* Halle
- *Taeniopteris* cf. *multinervis* Weiss
- *Vertebraria* sp.

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* Determination by C.A. Hopping, palaebotanist N.V. De Bataafsche Petroleum Maatschappij (Royal Dutch/Shell Group)

ON SOME NEW POINTS OF VIEW ADOPTED CONCERNING THE STRATIGRAPHIC AND CORRELATIVE KNOWLEDGE OF THE SEDIMENTARY STRUCTURES OF NEW CALEDONIA

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At the 8th. Pan Pacific Science Congress the author retraced the history and the main stages of stratigraphic knowledge in New Caledonia, from the discovery of the island until the 100th anniversary of France's taking possession of it, in 1952; I here refer to this exposé as well as to the two fundamental works published in 1953 (J. Avias, in Contribution à l'étude stratigraphique, paléontologique des formations anté-crétacées de la Nouvelle Calédonie centrale; P. Routhier, Etude géologique du versant occidental de la Nouvelle Calédonie). These two works constituted then a comprehensive survey of the notions acquired in 1952. Thus we shall here limit ourselves to the new data acquired since 1952, i.e. approximately since the 8th. pan-Pacific Science Congress.

PERMO TRIASSIC FORMATION

A review has been undertaken of all cephalopoda known to date, from the Piroutet collections or from the author's personal collections, wich have been collected from permo-triassic formations. This review, effected by the author in collaboration with Melle. Simone Guerin, brought about the composition of a MS. wich was entered in June 1957 and is now at the publisher's, to be published in vol. I n° I of the "Bulletin du Service des Mines et de la Géologie" of New Caledonia. The main results are:

a) a review of the fauna does not confirm the existence of the two *Popanoceras* and *Wagenoceras* zones in the Middle Permian.

b) the confirmation of the unquestionable existence of the *Meckoceras* genus of Lower Trias (Werfenian) in New Caledonia.

c) the great similarities existing in the formations of the upper Permian and Lower Trias of New Caledonia, and those of the Himalayan subsidence area (the "*ceratites sandstones*" of the Salt Range) on one hand, those of the same age at Timor on the other.

d) the transition, seemingly almost imperceptible lithologically and paleontologically, between the upper Permian and the lower Trias in New Caledonia, as in India, Armenia and Madagascar.

A second work, now in progress, deals with the review of the Ammonites of the upper Trias. We can already draw attention to the discovery—in the upper Triasic formations of the Baie de St. Vincent (Ducos island)—of a very definite zone with many *Sternarcestes Arnouldi*, a species described for the first time in 1885 by Von Mojsisovics, the exact stratigraphic localisation of wich had so far remained unknown.

THE PROBLEM OF JURASSIC AND LOWER CRETACEOUS FORMATIONS

Here we shall draw attention to the fact that the review of the "*Perisphinctes*" described by P. Routhier (1953 p. 55 pl. III fig. I) and put by this author into the hands of the specialist J. Arkel (1956, p. 451) has shown that it was rather an affine form of the kimmeridgian *Idoceras* genus. In any case, the jurassic age is thereby corroborated.

Before we know the results of the review in progress,—wich the author has put into the hands of the same specialist—of the badly preserved specimens, wich M. Piroutet, in 1917, determined as '"*Beriasella* aff. *novozelandica*", (a fact wich very likely conferred a Portlandien or Eocretaceous age to the corresponding gritty formations); the review of the lamellibranchia fauna associated with this ammonite has shown (J. Avias and S. Frenex, unpublished) that it belonged in fact to the Upper Cretaceous (probably Senonian: the presence particularly of associated *Pterotrigonia*). The two preceding facts are important because they seem to show that, in the present state of knowledge, no formation of terminal Jurassic (post kimmeridgian) or Eocretaceous age is known in New Caledonia so far.

PROBLEM OF THE MIDDLE AND UPPER CRETACEOUS FORMATIONS

The review,-wich the author put in Madame S. Frenex's hands,—of the lamellibranches of the Piroutet, Avias and Routhier collections has shown (by the presence of the *Pacitrigonia, Pterotrigonia, Acanthocardia acuticostatum* Lahillia, *Tikia*, . . . etc, genera) that all Piroutet's fauna determined by the author as belonging to the lower or middle Cretaceous (mainly Senonian). Moreover, the preceding conclusions have been confirmed by the author during the review of the corresponding cephalopoda from the same collections of the Bureau Minier de la France d'Outre Mer (Lormand and Herman collections). It is proved, then that not only during the Eocretaceous but also during most of the Cretaceous most of New Caledonia was emerged. Sedimentation having started again with the great Senonian transgression, well known and characterised in all the Pacific Ocean and the beginning of which, according to Madame E. Basse de Menerval (1949, p. 134) and the study of the Cephalopods, would more exactly correspond to Santonian in New Caledonia. A study in progress of the shalow water gastropoda of the Moindou Coal Formation, discovered by the author in 1946 and found again more recently by Pierre Koch, head of the Geology Department of the Service des Mines of New Caledonia, in other Cretaceous basins of the western coast, will perhaps enable us to clean up the Problem of the lower age limit of the "formation à charbon" (possibility in the Paleocene ?).

TERTIARY AND QUATERNARY FORMATIONS

Very few things, as far as we know, have come to modify Piroutet's conclusions (presence of Eocene) corrected by Y. Gubler and R. Pomeyrol (1948, p. 1292) N. Grekoff and Gubler (1951 p. 283) presence of Miocene); by P. Routhier (1948 p. 358. Precisions on the Miocene and distinction of Eocene 1 and 2 in a reversed order of superposition compared with the order of Eocene formations supposed by Piroutet and Pomeyrol).

Concerning the Miocene, the author has recently confirmed the presence of the Lepidocyclina genus during the Miocene age (which he had proposed for dune sandstones with cross-bedding which outcrop between Lebris island and Hugon Island) (J. Avias, 1953 p. 35) on the western coast of the island, in that there are in these sandstones grains of chromite which can only come from ultrabasic formations set during the oligocene. The reforming by horizontal Miocene strata discordantly covering the plicated Eocene strata of decomposition products from ultrabasic rocks (P. Routhier, 1948 p. 358) linked with the setting of the New Caledonia chain, and the absence, in the present state of knowledge, of any Oligocene deposit show that the major plication of the New Caledonia chain is obviously of the Oligocene age, as Piroutet has supposed (1917).

In conclusion: we see that the existence of lacunae at definite periods (cf. J.A. 1953, Tab. VI and XVI) is confirmed and made precise.

1) the first dated formation being the lower Permian (Artinskian), strata and no fossils being attachable to the Middle Permian there is a possible first lacuna in the Middle Permian.

2) there is at least a partial lacuna in the Lower Triassic.

3) there is probably a general lacuna in the Middle Triassic.

4) there is a fairly general, and possibly total, lacuna in the Middle jurassic.

5) a lacuna wich seems total, or at least nearly total, in the Upper Jurassic and the Lower and Middle Cretaceous.

6) a possible lacuna in the terminal Cretaceous (Maestrichtian and Danian) as well and possibly in the Paleocene.

7) a total lacuna in the Oligocene.

These lacunae are in certain points accompanied by clear unconformities, by which, from the orogenic point of view, there seems to be in New Caledonia:

a) a definite unconformity (of more than 55° at the Uitoé peninsula) between ante-artinskian formations (formation "des tuffs polycolores") and the Upper Trias, which shows that *an orogenic phase, having started during the middle Permian and having continued until the end of the Trias at the latest, has existed in New Caledonia;* it is a *late hercynian phase*, roughly equivalent to the *Saalian phase* of hercynian orogenesis in Europe and to the *Unter Bowen Orogen* of the East Australian hercynian chains.

b) a slight an variable unconformity between the Triassic and the Jurassic formations and the Upper Cretaceous, which can be explained either by epeirogenetic movements or by a slight phase of plication, this phenomenon having, anyway, started during the Middle Jurassic and having possibly lasted until the end of the Middle Cretaceous.

c) a possible premonitory movement during the terminal Cretaceous and the Paleocene.

d) a final *paroxistic alpine phase during the Oligocene.*

REFERENCES

Arkel, J., 1956, Jurassic Geology of the World. London.

Avias, J., 1952-53, Contribution à l'étude stratigraphique et paléontologique des formations antécrétacées de la Nouvelle Calédonie Centrale. *Science de la Terre.* **1.** (1 et 2) Nancy.

Avias, J. et S. Guerin, 1957, Contribution à l'étude des faune de céphalopodes permotriasiques de Nouvelle Calédonie I: Nautiloïdes et ammonoïdes du Permien et du Trias Inférieur. sous presse T. **1** (1) du Bulletin du Service des Mines et de la Géologie de la Nouvelle Calédonie. Nouméa.

Basse De Meneval, E., 1949, L'extension des Kossmaticeras dans les mers Antartico-Indo Pacifiques au Néocrétacé. *Proc. VIIth. Pacific Science Congress* **2**:130-135 Wellington 1953.

Freinex, S., 1955-57, Contribution à l'étude des Lamellibranches du Crétacé de la Nouvelle Calédonie. *Sciences de la terre.* **3** (sous presse). Nancy.

Grekoff, N. et Y. Gubler, 1951, Données complémentaires sur les terrains tertiaires de la Nouvelle Calédonie. *Revue de l'Institut Français du Pétrole.* Paris **6** (8): 283-293.

Gubler, Y. er R. Pomeyrol, 1948, Existence du Néogène marin en Nouvelle Calédonie *C. R. S. Acad. des Sciences Paris* **226** (16) : 1292-1293.

Piroutet, H., 1917, Étude Stratigraphique sur la Nouvelle Calédonie. Thèse. Mâcon.

Routhier, P., 1948, A propos d'une récente note sur le Néogène marin en Nouvelle Calédonie. *C.R. som. Soc. gêol. France*, Paris, (15-16) : 358-359.

Routhier, P., 1952-53, Étude Géologique du versant occidental de la Nouvelle Calédonie. . . . *Mém. Soc. Géol. France.* **32** (67) Paris.

AGE AND RELATIONSHIP OF TASMANIAN FOSSIL FAUNAS AND FLORAS

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INTRODUCTION

Only about 750 fossil species have been listed from Tasmania and of these less than two hundred have been studied by methods now considered adequate. Marine invertebrates are found in the Precambrian, Cambrian, Ordovician, Silurian, Lower Devonian, Permian, Tertiary and Quaternary: vertebrate fossils are rare except in the Pleistocene but occur in the Permian, Triassic and Tertiary; small Ordovician, Silurian and Lower Devonian floras are known with richer floras in the Permian, Triassic, Tertiary and Quaternary. No Carboniferous, Jurassic or Cretaceous fossils are known. The remarks which follow could best be described as forming a progress report and it should be appreciated that they are based on very few fossils.

PRECAMBRIAN

Groups of schists and gneisses intruded by metamorphosed basic rocks are overlain unconformably by groups of sediments containing quartzites, siltstones, dolomites, rare conglomerates and tillite. These latter are themselves intruded by basic dykes and sills. The older schists and gneisses represent regionally metamorphosed sediments of the ortho-quartzite suite. Some details of the stratigraphy of the Precambrian are set out in Table I. Worm tubes and casts have been recorded from quartzites in the higher Precambrian rocks at three places, Mount Balfour, Port Davey and Sisters Beach. The exact age of these is unknown. At Dundas rocks correlated with these are overlain with an angular unconformity by rocks containing trilobites of the *Ptychagnostus gibbus* zone of the Middle Cambrian.

CAMBRIAN

Middle and Upper Cambrian rocks overlie older rocks unconformably and are themselves overlain unconformably by rocks high in the Upper Cambrian or low in the Ordovician. The Middle and Upper Cambrian rocks consist of more than 10,000 feet of conglomerates, sandstones, and lutites of the sub-greywacke or greywacke suite, rare limestone and dolomite, chert and basic, intermediate and acid volcanic and pyroclastic rocks, some of them of the spilite suite. Direct volcanic contribution is probably less than 20% of the total volume. At least eleven cycles of sedimentation, which have been taken to indicate contemporaneous orogenic movement, are present, each cycle commencing with coarse material and becoming finer. Volcanic rocks are usually associated with the finer grained parts of the cycles. These sediments and the Precambrian below them were intruded by ultrabasic rocks, especially pyroxenites, before the Ordovician. The intrusions are in most cases close to the contact between the Precambrian and Cambrian. A fuller description may be found in papers by the author (1956, 1957 b.)

Sponges, brachiopods, annelids, trilobites, phyllocarids, cystoids and dendroids have been found in this group of rocks (Banks, 1956 for complete list). The lowest formation contains *Ptychagnostus* (?), *Peronopsis*, *Pagetia*, *Triplagnostus* and *Lorenzella* and has been correlated with the *Ptychagnostus gibbus* Zone in Queensland and elsewhere. The next assemblage contains dendroids such as *Archaeocryptolaria skeatsi*, *Archaeoloforaea serialis* and other species first described from Victoria. On an equivalent horizon *Solenoparia*, bathyuriscids and *Diplagnostus* occur. Opik considered these to be equivalent to the upper part of the *Ptychagnostus atavus* Zone or the *P. punctuosus* Zone. On a higher horizon *Blackwelderia* cf. *biloba*, *Phalacroma*, *Oidalagnostus* and *Conocephalites* occur and on an approximately equivalent horizon *Clavagnostus*, *Leiopyge laevigata* and *L. laevigata* var. *armata* are found. These are thought to be in the zone of *L. laevigata*. The Lower Dresbachian (Cedaria Zone) is represented by *Pseudagnostus*, *Coosia*, *Aphelaspis*?, a dikelocephalid and trilobite allied to *Monocheilus*. The highest zone represented is that of *Glyptagnostus reticulatus* with *Protospongia* and the zonal species. Both Opik (1956) and Thomas and Singleton (1956) have dealt with the provincial relationships of the Eastern Australian Middle and Upper Cambrian faunas. The oldest fauna in Tasmania contains both

Pacific (sense of Opik, 1956, p. 268) and Acado-Baltic elements. The dendroid fauna is specifically similar to that found in Victoria. The *Blackwelderia* and *Leiopyge* associations are dominantly Acado-Baltic with some Pacific (especially East Asian) affinities. The Lower Dresbachian faunas are Appalachian and the highest one Acado-Baltic again.

Thus deposition occurred in Tasmania from the time of the Middle Cambrian *Ptychagnostus gibbus* Zone to that of the Upper Cambrian *Glyptagnostus reticulatus* Zone and during this time the faunas were dominantly Acado-Baltic with some Pacific elements allied to both East Asian and Appalachian forms.

ORDOVICIAN

The Ordovician System comprises a major cycle of sedimentation. It begins with greywacke and sub-greywacke breccias and conglomerates, followed by conglomerates, sandstones, siltstones and limestones in that order. These higher rocks are of the orthoquartzite suite. This cycle is referred to as the Junee Group and reaches a maximum thickness in any one section of over 6,000 feet (Table I.). In some places the limestone passes up into siltstone and this into sandstone but elsewhere the boundary between limestone and sandstone is sharp with the possibility of normal faulting and erosion before deposition of the succeeding bed in one place.

The lowest formation, Jukes Breccia, contains trilobites, orthid and inarticulate brachiopods and a gastropod tentatively identified as *Scaevogyra* in one area. None of these fossils have yet been studied in detail so that the age and relationship of the fauna remains obscure. The succeeding Owen Conglomerate contains only tubicolar worm casts. A better known assemblage occurs in the Caroline Creek Sandstone (=Tubicolar Sandstone of Owen Conglomerate) and includes the alga *Licrophycus tasmanicus*, the gastropods *Ophileta* and *Cryptolites*, the worms *Scolithus* aff. *canadiensis* and *S. tasmanicus*, and the trilobites *Asaphellus lewisi*, *Carolinites bulbosa*, *C. quadrata*, *C. tasmaniensis*, *Etheridgaspis carolinensis*, *E. Johnstoni*, *Prosopiscus subquadratus* and *Tasmanocephalus stephensi*. Kobayashi (1940) considered this fauna to be early Ordovician in age, and to show marked East Asian affinities. The subsequent discovery of *Carolinites* in Central Australia and the Garden City Fauna in Utah and Nevada (Ross, 1951) and in the British Isles (Stubblefield, 1950) is palaeogeographically significant. Stratigraphically above the Caroline Creek Sandstone is the Florentine Valley Mudstone which also contains a rich fauna. This includes the brachiopods *Syntrophopsis Karmbergi*, ?*Tritoechia careyi*, *T. lewisi* (Brown, 1947) and *Orusia* (?), the gastropods *Lecanospira tasmaniensis*, *Sinuopea*, *Roubidouxia* and *Tentaculites* (Kobayashi, 1940a; Etheridge, 1904), and the trilobites *Asaphopsis florentinensis*, *A.*, *Juneensis*, *A.* (?) *graciostatus*, *Tasmanaspis lewisi* and *T. longus*. Kobayashi (1940a, p. 62) considered the trilobites to show a Lower Ordovician age and remarked on their East Asian affinities. He noted also a North American element, in the gastropods. Brown (1947) showed that the brachiopods indicated a Middle Canadian age and affinities with North America. Browne (1952) remarked on the similarity between the brachiopods and some from a limestone at Bowan Park, New South Wales. Graptolites occur in this formation but have not yet been described.

The Florentine Valley Mudstone is overlain by the Gordon Limestone which contains a rich marine assemblage but only corals, cephalopods, and a few gastropods and algae have been figured to date. At the base of the formation is a fauna of cephalopods with some sponges. The cephalopods include *Allocotoceras insigne*, *Endoceras*, *Manchuroceras excavatum*, *M. steanei*, *Piloceras tasmaniense*, *Suecoceras robustum* and *Utoceras*? (Teichert and Glenister, 1953) which show an Upper Canadian age and marked East Asian affinities with western North American and Baltic elements. Also considered as probably Upper Canadian is an horizon with *Mysterioceras australe* and *Trocholitoceras idaense* from Ida Bay in south-eastern Tasmania. At Railton in northern Tasmania beds with *Nybyoceras paucicubiculatum*, *N. multicubiculatum*, *Ormoceras* and *Anaspyroceras* occur just above the base of the limestone. Teichert and Glenister (1853) consider these to be Chazyan or Mohawkian. Several hundred feet above the base of the formation in several places *Maclurites florentinensis*, *Maclurites* sp., *Girvanella grandis*, *G. problematica* and *G. tasmaniaensis* occur either individually or in association. This horizon is thought to be Chazyan (Banks and Johnson, 1957) and it overlies the cephalopod beds at Railton. Hill (1955) recorded *Acidolites*, *Billingsaria banksi*, *Coccoseris ramosa*, *Eofletcheria ida*, *Lichenaria ramosa*, *Tetradium compactum*, *Tryplasma cerioides* and *Streptelasma* cf. *aequisulcatum* from Ida Bay and suggested that horizons from oldest Blackriveran to Trentonian age at least were

Table I.

Summary of Succession of Tasmanian Faunas and Floras.

System	Series	Local Group	Rock Types	Faunas	Floras	Relationship
Quaternary	Pleistocene		Swamp and cave deposits	*Nototherium*, *Thylacoleo*	*Eucalyptus*, *Acacia* Conifers, etc.	Australian
Tertiary	Pliocene		Marine sands, lacustrine deposits	*Milthia*, etc.	*Eucalyptus*, *Acacia* Podocarp conifers	Bassian
	Miocene		Marine limestones and sands	*Trybliolepidina*		Bassian
	Oligocene	Table Cape Group	sandstone, limestone marine	*Sherbornina*, *Aturia australis*, *Prosqualodon*, *Wynyardia*.		Australian and South American
	Eocene	Launceston Beds	gravels, sands, clays, lignite	fresh-water pelecypods	*Trisaccites*, *Ephedra* and native conifers etc.	Australian
Cretaceous Jurassic Triassic	Middle		sandstone, siltstone, coal, tuffaceous sandstone	captorhinid fish	*Thinnfeldia*, *Cladophlebis*, *Johnstonia*, *Phoenicopsis*	East Australian, South Africa, South American
Permian	Tartarian	Cygnet Formation	sandstone, siltstone, Coal		*Glossopteris*, *Gangamopteris*, *Vertebraria indica*	Gondwanaland
	Kazanian	Ferntree Group	siltstone, marine	spiriferids		East Australia
	Kungurian	"Woodbridge Group"	sandstone, siltstone	spiriferids, *Chaenomya*, *Stenopora crinita*		East Australia
	Artinskian	Cascades Group	limestones, siltstones	*Taeniothaerus subquadratus*, *Calceolispongia*, *Lyroporella*, *Pterotoblastus*.		East Australia West Australia Gondwanaland
		Mersey Group	sandstones, siltstones, coal, oil shale		*Glossopteris*, *Gangamopteris*, *Noeggerathiopsis hislopi*	Gondwanaland
		Golden Valley Group	sandstones, siltstones, limestones	*Calcitornella Geinitzina Eurydesma cordatum Keeneia platyschismoides*		East Australia West Australia Gondwanaland
	Sakmarian	Quamby Group	siltstones, oil shale	Forams, *Keeneia twelvetreesi*, *Eurydesma*, *Calceolispongia* "*Streblascopora*" *marmionensis*		East Australia West Australia Gondwanaland
		Wynyard Tillite	tillite, varved claystones etc.			
Carboniferous Devonian	Lower	Eldon Group Bell Shale	siltstone and sandstone	*Pleurodictyum megastomum*, *Australocoelia polyspera*, *Maoristrophia*, *Plectodonta*,		South-east Australia New Zealand Europe, North America South America, South Africa

System	Series	Local Group	Rock Types	Faunas	Floras	Relationship
		Florence Sandstone	calcareous sandstone	*Pleurodictyum megastomum*, *Notoconchidium*, *Protoleptostrophia*		South-east Australia New Zealand Europe, North America
Silurian	Ludlovian	Keel Quartzite	siltstone sandstone			
	Wenlockian	Amber Slate	siltstone and sandstone	*Cyrtograptus*, *Tentaculites*, *Gillatia*		South East Australia
	Llandoverian	Crotty Sandstone	sandstone, siltstone, conglomerate	*Camarotoechia synchoneua*, *Monograptus*		
Ordovician	Cincinnatian	"Fenestella Shale"	siltstone			
			Limestone, rare siltstone and sandstone	*Tetradium* spp. *Billingsaria* *Lichenaria* *Eofletcheria*		N.S.W., North America, Baltic
	Champlainian	Gordon Limestone		*Maclurites*, *Girvanella* *Piloceras*, *Manchuroceras*		North America, Baltic East Asia, North America, Baltic
	Canadian	Florentine Valley Mudstone	calcareous mudstone	*Asaphopsis*, *Tritoechia*		N.S.W., East Asia, North America
		Caroline Creek Sandstone	sandstone	*Carolinites*, *Asaphopsis*		Central Australia, East Asia, North America, Baltic
		Owen Conglomerate	quartz, conglomerate and sandstone			
		Jukes Breccia	greywacke, breccia and conglomerate	*Scaevogyra*		
Cambrian	Upper	Dundas Group		*Glyptagnostus reticulatus*, *Protospongia*		Acado-Baltic, East Australia
			sub-greywacke, siltstone conglomerate, acid and basic lavas, cherts	*Pseudagnostus*, *Coosia* etc. *Blackwelderia*, *Phalacroma*, *Leiopyge*		Acado-Baltic, Pacific Acado-Baltic, Pacific
	Middle			Dendroids (*Archaeocryptolaria*, etc.) *Ptychagnostus* (?) *Peronopsis*, *Pagetia*		Acado-Baltic, East Australia Acado-Baltic, East Australia
	Lower					
Precambrian			basic intrusions quartzites siltstones conglomerates dolomites	worm burrows and tracks		
			basic intrusions schists, gneisses			

present. A Trentonian age has been suggested for a coralline horizon at the Oceana Mine, Zeehan, where Hill (1955) noted *Billingsarea*? *banksi*, *Eofletcheria contigua*, ? *Lichenaria*, *Lyopora* cf. *favosa*, *L. ramosa*, *Nyctopora zeehanensis*, *Tetradium* ? *compactum*, *T. dendroides*, *T. petaliforme*, and *T.* ? *tasmaniense*. Also probably Trentonian and/or Upper Ordovician is the fauna from the Smelters Quarry and Despatch Mine, Zeehan, from which the following fossils have been recorded: ?*Lichenaria*? *ramosa*, ?*Nyctopora*, ?*Protaraea*, *Tetradium conjugatum*, *T. dendroides* and *T. tasmaniens* (Hill, 1955), *Leptodomus*? *nuciformis*, *Trochonema montgomerii*, (Etheridge, 1896), *Anaspyroceras anzaas*, *Hecatoceras longinquum*, *H. obliquum* and *Tasmanoceras zeehanense* (Teichert and Glenister, 1953), *Illaenus johnstoni*, *Asaphus* and *Pliomera brevispinus* (Etheridge, 1896). Possibly equivalent or a little higher are the beds at the Smelters Quarry, Queenstown with *Acidolites*, *Alveolites*, *Protaraea* cf. *richmondensis*, *Tetradium conjugatum*, *T. dendroides*, ?*T. syringoporoides*, *T. tasmaniense* (Hill, 1955), and *Beloitoceras kirtoni* (Teichert and Glenister, 1953). Limestone at Bubbs Hill includes *Eofletcheria ida*, *Nytopora* and *Plasmoporela* and is Upper Ordovician (Hill, 1955). A limestone at Liena contains *Favistella cerioides*, *Favosites marginatus*, *Halysites* ?*chillagoensis* and *Plasmoporella* cf. *convexotabulata* (Hill, 1943) and is probably Upper Ordovician. Finally from the Gordon River *Entelophyllum*, *Phaulactis shearsbyi* (Hill, 1943), *Anaspyroceras*, *Gastonsoceras insperatum*, *Gordonoceras bondi*, *Ephippiorthoceras decorum*, *Stromatoceras eximium* and *Tasmanoceras zeehani* (Teichert and Glenister, 1953) have been recorded. These probably come from many horizons but Silurian rocks may be present based on the corals and *Gasconsoceras*. Affinities of the faunas are East Asian and Appalachian (Teichert and Glenister, 1953), and not at all with contemporaneous north-western Australian faunas. Some affinities with the Baltic Province are also shown by the cephalopods. The corals similarly show affinities with the Appalachian and Baltic Provinces and with a fauna from central New South Wales. At least one of the gastropods shows Appalachian affinities.

The Gordon Limestone is in places overlain by a richly fossiliferous calcareous siltstone first called the "*Fenestella* Shale", a name derived from the presence of fenestrate bryozoa which on preliminary examination appear to be trepostomes. No fossils from this formation have yet been described.

Thus what little is known of the Ordovician fauna of Tasmania suggests affinities with New South Wales, East Asia, Western North America, the Appalachian province and the Baltic province. The East Asian influences are strongest early in the period and later influences appear to be mainly North American.

SILURIAN AND DEVONIAN

It is convenient to deal with these together as in Tasmania they form a single major cycle of sedimentation lasting from early in the Silurian to high in the Lower Devonian. This major cycle is called the Eldon Group. There is an overall decrease in grainsize upwards through the major cycle, on which there are superimposed three smaller cycles each consisting of an alternation of sandstone and siltstone. The Eldon Group is conformable in some places and perhaps disconformable in others on the Junee Group. It was folded, probably in the Devonian, and with all older rocks is overlain unconformably by the Lower Permian sediments. Of comparable age in north-eastern Tasmania is a group of sandstones, sub-greywackes and siltstones from which only primitive vascular plants, *Hostimella* sp. and *Hedeia*, have been figured. Unidentifiable trilobites, brachiopods, corals, and crinoids also occur in it in one place. This group, the Mathinna Group. might well be the off-shore equivalent of the on-shore association of the Eldon Group.

The lowest formation of the Eldon Group is the Crotty Quartzite which is richly fossiliferous on some horizons. The fossils include tabulates, rhynchonellid brachiopods, pelecypods, gastropods, cephalopods, worm tubes and casts, crinoid plates and algal markings. Of these one brachiopod *Camarotoechia synchoneua* is the only adequately described fossil for which the stratigraphic horizon is known. Rocks correlated with the Crotty Quartzite also contain *Monograptus* but this has not yet been described. From the overlying Amber Slate no fossil has yet been described and figured. *Tentaculites* is common on some horizons associated with brachiopods. Ostracodes are also common, and include *Gillatia* (Opik, 1951) which occurs in the Upper Llandoverian in Victoria and at Canberra. *Monograptus* occurs in rocks equated to the Amber Slate. No fossils have been described from the overlying Keel Quartzite and an unnamed siltstone above it. However, from the Florence Quartzite, the next formation, twenty species have so far been figured (Gill, 1949; 1950). From its type area

Pleurodictyum megastomum, *Notoconchidium florencencis*, *Eatonia pleonecta* and *Protoleptostrophia plateia* have been described (Gill, 1950), and indicate a Lower Devonian age, at least for the top part of the formation. The affinities are with Victoria and New Zealand. From east of Queenstown, in a sandstone correlated with the Florence Quartzite, Gill (1949; 1952) has recorded *Pleurodictyum megastomum*, "*Lindstroemia*," *Pareatonia euplecta*, *Cyrtia tasmaniensis*, "*Spirifer*," *Nucleospira megalorhyncha*, *Strophonella australiensis*, *S. lyellensis*, *Protoleptostrophia plateia*, *Parmorthis vandiemeni*, *Maoristrophia banksi* and *M. careyi*, *Cheirurus* sp., *Dalmanites* aff. *wandongensis*, *Encrinurus* aff. *silverdalensis*, *Gravicalymene australis* and *Odontopleura* aff. *rattei*. This fauna occurs near the top of the formation and contains a number of species from the Lower Devonian of Victoria, New South Wales and New Zealand. Hill (1957) notes that *Pleurodictyum* appears in the Upper Gedinnian so that much of the Florence Quartzite may be Devonian although the base may be Silurian. The topmost formation of the Eldon Group, the Bell Shale, is richly fossiliferous, *Pleurodictyum megastomum*, *Australocoelia polyspera*, *Chonetes* aff. *ruddockensis*, *Eospirifer parahentius*, *Meristella bellensis*, *Maoristrophia banksi*, *M. careyi*, *Notanoplia pherista*, *Notoleptaena*, *Parmorthis* aff. *allani*, *Plectodonta bipartita*, *Cypricardinia*, *Proetus euryceps* and *Trimerus zeehanensis* having been recorded. This is a Lower Devonian fauna and has dominantly Victorian and New Zealand affinities, with the exception of *Australocoelia polyspera* which as Boucot and Gill (1956, p. 1178) have pointed out, is the first Malvinocaffric element so far recorded in Australasia. Gill (1953) has dealt with the relationship of the Australasian Lower Devonian faunas with those of other parts of the world and has remarked on the European affinities of many of the species. Hill (1957, p. 49) has also remarked on the "Eurasaustralian fauna" in the Lower Devonian.

Thus the Eldon Group contains rocks of Silurian and Lower Devonian age. Faunal affinities are unclear until the Lower Devonian when they are strongly with Victoria, New South Wales and New Zealand with one Malvinocaffric species

At Point Hibbs a richly fossiliferous limestone occurs from which *Favosites*? *bryani*, *F. goldfussi* and *Heliophyllum*? *chillagoense* have been described (Hill, 1943). Although this limestone has in the past been regarded as Gordon Limestone, new work established clearly that this is not so, it is probably Lower Devonian.

PERMIAN

Over two hundred species have been recorded from the Permian System in Tasmania but most of these are in need of revision. The Permian System consists of about 2.500 feet of sediments of the sub-greywacke suite with some orthoquartzite suite sediments whenever conditions became terrestrial. The impurity and poor sorting of the sub-greywacke suite sediments is attributed to the effects of glaciation on the near-by land surface and to the presence of numerous icebergs in the sea. Vulcanism is represented by bands of meta-bentonite in one formation. The succession (Table I) represents two alternations of marine and fresh-water conditions with other cycles superimposed on the main ones. Banding of the sediments is common. One cyclothem has so far been recognized (Banks and Hale, 1957). Evidences of local glaciation are abundant in the Sakmarian (and perhaps Upper Carboniferous) and glacial erratics occur in marine sediments at least as young as Kungurian.

The oldest Permian fauna is that of the oil shale of the Quamby Group. This oil shale contains the spore *Tasmanites punctatus*, the foraminifera *Ammodiscus multicinctus*, *Hyperamminoides acicula*, *Crithionina teicherti*, *Pelosina hemispherica*, *Ammobaculites woolnoughi* and *Digitina recurvata*, the pelecypods *Eurydesma hobartense*, *Aviculopecten sprentii*, the gastropod *Keeneia twelvetreesi*, and the asterozoan *Etheridgaster* cf. *clarkei*. Somewhat higher in the Quamby Group on Woody Island, Banks, Hale and Yaxley (1955) have recorded *Stenopora tasmaniensis*, *Fenestella dispersa*, ?*Streblascopora marmionensis*, *Calceolispongia*, *Jimbacrinus*, *Calcitornella stephensi* and *Eurydesma cordatum*. The Darlington Limestone of the overlying Golden Valley Group is richly fossiliferous with *Calcitornella stephensi*, *Geinitzina triangularis*, *Stenopora tasmaniensis*, *S. johnstoni*, *Eurydesma cordatum*, *Keeneia platyschismoides* and many other fossils including *Calceolispongia* spp. If correlation with the Callytharra Limestone in Western Australia on the basis of *Calcitornella*, *Geinitzina* and other foraminifera is correct, the Darlington Limestone is Lower Artinskian (Teichert, 1941—for correlation of Callytharra Limestone). Other formations of the Golden Valley Group contain rich faunas including at least some of those species mentioned above.

The flora of the Mersey Group contains *Glossopteris ampla*, *G. browniana*, *G. indica*, *G.*

ovata, *Gangamopteris angustifolia*, *G. cyclopteroides*, *Noeggerathiopsis hislopi*, and the sporomorphs *Marsupiopollenites scutatus*, *Nuskoisporites rotatus*, *Pilasporites calculus*, *Pityosporites giganteus*, *Punctatisporites gretensis*, *Verrucosisporites leopardus*, *V. pseudoreticulatus* and *Vestigiosporites rudis* (Balme and Hennelly, 1956). The sporomorphs quoted are restricted to the Greta Coal Measures in New South Wales. Another sporomorph *Marsupiopollenites sinuosus* occurs in New South Wales only in the Newcastle and Tomago Coal Measures, and in Tasmania in the Mersey Group (Coal Measures). Other plants and sporomorphs also occur but are not critical. One vertebrate only is recorded and even this is doubtful. The flora is typical of the Gondwanaland countries.

The fauna of the Cascades Group is very rich. It includes *Cladochonus*, *Thamnopora*, *Euryphyllum*, *Stenopora pustulosa*, *S. crinita Stenodiscus moniliformis*, *Polypora woodsi*, *Fenestella granulifera*, *Lyroporella*, *Taeniothaerus subquadratus*, *Strophalosia jukesi*, *S. typica*, *Anidanthus springsurensis*, *Trigonotreta stokesii*, *Cancrinella farleyensis*, *Eurydesma cordatum* var. *sacculum*, *Aviculopecten squamuliferus*, *Calceolispongia noetlingi*, *Pterotoblastus* and *Conularia derwentensis*. *Calcitornella* also occurs at least in the lower part of the group. This fauna indicates correlation with the Maitland Group of New South Wales and the Cattle Creek and/or Ingelara Formations in Queensland (Banks, 1957 a) which are thought to be Artinskian. The fauna is dominantly eastern Australian but Western Australian elements such as *Lyroporella*, *Taeniothaerus subquadratus*, *Calceolispongia noetlingi* and *Pteroblastus* also occur in it. Recently Crockford (1957) has recorded *Stenodiscus*, a genus first described from Tasmania, from Western Australia. Also in the Cascades Group is a bryozoan which externally resembles *Streblascopora marmionensis* (Crockford, 1957) from Western Australia

The fauna of the "Woodbridge" Group is neither so rich nor so well known as that of the Cascades Group. It includes *Stenopora crinita*, *Chaenomya etheridgei*, *Eurydesma cordatum* var. *sacculum*, *Warthia micromphala*, *Hyolithes lanceolata*, and *Tribrachyocrinus tasmaniensis*. In general a correlation with the middle and upper parts of the Maitland Group of New South Wales is indicated and the fauna is entirely Eastern Australia.

The fauna of the Ferntree Group is very poor but enough to indicate marine deposition. The flora of the Cygnet Formation contains *Glossopteris angustifolia*, *G. browniana*, *Gangamopteris angustifolia*, *G. cyclopteroides* and *Vertebraria australis* as well as the sporomorphs *Acanthotriletes tereteangulatus* and *Lueckisporites fusu*. The former sporomorph occurs only in the Newcastle Coal Measures in New South Wales and the latter in only the Newcastle and Tomago Coal Measures. Other plants and sporomorphs also occur. The known flora is entirely a Gondwanaland one. Balme and Hennelly (1956) have suggested a correlation between the Newcastle Coal Measures and the Liveringa Formations, the top of which contains plant remains and is considered by Thomas and Dickens (1954) to be Tartarian.

The faunas of the Tasmanian Permian are dominantly eastern Australian in affinity but there are similarities with Western Australia and Timor at least from some time in the Sakmarian (Quamby Group) until the end of the Artinskian (Cascades Group). In the three topmost groups no Westralian elements are known. The Westralian elements in the Tasmanian Permian are lacking in New South Wales and Queensland and this suggests a marine connection south of the present continent of Australia. In conjunction with the evidence of different Westralian elements in the Queensland Permian, this suggests that at times in the Permian the Australian continent was entirely surrounded by sea (see also Teichert 1951, p. 87). Some Gondwana elements are also present.

TRIASSIC

The stratigraphy of the Triassic rocks of Tasmania is poorly known. At the base is a quartz sandstone and higher up are quartz sandstones and siltstones, followed by coal seams associated with claystones and feldspathic sandstones which are possibly partly of pyroclastic origin (see Banks, 1952).

Three vertebrates only are known from the Triassic. Two captorhinid femora of Lower Triassic aspect occur in quartz sandstone isolated in a fault block and two fish *Acrolepis hamiltoni* and *A. tasmanicus* occur in quartz siltstones of unknown stratigraphic position.

The flora is quite a rich one especially in the coal measures. There are unidentified lycopods in the sandstone and siltstone units in several places, and a lycopod strobilus, *Lepidostrobus muelleri*, has been recorded, but must be considered doubtful. Three sphenopsids, *Neocalamites* *carrerei*, *N. hoerensis* and *Phyllotheca australis* are known. Ferns are common, the main one being *Cladophlebis australis* but *C. johnstoni* and *C. tasmanica*, *Chiropteris tasmanica*, *Asterotheca* cf. *hillae* and *Gleichenia dubia* also occur. Pteridosperms are very common and include *Thinnfeldia acuta*, *T. feistmanteli*, *T. odontopteroides*, *T.* cf. *talbragarensis*, *Johnstonia dentata*, *J. coriacea*, *J. trilobita*, *Sphenopteris lobifolia* and *S. morrisiana*. Other fern-like fronds include *Cardiopteris tasmanica*, "*Pecopteris*" *lunensis* and ?*Phlebopteris alethopteroides*. Cycads are very common and include *Doratophyllum tenisonwoodsi*, *Linguifolium diemenense*, *L. lilleanum*, *Sphenozamites feistmantelli*, *Otozamites mandeslohi*, ? *Pseudoctenis*, *Pterophyllum inconstans*, *P. risdonensis*, *P. strahani*, *Taeniopteris carruthersi*, *T. morrisiana* and *T. polymorpha*. Ginkgoales are present and common on some horizons. They include *Ginkgo digitata*, *G. hobartensis*, *G. salisburoides*, *Ginkgoites bidens*, *G. australis*, *Czekanowskia tenuifolia*, *Pteruchus annularoides* and *Phoenicopsis elongatus*. *Sagenopteris moribunda* and *S. tasmanica* complete the known flora. All Tasmanian identifications are based on leaf form and venation. As pointed out by Jones and de Jersey (1947, p. 81) there are many species in common between the Tasmania flora and that of the Ipswich Coal Measures of Queensland. Of the forty-five species known in Tasmania, eighteen occur in that formation and some of them have a restricted stratigraphic distribution within it. Five species occur in Tasmania and the Wianamatta Group in New South Wales, five in the Narrabeen Group, four in New Zealand, five in the Upper Beaufort Beds, nine in the Molteno Beds in South Africa and seven in Argentina. There are six species common to the Tasmanian Triassic and that of Bald Hill, near Bacchus Marsh, Victoria and six with the Lower Jurassic flora of Victoria.

Thus the Triassic of Tasmania can in part at least be correlated with the Ipswich Coal Measures of Queensland which is considered by Jones and de Jersey (1947) to be equivalent to the Upper Narrabeen, Hawkesbury and Wianamatta Groups in New South Wales. Browne (David, 1950, p. 431) considered the Lower Wianamatta to be basal Upper Triassic on evidence of the vertebrates so that the Tasmanian floras might be considered as more or less Middle Triassic with both Lower and Upper Triassic beds possibly present. The flora shows strong relationship at the specific level with Eastern Australia, with some relationship to floras in New Zealand, South Africa and Argentina. South African affinities are strengthened by the presence of the captorhinid femora. The Argentinian relationship is of considerable interest in view of the discovery (Harrington, 1955) of a strongly Eastern Australian fauna in the Permian south of Buenos Aires.

TERTIARY

The Tertiary flora of Tasmania was large. Numerous forms have been differentiated on leaf form and venation but few cuticle studies have been made. Silicified wood is common but little has been described. Coniferous twigs and cones have recently been re-examined. Fruits and seeds are common but few have been critically examined. Within the last ten years palynological studies by Cookson and others have given more exact information on the flora than was previously available. The plant remains are mainly found in lacustrine, fluviatile, paludal and spring deposits of sands, clays and lignite but some also occur in marine deposits. Most of the freshwater beds were deposited in large fault trough lowlands.

The oldest flora known is that occurring in lignites near Launceston and Ouse. These contain the pollens *Trisaccites micropterus*, *Ephedra notensis*, *Microcachrydites antarcticus*, *Araucariacites australis*, *Phyllocladus palaeogenicus*, *Dacrydiumites florinii*, *Banksiaedites*, *Beaupreaidites verrucosus*, *Casuarinidites cainozoicus*, *Dacrycarpites australiensis*, *Myrtaceadites eugenioides*, *M. mesonesus*, and *M. parvus*, *Podocarpus praecupressinus*, *Proteacidites* cf. *crassus*, *P. parvus*, *Triorites harrisii* and *Nothofagus*. The first two of these pollens are present in beds older than the Oligocene brown coals of Victoria but not in those coals (Gill and Banks, 1956, p. 12). For this reason this flora is considered as of Lower Tertiary age. At Geilston Bay *Araucaria derwentensis* and *A. johnstonii* occur as cones and twigs and *Arthrotaxis tasmanica* as cones. Leaves of *Podocarpus* (*Dacrycarpus*) and *Podocarpus* (*Polypodiopsis*) *brownei* (Selling, 1950) are associated with basalt at Burnie and podocarpaceous wood (*Cupressinoxylon hookeri* Arber, 1904) occurs between basalt flows at Macquarie Plains. *Araucaria imbricatiformis* is based on cones from Macquarie Harbour in beds from which Johnston (1888) recorded *Acacia meiringii* and *Eucalyptus milligani*, based on leaf impressions. The only other place where Johnston recorded either *Eucalyptus* or *Acacia* was Mt. Bischoff where he recorded *E. kayseri*. If Johnston's determinations are correct and the range of these two genera as known in Australia (Cookson, 1954) apply to Tasmania the Macquarie Harbour beds may be late Pliocene or later in age. Thus throughout the Tertiary in Tasmania the flora was dominantly of native conifers, proteaceans and myrtaceans with other species related to those now living further north and in New Guinea and New Caledonia (Cookson, 1953).

Tertiary vertebrates are rare but the oldest marsupial in Australia, *Wynyardia bassiana*, occurs in Upper Oligocene beds near Wynyard, where it is associated with *Prosqualodon davidi*, a whale of South American affinities, and shark's teeth.

Nearly three hundred species of marine invertebrates have been described from the Tasmanian Tertiary. Most of these are in need of revision. Marine beds mainly sandstones and calcarenites, occur as a coastal fringe around the north-west coast and on the Bass Strait islands. The oldest beds contain *Sherbornina atkinsoni*, *Eucrassatella oblonga* and many other species. These are overlain by beds with numerous *Turritella* spp., *Cellepora gambierense*, *Lovenia forbesi*, *Prosqualodon*, *Wynyardia* and *Aturia australis*. Younger beds with *Lepidocyclina (Trybliolepidina)* occur elsewhere, and are probably late Lower Miocene. No further marine beds occur until the Upper Pliocene or Pleistocene beds of Flinders Island with *Milthia grandis*. The invertebrate faunas are distinctly Bassian in character.

QUATERNARY

The fauna and flora of these superficial deposits are essentially modern and Tasmanian. The only group that justifies comment is that of the marsupials. These included *Diprotodon australis*, *Nototherium victoriae*, *N. mitchelli*, *Thylacaleo*, *Thylacinus*, *Phascolonus* and other extinct forms. Many of these were of considerable size. The only fossil bird from Tasmania is an emu from Pleistocene swamp deposits.

SUMMARY

Worm tubes and casts occur in a pre-Middle Cambrian sequence of quartzites, siltstones, dolomites, conglomerates and basic dykes and sills which overlie unconformably a sequence of schists, quartzites, sheared conglomerates and amphibolites.

Rocks of the *Ptychagnostus gibbus* Zone of the Middle Cambrian unconformably overlie older rocks. They form part of a thick sequence of rocks of the sub-greywacke and greywacke suites associated with volcanic and pyroclastic rocks, cherts and rare dolomites and limestones which extend into the Upper Cambrian at least up to the *Glyptagnostus reticulatus* Zone. This sequence consists of at least eleven cycles of sedimentation. It is intruded by slightly transgressive sheets of pyroxenite, now largely serpentinized. The faunas show affinities with those of Victoria, Queensland and the Acado-Baltic province with some Appalachian and East Asian elements especially late in the Middle Cambrian and early in the Upper Cambrian.

Ordovician rocks rest unconformably on older rocks and form a single cycle of sedimentation over 6,000 feet thick in parts. They belong dominantly to the orthoquartzite suite. The oldest known fauna is Middle Canadian in age and the youngest possibly Richmondian. In the Lower Ordovician affinities are with East Asia and North America with some similarity to faunas in New South Wales, Central Australia and Great Britain. During the Middle and Upper Ordovician the affinities are with North America and the Baltic province.

The Silurian and Lower Devonian rocks form a single major cycle with three minor cycles superimposed on it. The sequence is over 6,000 feet thick and consists of sandstones, siltstones, limestones and rare conglomerates of the orthoquartzite suite. The Silurian fauna is poorly known but the Lower Devonian fauna is very rich and shows strong affinities with that of Victoria and New Zealand, less with New South Wales, some with Europe, a little with North America and there is one species of the Malvinocaffric province. The change in affinity from dominant North American in the Ordovician to the dominant south-east Australasian in the Silurian (?) and Lower Devonian may be at least partly due to the changes in the palaeogeography of eastern Australia resulting from the Benambran Orogeny in the late Ordovician or early Silurian.

The Precambrian, Lower and Middle Palaeozoic rocks were folded, faulted and intruded by granite, probably in the Devonian. Unconformably on these were deposited Permian rocks. The Permian System consists of two alternations of marine sediments of the sub-greywacke suite and fresh-water sediments of the orthoquartzite suite resting in many places on a basal tillite. The total thickness is probably about 2,500 feet. The oldest fauna is probably Sakmarian and the youngest Kungurian or Kazanian. The fresh-water intervals occurred in the Middle Artinskian and Tartarian approximately and are roughly contemporaneous with those in New South Wales. The flora contains nothing but Gondwanaland elements. The fauna is dominantly eastern Australian with some Westralian-Timor elements and some Gondwanaland elements. The Westralian-Timor elements are present from Sakmarian to Artinskian but no later. This exclusion of the Westralian elements coincides with the beginning of a new cycle of sedimentation in Tasmania and this may be correlated with the changes in palaeogeography consequent upon fold movements near the end of the Artinskian in New South Wales or to lowering of sea level associated with the renewed onset of glaciation which could well have broken the earlier marine connection south of Australia.

The Triassic System consists of several thousand feet of quartz sandstone, and siltstones, coal seams and tuffaceous (?) sandstones. The fauna is very poor but includes two captorhinid femora of South African affinities. The flora of the coal measures indicates an approximately Middle Triassic age but may extend down into the Lower Triassic and up into the Upper Triassic. Strongest affinities are with Queensland South Africa and Argentina.

The Triassic and older sediments were intruded by sheets and dykes of dolerite. A surface including dolerite was bauxitized and later faulted. In the fault troughs freshwater sediments including lignite accumulated. The lignite contains pollens considered to indicate a Lower Tertiary age. The flora of the Tertiary consisted dominantly of native confiers, with myrtaceans, proteaceans and other plants, some of which show a relationship to those growing in northern Australia, New Guinea and New Caledonia now.

In the Upper Oligocene and Lower Miocene several hundred feet of marine sands and calcarenites were deposited as a fringe around parts of the Bass Strait coast. The faunas are dominantly southeast Australian and include the oldest marsupial from Australia in the Upper Oligocene. This appears to have been related to the present brush possum. Upper Pliocene or Lower Pleistocene marine sediments are also known from some of the Bass Strait islands. Basalts in Tasmania are pre-Upper Oligocene and post-Lower Miocene, probably Pliocene.

Glaciation affected Tasmania in the Pleistocene when the flora was more or less as at present. The fauna included extinct giant marsupials and emus as well as living species.

REFERENCES

Arber, E.A.N., 1904, "*Cupressinocylon hookeri* sp. nov. a Large Silicified Tree from Tasmania." *Geol. Mag.*, **1** :7-11.

Balme, B.E. and Hennelly, J.P.F., 1956, Trilete Sporomorphs from Australian Permian Sediments,. *Aust. Journ. Bot.*, **4** (3): 240-260.

Banks, M.R., 1952, Permian, Triassic and Jurassic Rocks in Tasmania. XIX *Int. Geol. Cong., Algiers.* Gondwana Symp. 63-88.

————, 1956, The Middle and Upper Cambrian Series (Dundas Group and its Correlates) in Tasmania. XX *Int. Geol. Cong., Mexico.* Cambrian Symp., Part II : 165-212.

————, 1957a, Recent Additions to Knowledge of the Permian System in Tasmania. XX *Int. Geol. Cong., Mexico.* Gondwana Symp., (in press).

————, 1957b, An Outline of the Geological History and Mineral Resources of Tasmania in "Introducing Tasmania." (in press).

Banks, M.R. and Hale, G.E.A., 1957, A Type Section of the Permian System in the Hobart Area. *Pap. Proc. Roy. Soc. Tas.*, **91**: 41-64.

Banks, M.R., Hale, G.E.A. and Yaxley, M.L., 1955, Permian Rocks from Woody Island, Tasmania. *Pap. Proc. Roy. Soc. Tas.*, **89**: 219-230.

Banks, M.R. and Johnson, J.H., 1957, *Maclurites* and *Girvanella* in the Gordon River Limestone (Ordovician) of Tasmania. *Journ. Pal.*, **31** (3) : 632-640.

Boucot, A.J. and Gill, E.D., 1956, *Australocoelia*, a new Lower Devonian Brachiopod from South Africa, South America and Australia. *Journ. Pal.*, **30** (5) : 1173-1178

Brown, I.A., 1947, Lower Ordovician Brachiopods from Junee District, Tasmania. *Journ. Pal.*, **22** (1) : 35-39.

————, 1952, Ordovician Limestone at Bowan Park, N.S.W. *Aust. Journ. Sci.*, **15** (1) : 29-30.

Cookson I.C., 1953, On *Macrozamia hopeites* -an Early Tertiary Cycad from Australia. *Phytomorphology*, **3** (3) : 306-312.

————, 1954, The Cainozoic Occurrence of *Acacia* in Australia. *Aust. Journ. Bot.*, **2** (1) : 52-59.

Cookson, I.C., 1957, On Some Australian Tertiary Spores and Pollen Grains that Extend the Geological and Geographical Range of Living Genera. *Proc. Roy. Soc. Vic.*, **69** : 41-53.

Cookson, I.C. and Pike, K., 1954, The Fossil Occurrence of *Phyllocladus* and two other Podocarpaceous Types in Australia. *Aust. Journ. Bot.* **2** (1) : 60-68.

Crockford, J., 1951, The Development of Bryozoan Faunas in the Upper Palaeozoic of Australia. *Proc. Linn. Soc. N.S.W.*, **76** : 105-122.

———, 1957, Permian Bryozoa from the Fitzroy Basin, Western Australia. *Bur. Min. Res. Bull.*, **34** : 1-91.

David, T.W.E., 1950, Geology of the Commonwealth of Australia. vol. I. Ed. W.R. Browne, Arnold, London.

Etheridge, R., 1896, Description of a Small Collection of Tasmanian Silurian Fossils. *Tas. Dept. Mines Secy. Rept.* (1895-96).

Etheridge, R., 1904, Trilobite Remains Collected in the Florentine Valley, West Tasmania, by Mr. T. Stephens, M.A., *Rec. Aust. Mus.*, **5** (2).

Gill, E.D., 1948, Eldon Group Fossils from the Lyell Highway. Western Tasmania. *Rec. Qu. Vic. Mus., Launc.*, **11** (2) : 57-74.

———, 1950, Preliminary Account of the Palaeontology and Palaeoecology of the Eldon Group Formations of the Zeehan Area, Tasmania. *Pap. Proc. Roy. Soc. Tas.*, (1949) : 231-258.

———, 1952 , Palaeogeography of the Australian-New Zealand Region in Lower Devonian Time. *Roy. Soc. N.Z.*, **80** (2) : 171-185.

———, 1953, Relationship of the Australasian and North African Lower Devonian Faunas. XIX *Int. Geol. Cong. Algiers.* Section II, Fasc. II : 87-92.

Gill, E.D. and Banks, M.R., 1956, Cainozoic History of Mowbray Swamp and other Areas of North-Western Tasmania. *Rec. Qu. Vic. Mus., Launc.*, N.S., **6** : 1-42.

Harrington, H.J., 1955, The Permian *Eurydesma* Fauna of Eastern Argentina. *Journ. Pal.*, **29** (1) : 112-128.

Hill, D., 1943, A Reinterpretation of the Australian Palaeozoic Record, based on a Study of the Rugose Corals. *Roy. Soc. Queens. Proc.*, **54** (6) : 53-66.

———, 1951, The Ordovician Corals. *Roy. Soc. Queens. Proc.*, **62** : 1-28.

Hill, D., 1955, Ordovician Corals from Ida Bay, Queenstown and Zeehan, Tasmania. *Pap. Proc. Roy. Soc. Tas.*, **89** : 237-254.

———, 1957, The Sequence and Distribution of Upper Palaeozoic Coral Faunas. *Aust. Jour. Sci.*, **19** (3a) : 42-61.

Johnston, R.M., 1888, Systematic Account of the Geology of Tasmania. *Hobart.*

Jones, O.A. and de Jersey, N.J., 1947, The Flora of the Ipswich Coal Measures-Morphology and Floral Succession. *Univ. of Queens. Papers, Dept. Geol.*, **3** N.S., (3).

Kobayashi, T., 1940a, Lower Ordovician Fossils from Junee, Tasmania. *Pap. Proc. Roy. Soc. Tas.*, (1939) : 61-66.

———, 1940b, Lower Ordovician Fossils from Caroline Creek, near Latrobe, Mersey River District, Tasmania. *Pap. Proc. Roy. Soc. Tas.*, (1939) : 67-76.

Opik, A.A., 1951, Notes on the Stratigraphy and Palaeontology of Cambrian, Ordovician and Silurian Rocks in Tasmania. *Bur. Min. Res. Recs.*, 1951-55.

———, 1956, Cambrian Palaeogeography of Australia. XX *Int. Geol. Cong., Mexico. Cambrian Symposium*, pt. II: 239-284.

Ross, R.J., 1951, Stratigraphy of the Garden City Formation in North-eastern Utah and its Trilobite Faunas. *Peabody Mus. Nat. Hist.*, Yale, Bull. **6**.

Selling, O., 1950, Some Tertiary Plants from Australia. *Svensk. Bot. Tidsk.*, **44** : 551-561.

Stubblefield, C.J., 1950, *Dimastocephalus* Stubblefield 1950, a synonym of *Carolinites* Kobayashi, 1940. *Ann. Mag. Nat. Hist.* (12), **3** (29).

Teichert, C., 1941, Upper Palaeozoic of Western Australia; Correlation and Palaeogeography. *Bull. Amer. Ass. Pet. Geol.*, **25** : 271.

———, 1951, The Marine Permian Faunas of Western Australia. *Palaont. Zeitsch.* **24** : 76-90.

Teichert, C. and Glenister, B.F., 1953, Ordovician and Silurian Cephalopods from Tasmania, Australia. *Bull. Amer. Pal.*, **34** (144).

Thomas, D.E. and Singleton, O.A., 1956, The Cambrian Stratigraphy of Victoria. XX *Int. Geol. Cong., Mexico. Cambrian Symposium*, **2** : 149-163.

Thomas, G.A. and Dickins, J.M., 1954, Correlation and Age of the Marine Permian Formations of Western Australia. *Aust. Journ. Sci.*, **16** : 219-223.

ON THE CONSOLIDATION AND THICKNESS OF DEEP-SEA SEDIMENTS

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(Abstract)

One of the big problems of marine geology is the apparent thinness of sediments in deep-sea basins; 100 to 500 m of unconsolidated sediments are typically reported from seismic surveys.

Application of the theory of consolidation of clays, and settlement analysis techniques, from the field of soil mechanics to the problems of deep-sea sediments allows the following conclusions:

(1) In areas where red clay is the only deposit the reduction of sediment pore space due to gravitational consolidation should result in porosities of the order of 35% at depths of about 400 m; at about this porosity, pressure-chemical effects in the de-watered sediment should result in lithification with marked increase in seismic velocity.

(2) In areas where globigerina ooze has accumulated since the Cretaceous, porosity will decrease with depth at a slower rate than in clay areas, but lithification of the foraminiferal oozes with age and pressure can result in marked seismic velocity increases; the discovery of deep-sea limestone in the form of lithified globigerina oozes ranging in porosities from 5 to 68% and in probable compressional elastic wave velocities from 2 to 5.5 km/sec indictes the possible velocity variations. Various combinations of (1) and (2) are possible and probable in various areas.

(3) Settlement analysis techniques allow computation of total thicknesses of unconsolidated sediments needed to form present consolidated deposits; approximately 1000 m of red clay will consolidate to 500 m and slightly over 7.3 km will consolidate to about 3 km; at 400 m depth the red clay, at rates of deposition from 1 cm to 0.25 cm per 1000 years, should be from 80 to 320 million years old.

Seismic surveys in the Pacific Basin by Raitt, Shor, and Fisher of the Scripps Institution, and in the Gulf of Mexico - Caribbean area by Ewing, Worzel, Ericson, Heezen, and others of the Lamont Geological Observatory indicate the presence of intermediate velocity layers between the unconsolidated sediment and basaltic basement rock which in some areas, can be explained as normal, expected consolidation of the present types of sediment. The present "sediment thickness" in the deep-sea basins is the total thickness of these layers. A measurement of sediment thickness at any time-horizon of the past, or future, should show about the same "anomalously thin" value for the topmost part of the slowly consolidating sediment.

If the above concepts are true then the geochemical balance which calls for about 2½ km of solids on the sea floor (Kuenen, 1950), recent seismic discoveries, and engineering theory fall approximately into line.

SUMMARY OF THE STRATIGRAPHY OF THE SOUTHERN RYUKYU-RETTO†

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The Ryukyu-retto is an arcuate chain of islands that extends from Kyushu, the southernmost main island of Japan, southward about 1,115 kilometers to within 100 kilometers of Taiwan (Formosa) (Fig. 1). The arc is bordered on the east by the Ryukyu Trench which has a maximum depth of 7,507 meters, southeast of Okinawa-jima.

This discussion is principally concerned with Okinawa-jima and neighboring small islands, the islands of the Miyako-gunto, and the islands of the Yaeyama-gunto which together compose the southern sector of the Ryukyu island chain. These islands have significant stratigraphic and structural relationships to each other, to Japan, and to Taiwan.

Several Japanese geologists carried out geological investigations of these islands before World War II. The most comprehensive report was by Shoshiro Hanzawa in 1935. This publication, in English, has served as a basis for later work and for correlation with other areas. From 1946-1949 the U.S. Geological Survey in cooperation with the Corps of Engineers undertook detailed geologic and soils mapping of Okinawa-jima. In 1955-1956 similar work was done on Ishigaki-jima in the Yaeyama-gunto and in 1956 on the Miyako- gunto. Much of the data reviewed here is based on material gathered by U.S. Geological Survey geologists assigned to these projects.

The rocks of the southern Ryukyu-retto range in age from Paleozoic to Recent (Fig. 2). Mesozoic rocks have not been recognized although some igneous intrusions and metamorphic rocks could be of Mesozoic age. Because of tectonic disturbances and varying local conditions the stratigraphic sections differ considerably in the island groups and on individual islands of the same group.

Metamorphic rocks supposedly of Paleozoic age compose a foundation upon which Tertiary and Quaternary sediments have been deposited. These rocks consist of chert, sandstone, phyllite, greenstone, and recrystallized limestone in northern Okinawa-jima. Schist, phyllite, hornfels, quartzite and chert crop out on Ishigaki-shima and Iriomote-jima in the Yaeyama-gunto. Glaucophane schist is an important rock type on Ishigaki-shima. Similar metamorphic rocks probably form the foundation of other islands of the southern Ryukyu-retto, even though the rocks do not crop out.

The metamorphic rocks are all highly contorted and much faulted. Their thickness is unknown but is probably measured in thousands of feet. Faulting, including thrust faulting, so complicates the geology that the stratigraphic sequence is difficult to determine. The only clue to the age of the foundation rocks is from Okinawa-jima where Hanzawa identified fusilinids of Permian age from a crystalline limestone, now called the Motobu limestone, which is associated with the chert, greenstone, and phyllite. However, this limestone is in thrust contact with the other metamorphic rocks on Okinawa-jima so stratigraphic relationships are not definite. No fossils were found in the metamorphic rocks of the Yaeyama-gunto.

Two islands of the Yaeyama-gunto, Ishigaki-shima and Kobama-jima, have small patches of conglomerate, sandstone, and limestone of late Eocene age (Tertiary b). These sedimentary rocks, called the Miyara formation or Miyara beds (Hanzawa, 1935) overlie the metamorphic rocks unconformably. They have been faulted and tilted, but not metamorphosed. The conglomerate contains pebbles from the underlying metamorphic rocks, but no granitic pebbles have been found. Foraminifera and calcareous algae are abundant in the limestone. The maximum thickness of the Miyara formation is estimated to be 112 meters on Ishigaki-shima. The Eocene strata on Ishigaki-shima are intruded by andesite and some of the sandstone is tuffaceous. In places, on Ishigaki-shima, volcanic rocks consisting of lava, tuff, and breccia overlie upper Eocene rocks, generally unconformably. Their age is not known but is most likely latest Eocene to Miocene. Tertiary volcanic rocks are

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† Publication authorized by the Director, United States Geological Survey.

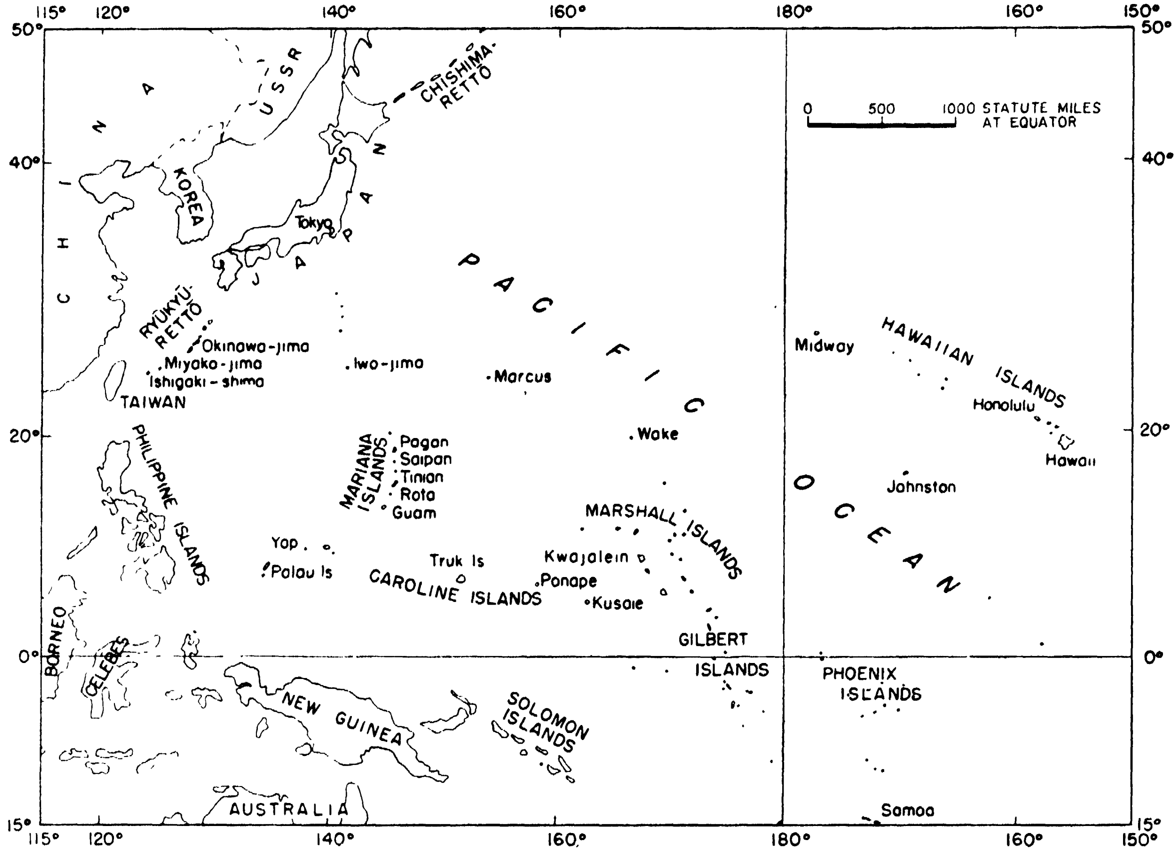


Fig. 1.

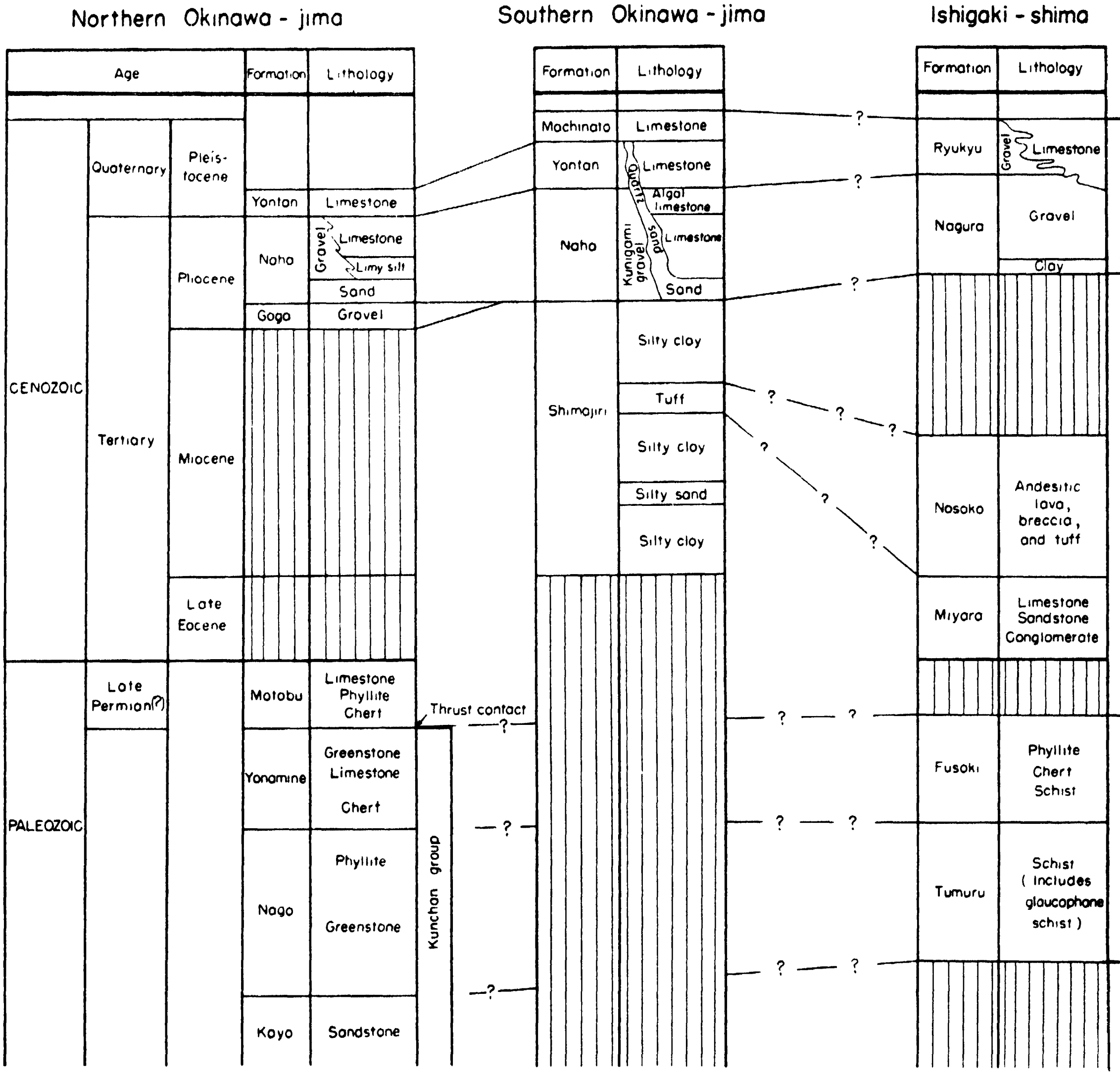
also present on other islands in the Yaeyama-gunto: Oligocene rocks, if present, have not been identified in the southern part of the Ryukyu-retto.

Miocene strata are present on Okinawa-jima, in the Miyako-gunto, and in the Yaeyama-gunto. On Okinawa-jima the Miocene strata are mostly silty calcareous clay with minor amounts of silty sand and vitreous tuff and are known as the Shimajiri formation. Some beds are fossiliferous. These rocks crop out only in southern Okinawa-jima where they have a known thickness measurable in thousands of feet in some places. One drill hole penetrated 4,000 feet of Shimajiri sediments in southern Okinawa-jima and still the base had not been reached. However, the Shimajiri formation is completely absent in the northern part of the island.

Beds similar in age and lithology to the Shimajiri formation are present in the Miyako-gunto, but have not been described from the Yaeyama-gunto. However, on Iriomote-jima and Yonaguni-jima a thick sandstone sequence containing thin coal seams may be a correlative of the Shimajiri formation. These sandstone beds, called the Yaeyama coal-bearing formation (Hanzawa, 1935), may represent a coarse phase of deposition of Miocene material. Ishigaki-shima has no definite Miocene deposits although the thick sequence of volcanic rocks which were deposited under marine conditions might be Miocene in age. Hanzawa describes similar volcanic rocks on Iriomote-jima which he believes grade upward into the sandstones of the Miocene Yaeyama coal-bearing formation.

Pliocene rocks have been recognized on Okinawa-jima and in the Miyako-gunto and are probably also present in the Yaeyama-gunto. However, the boundary between the Pliocene and Pleistocene is indefinite and deposition of some

Diagrammatic Stratigraphic Columns for Okinawa-jima and Ishigaki-shima



After Flint and Saplis (preliminary)

After Flint and Saplis (preliminary)

Fig. 2.

formations probably began in late Pliocene time and continued into Pleistocene time. In the Yaeyama-gunto and on Okinawa-jima the Pliocene and Pleistocene rocks are a series of reef limestone and clayey gravels. The depositional sequence is different on different islands and even in different places on the same island. Local unconformities are common. For example on Ishigaki-shima, in places the sequence begins with a grey fossiliferous clay. In one locality deer antlers were found in the uppermost part of the clay. The gray clay is generally overlain by clayey non-calcareous gravel, and the gravel is overlain by or interbedded with reef limestone. In a few places a late phase of the gravel overlies limestone. A somewhat similar situation occurs on Okinawa-jima. However, here at least three different periods of limestone deposition have been recognized and the older one, the Naha limestone, may be equivalent, in part, to the gray clay or some of the gravel deposition on Ishigaki-shima.

The Yontan limestone which forms a thin veneer over the older Naha limestone on Okinawa-jima, is probably largely equivalent to the reef limestones on Ishigaki-shima which are still called the Ryukyu limestone as originally named by Hanzawa.

Granite, granodiorite and granophyre have intruded the metamorphic rocks of Ishigaki-shima. Whether the main intrusions occurred before or after the deposition of the upper Eocene rocks cannot be determined, but to date, no granitic material has been found in the Eocene conglomerates. Some granophyre is known to be later than Eocene but it is not necessarily the same age as the principal intrusions. Igneous dikes are present on Okinawa-jima and a rhyolite porphyry might be related to the granite of Ishigaki-shima.

Fossil collections recently made from the southern Ryukyu islands have not yet been studied in detail. Additional studies of foraminifera and calcareous algae from the limestone of Eocene age are planned. Marine invertebrates from gray clays on Ishigaki-shima will be studied in more detail and carbon 14-age determination of woody material from this formation is underway. Vertebrate fossils including deer bones and bones of wild boar may help determine the time of existence of land bridges between islands and the main land.

Fossils from Miyako-jima, which may help in relating the Yaeyama-gunto, Miyako-gunto and Okinawa-jima have not yet been studied. Additional information is needed from such places as Iriomote-jima and Yonaguni-jima in order to help correlate with Taiwan.

Correlation of upper Pliocene and Pleistocene rocks will have to depend considerably on interpretation of local unconformities, stands of the sea as determined from both deposits and physiographic features, and interpretation of tectonic events. The islands of the Miyako-gunto are expected to give considerable helpful information in regard to these events.

At this time little additional information can be given in regard to correlation with Taiwan and Japan. The correlation of the metamorphic rocks of the southern Ryukyu islands with the Paleozoic Sambagawa metamorphic rocks of Japan made many years ago by Japanese geologists still seems reasonable. The granite intrusions of Ishigaki-shima likely correlate with similar intrusions in Japan, but even in Japan differences of opinion exist regarding times of intrusion. However, they most likely correlate with late Mesozoic or early Tertiary intrusive activity in Japan.

The Eocene rocks of Ishigaki-shima are well dated by the fossils which they contain and correspond to the Tertiary b horizon of other Asian areas. Additional study of the distribution of the Miocene rocks and their fossils may help in determining the position of the land mass or masses which furnished the material and the relation of these beds to those in Taiwan.

Although, the Tableland gravel of Taiwan has considerable resemblance to gravel deposits of Ishigaki-jima and Okinawa-jima there are many problems to be worked out before the exactness of correlation can be determined. This is also true for the reef limestones.

Correlation of the stratigraphic section of the southern Ryukyu islands, especially to Taiwan, as a first link in making other correlations, is a most interesting and complex problem and one to which members of the Pacific Science Congress can undoubtedly contribute much toward solving now and in the future.

REFERENCE

Hanzawa, Shoshiro, 1935, Topography and geology of the Riukiu Islands: *Sci. Repts. of Tohoku Imp. Univ.*, Second Series (Geology) **17**.

STRATIGRAPHY OF TAIWAN AND ITS CORRELATION WITH THE ADJACENT AREAS†

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(Abstract)

The Tananao schist developed in the eastern flank of the backbone range consists of black schist, green schist, crystalline limestone, and paragneiss, attaining about 6,000 m in thickness. Permian fusulinids and corals were found from some limestones, but the formation may include younger and older sediments. Metamorphosed basic rocks, orthogneiss, and migmatite are found within the formation.

Flanking unconformably on the Tananao schist are isolated patches of possible Mesozoic phyllite, slate, and sandstone, among which two are grouped into the Pihou (2,900 m thick) and Tafun (2,700 m thick) formations. The basal conglomerate of the Pihou formation contains boulders from both the Tananao schist and the orthogneiss. Hence the metamorphism took place during the Nanao orogeny represented by this unconformity. Recently a series of tuffaceous sandstone, graywacke, and black shale with Jurassic (?) ammonites was encountered in a bore hole near the coast to the west of Chiayi below the depth of 1,466 m from the coastal plain surface.

The Eocene-Oligocene slate and sandstone of the Suo and Urai groups (up to 3,000 m thick) lie unconformably either on both the Pihou and Tafun formations or on the Tananao schist. *Astrocoenia* and *Elephantaria* occur in limestone boulders of the basal conglomerate, and *Nummulites*, *Assilina*, and *Discocyclina* in its matrix and the overlying strata. Therefore the Taiping orogeny represented by the unconformity must have taken place before the middle Eocene. The Yuantoushan migmatization may be simultaneous with it. *Orbulina* and other smaller foraminifers as well as *Schizaster* and mollusks are occasionally found in the upper formations of both groups.

The Neogene occupies three distinct areas in Taiwan: the western mountainous and foothill region, the southernmost part, and the Coastal Range on the east. In the Coastal Range it contains sandstone, shale, and a great amount of andesitic lavas and pyroclastics, having a total thickness up to more than 6,000 m. *Lepidocyclina-Miogypsina* fauna occurs in the upper part of the agglomerate and above. Similar andesitic rocks developed on Lanhsu intercalate the limestone containing *Spiroclypeus leupoldi.* Hence the Neogene in the Coastal Range extends probably into the Aquitanian.

The Neogene in the southernmost part is a thick alternation of sandstone and shale with occasional conglomerate bearing boulders that contains *Operculina ammonoides*. Pliocene limestones are inserted in the upper part.

The Neogene in western Taiwan is in fault contact with the Urai group, being composed essentially of neritic sediments of more than 7,000 m. in thickness. From the *Lepidocyclina-Miogypsina* bearing Hsihchi group up to the *Elephas-Stegodon* bearing Tokazan formation no remarkable depositional hiatus had been observed, though three minor cycles of sedimentation and basaltic activity are distinguished. Reworked *Discocyclina* and *Nummulites* are found in the Miocene of western Taiwan, and boulders from the Tananao schist are found in the Miocene of the Coastal Range. Thus the pre-Miocene terrain in the backbone range was then already exposed to erosion. In general the bedding plane and cleavage of the Paleogene do not coincide with the bedding plane of the Neogene in western Taiwan. Therefore a pre-Burdigalian, most probably pre-Late Aquitanian, orogeny (the Puli) is inferred. The lamprophyre intruding into the Urai group represents probably a related granitic activity. Reworked Miocene foraminifers are found in the Pliocene, and *Ostrea-Pecten* or *Operculina* bearing boulders from the Miocene and Pliocene (?) are found in the Tokazan formation. This shows the successive upheaval of the geanticline on the east in accor-

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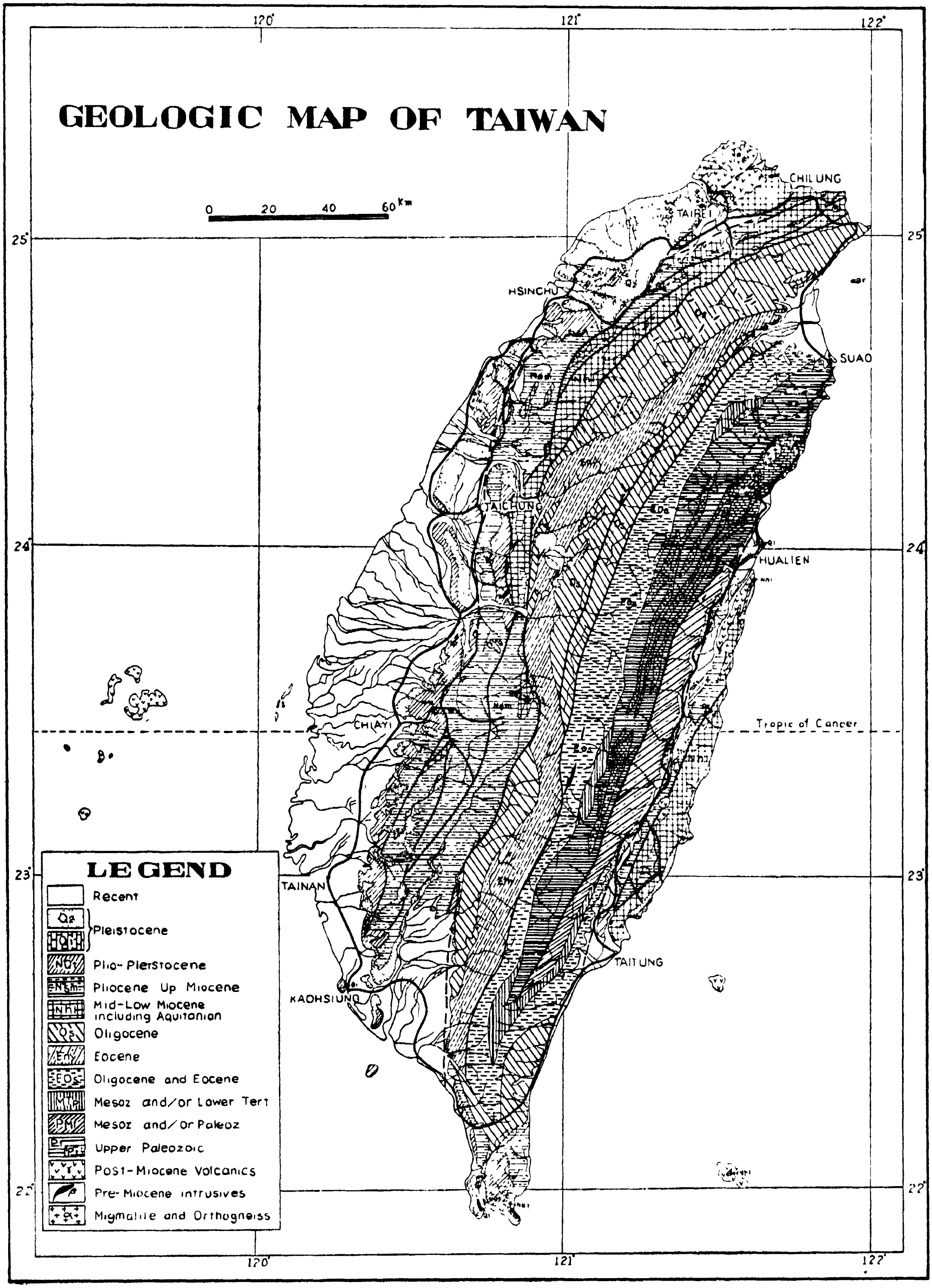
GEOLOGIC MAP OF TAIWAN
0 20 40 60 Km
120°
121°
122°
25°
24°
23°
22°
CHILUNG
TAIPEI
HSINCHU
SUAO
TAICHUNG
HUALIEN
CHIAYI
Tropic of Cancer
TAINAN
TAITUNG
KAOHSIUNG
LEGEND
Recent
Qp
Pleistocene
Plio-Pleistocene
Pliocene Up Miocene
Mid-Low Miocene including Aquitanian
Oligocene
Eocene
Oligocene and Eocene
Mesoz and/or Lower Tert
Mesoz and/or Paleoz
Upper Paleozoic
Post-Miocene Volcanics
Pre-Miocene intrusives
Migmatite and Orthogneiss

Stratigraphy of Taiwan with probable correlatives in the adjacent areas (Chang, 1957)

Probable System & Series Equivalents		Taiwan						East Indies (mainly NW Borneo) (F.W Roe, 1954, F H. Fitch, 1956)		Philippines (P E. Cloud, Jr., 1956, et al)		Ryukyus (S Hanzawa, 1935, P E. Cloud, Jr., 1956)	Japan (N Ikebe, 1956, et al)	
		Group and Formation			Thickness (m)	Leading Fossil	Remarks							
Quaternary	Recent		Younger terrace deposit, Younger coral reef, Matsuyama Formation (part), Tainan Formation				Intermittent upheaval Submergence				Emerged reef limestone	Reef limestone, etc.	K	Yurakutyo Formation
			—Disconformity—											
	Pleistocene		Older terrace deposit				Intermittent upheaval						J	Tatikawa Formation Yatomi Formation Semata Formation Zizodo Formation
			—Unconformity—											
			Tensiko Formation (Tableland Gravel)		30– to 80+		Warping & faulting							
			—Disconformity—											
			Older coral reef (Riukiu Limestone)		60 to 100–		Tatun andesitic volcanism							
			—Unconformity—											
		Tokazan Formation	Kavenzan Facies Local disconformity Koran Facies		1,500±	*Baculogypsinoides spinosus* *Stegodon sinensis S orientalis* *Parelephas trogontherii* *Cervus (Sika) taiouanus* *Striarca (Gallactella) yokoyamai*	Penglai orogeny Penghu basaltic volcanism		(Djetis fauna of Java)	Z_2	Guadalupe Tuff Malumbang Ls.	Clastic limestone Reef limestone Cavity filling dep with *Metacervulus* Naha Ls. / Sand and gravel	I_2 I_1	Sanuki Formation Kanezan Formation
			—Local disconformity—											
	Pliocene	Miaoli Group	Takuran Formation	Lichi Formation	1,400 to 2,000+	Entry of *Pecten (Notovola) albicans naganumanus*		h	Togopi and Ganduman formations	Z_1			H_2	Kakegawa Group
			Kinsui Shale	Chimei Formation Takangkou Fm	300 to 600					Y			H_1	
Tertiary	Miocene (including Aquitanian)	Sankyo Group	Tawo Siltstone		500 to 1 000			g	Sebahat Formation		Cangunsa Fm.	Shimajiri Formation	G	Sagara Group
			Shihliufeng Sandy Shale		0 to 200									
			Kantosan Sandstone		300 to 600		Chiaopanshan basaltic volcanism							
			Nansho Coal Measures (Up Coal-bearing Formation)		500 to 1,000					X_4				
		Hsichih Group	Nanko Sandstone	Tuluanshan Fm	450+	*Operculina japonica*		f	Setap Group (sandstone, shale, conglomerate, andesite, & andesitic tuff)		Maglihi Sandstone		F_3	Saige Group
			Sogo Formation		300+	*O bartschi multiseptata* *O bartschi ornata* *Miogypsina inflata*								
			Shikyakutei Coal Measures (Mid Coal bearing Formation)		450+		Shangping basaltic volcanism						F_2	Kurami Group
			Tairyo Formation		400±	*Nephrolepidina verbeeki* *Miogypsina mamillata*								
			Kokan Tuff		0 to 200	*Miolepid burdigalensis* *Cycloclypeus eidae* *Miogypsinoides formosensis* *Multilepidina irregularis* *Nephrolepidina sumatrensis & var mirabilis*	Kungkuan basaltic volcanism Andesitic volcanism			X_3	Molave Conglomerate	Yaeyama Formation	F_1	Megami Group
			Mokusan Coal Measures (Low Coal bearing Formation)		500±									
			Wuchihshan Formation (Setan Formation)		1,000±					X_1	Vigo Formation			
			Fault (?)											
			Lanhsu Formation			*Spiroclypeus leupoldi* *Eulepidina?* sp *Nephrolepidina brouweri*	Puli orogeny & metamorphism. Acid plutonism (?)	e	Upper T. orogeny	W_4 W_3			E D	Asagai Group Asiya Group
			(?)											
	Oligocene	Urai Group	Suchoryu Formation		2,000±	Entry of *Orbulina* *Pholadomya* sp *Crassatellites nipponensis* *Nautilus* cf *japonicus* *Lepidocyclina formosensis*	Andesite and basalt volcanism Taitung basic plutonism	d c	Sugut Formation (marine deposits with andesitic tuff) Orogeny and possible acid plutonism	W_1 V	Teresa Silt Binangonan Ls., Bulalacao Ls., Makalawang Ls. Bandao Limestone	Miyara Group	C	Oturi Group
	Eocene		Yonrvo Sandstone	Suo Group	500	*Assilina* sp		b	Kalabakan Shale				B	Nogata Group
			Nisimura Formation		1,000– 1 500 (?)	Entry of *Schizaster* *Nummulites* spp *Discocyclina* spp *Assilina formosensis*	Taiping orogeny & metamorphism. Yuangtoushan migmatization.	a	Orogeny metamorphism & dioritic plutonism	U	Maytiquid Ls. and Panganiban Ls		A A_1	Kamishima Group Akazaki Group
			Unconformity											
Mesozoic	Cret		Pihou Formation		3,000 (?)		Andesitic volcanism		Phyllite, ss., sh., ls., etc Basic plut. Chert Spilite Suite (Bau Series of Borneo)		Pandan Formation Baruyen Formation		Himenoura, Goshonoura, & Monobegawa Grp	
			(?)											
	Jura		Unconformity	(Subsurface only)		*Holcophylloceras* aff *mediterraneum*	Kiyoku acid plutonism Nanao orogeny and metamorphism		Mefa & Sassfu Fm.		Mid Up Jura. near Mansalay Bay		Mid part of Tetori Torinosu groups	
	Trias		(?)						(*Halobia Monotis* Zone)				(Saragai & Kochigatani groups)	
Late Paleozoic	Perm		Tananao Schist		6 000	*Neoschwagerina?* sp *Schwagerina?* sp *Parafusulina?* sp *Waagenophyllum* sp	Basic volcanism		Sebangan Hornstone (?) Terbat Formation		Slates, phyllites, schists, gneisses, granites, metavolcanics, & radiolarian cherts (?)	*Neoschwagerina* Ls.	*Neoschwagerina-Parafusulina* Zone	

dance with the gradual westerly shifting of the geosyncline axis.

The Tokazan formation is folded together with the underlying formations by the Taiwan or Penglai orogeny and overlain unconformably by the Pleistocene Riukiu limestone (redefined) and or Tableland gravels. Late Pleistocene terrace deposits are widely developed. The marine alluvia covering the Taipei basin and the southwestern coastal plain show submergence during the early Holocene; the raised coral reefs in southern Taiwan are the evidence of subsequent emergence.

In Taiwan the transgressions and orogenies occurred roughly at the same time with those in the Philippines and Ryukyus.

PRINCIPAL FEATURES OF THE TECTONICS OF AMUR REGION, SIKHOTA ALIN RANGE, SAKHALIN ISLAND, KURILE ISLANDS AND KAMCHATKA PENINSULA

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1. Regions of the Soviet Far East, including the Amur region, Sikhota-Alin range, Sakhalin island, the Kurile Islands and the Kamchatka peninsula, belong mainly to the belts of Mesozoic (Pacific) and Cenozoic orogeny (Kropotkin, 1954; Beliaevski, 1956; Smekhov, 1947; Alexeichik, 1954). There are also some stable masses among them being areas of an older (Palaeozoic and Precambrian) folding. In the Southern part of Okhotsk sea and in the Japanese sea there are nuclear masses of a different type, which, according to gravity anomalies, have a structure of the crust similar to that of oceanic platforms.

2. The structure of described part of the Circumpacific orogenic belt is represented on the new (1957) geological map of the USSR, scale 1:2500,000, and on the tectonic map of the USSR and adjacent areas (scale 1:5000,000, published 1956, editor Shatski). For the territory above mentioned this map is compiled by N.A. Beliaevski, V.N. Vereshchagin, G.M. Vlasov, L.I. Krasny and P.N. Kropotkin. On this map the territory is divided on the different belts, according to the age of main orogeny. In the limits of each orogenic belt—cenozoic (alpine), mesozoic, hercynian etc.—the extending of lower, middle and upper structural stages is marked by different colours. The intrusives also are divided by their composition and by their time relations to the age of main orogenic period of the corresponding belt.

3. A region of Precambrian folding is the Aldan shield, which since Proterozoic era is a part of the Siberian platform. Its margin (Stanovoi range, Dzugdzhur range) got involved into the block-folding movements of the Mesozoic period, accompanied by injections of granite intrusions.

4. The median mass (Zwischengebirge) of Zeya and Bureya river basins and the zone of Oldoi and Selemdzha rivers, stretching from the upper reaches of Amur to the Shantarski islands, represent a Palaeozoic folded region.

The geosynclinal development of the Oldoi Selemdsha zone was being finished mostly during the Hercynian cycle; then it was subjected to intense block dislocations of the Mesozoic era.

The Zeya-Bureya mass has, apparently, an older Precambrian core and forms a continuation of platform structures of Manchuria. Along the Eastern edge of this massif, on the boundary with the Mesozoic folded zone, the foredeep of the Bureinsk basin was formed and got filled by Jurrassic and Lower Cretaceous sediments.

A smaller median mass with outcrops of Precambrian rocks, Cambrian sediments and Palaeozoic granites is known in the Basin of lake Khanka and the Ussuri river. It is possible to suppose the existence of a consolidated Pre-Mesozoic region in the Central and Northern parts of the sea of Okhotsk.

5. In the structure of the Mesozoic folded zone of Amur region and the Sikhota Alin range several large anticlinoriums, consisting mainly of Upper Palaeozoic sedimentary and volcanic series, can be distinguished (anticlinoriums of Badzhal range, Bikin river, Muraviev peninsula, and the main Sikhota Alin anticlinorium); in the most Western of them, including the Little Khingan and Bureya ranges, Precambrian and Devonian rocks are developed. Synclinal zones (Tugur-Nemilen zone, Lower Amurian, Suchan zones, the main Sikhota Alin synclinorium) are composed mostly of Upper Triassic, Jurassic and Lower Cretaceous strata compressed into folds with a North-Eastern trend. The cycle of geosyncline development is well traced here, just as in North-Eastern Siberia, from Upper Carboniferous up to the middle Cretaceous time (the so-called Verkhoyansk orogenic cycle, see Kropotkin and Kheraskov, 1939).

6. The narrow coastal stretch at the Eastern slopes of Sikhota Alin range is a part of the peculiar zone of Upper Cretaceous and Tertiary effusives development pierced by granites of a Lower Tertiary age and subjected to folding dislocations during the Cenozoic era. This zone finds its continuation on the Western and Northern coasts of the Sea of Okhotsk, further in the Kolyma range (Gydan) and in the Southern

part of Chukotka peninsula, and separates the region of Mesozoic folding from the region of young Alpine folding, which, to a great extent, represents a live recent geosyncline system.

7. The structures of Sakhalin island have a meridional orientation and are an offshoot from the main system of geosyncline structures stretching from Hokkaido island to the North-East through the Kurile islands to Kamchatka peninsula, Koriak range and the Komandorski islands. Two anticlinoriums — one of the West-Sakhalin range, consisting mainly of Upper Cretaceous rocks, the other of East-Sakhalin range (with outcrops of Palaeozoic rocks in the core), are divided by the synclinal zone of the Poronai river. In this zone and in the trough of the Eastern coast of Sakhalin island the thickness of Tertiary deposits reaches 4-8 km. The degree of dislocation, magmatism and other features of geosyncline systems are weaker and come down to nil in the direction of the Northern part of the island.

8. In the structure of the Kurile islands two parallel geoanticlines, consisting mostly of upper Cretaceous and Tertiary deposits, are distinguished—one stretching along the main chain of islands and crowned by a number of volcanoes, and another, passing through the Minor Kurile islands and the submarine range Vitiaz. Several considerable shifts (shears) are traced along which separate links of this double arc were displaced to the South-East.

9. The anticlinoriums of Kamchatka peninsula display a virgation; their Northern ends diverge, while the Southern experience a deviation towards the South-East. The anticlinorium of Sredinny (Central) range consists of Precambrian and Palaeozoic rocks and has its continuation in the folds of Cretaceous and Paleogene ages on the Western coast of the peninsula. In anticlinoriums of the Kumroch, Ganalsky and Valaginsky ranges geosyncline deposits are developed which belong, probably, to Upper Paleozoic and Mesozoic (up to Cretaceous incl.). Big troughs at the Western and Eastern coasts are filled by Tertiary deposits dislocated with less intensity. As on Sakhalin island, the folding here took place during the end of the Pliocene and the beginning of the Quaternary periods. The median depression of Kamchatka peninsula is associated with the formation of grabens, stretching parallel to the middle flow of the Kamchatka river.

10. The Kurile-Kamchatka arc and the arc of the Komandorski and Aleutian islands are flanked on the East and South by the depressions of the Kurile-Kamchatka and Aleutian abyssal troughs. These extremely seismic troughs are foredeeps at the periphery of the Pacific oceanic platform, the structure of which is quite different from the structure of continental platforms. The entire zone of the Kurile-Kamchatka trough is characterized by high negative anomalies in isostatic reduction, which can indicate an extension of the earth's mantle at the margin of the Pacific platform.

REFERENCES

Alexeichik, S.N., 1954, The tectonic scheme of the Sakhalin island. *Izvest. Akad. Nauk SSSR*, ser. geolog., **5**.

Beliaevski, N.A., 1956, The outline of the geology of Maritime (Primorski) region. Vsesoiuzn. Nauchno Issledov. Geolog., Inst., Materialy po geologii i poleznym iskop. Vost. Sibiri i Dalnego Vostoka, vyp. 1. Moscow.

Kropotkin, P.N., 1954, Brief outline of the tectonics and palaeogeography of the Soviet South Far East. Voprosy geologii Azii, t. 1. Sbornik k 90-let. akad. V.A. Obrucheva. *Izd. Akad. Nauk SSSR*, : 736-764, tectonic map.

Kropotkin, P.N. and Kheraskov N.P., 1939, The tectonics of North-Eastern Asia. *Internat. Geolog. Congress. Report of the XVII session* 1937. **2**. Moscow.

Smekhov, E.M., 1954, The geological structure of the Sakhalin island. *Izvest. Akad. Nauk SSSR*, ser. geolog., **5**.

Tectonic map of the USSR and adjacent areas. Scale 1:5000,000. Editor N.S. Shatski. Moscow, 1956. Sheets NN 4, 8.

The geologic map of the USSR. Scale 1:2500, 000. Editor D.V. Nalivkin. Moscow-Leningrad, 1957. Sheets NN 6, 12, 18.

Symposium: *Geophysical Techniques in Mineral Prospecting*

Convener: T.F. Gaskell (United Kingdom)

UNDER-WATER MAPPING BY DIVING GEOLOGISTS

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This talk, which is a commentary in connection with a fifteen minute under-water motion picture, summarizes the experiences and techniques of geologists at the U.S. Navy Electronics Laboratory and Scripps Institution of Oceanography who have been mapping off-shore geology by diving for the past four years; photography was done by R.F. Dill of the Navy Electronics Laboratory.

The use of self-contained under-water breathing equipment (such as the aqualung) in scientific studies has revolutionized certain phases of shallow-water marine geology and biology. With such equipment the geologists, in pairs for safety, can freely swim along the bottom and map geology in almost the same way and with almost the same efficiency as on land. The strike and dip of bedrock can be taken with watertight compasses and inclinometers; observations are written on white plastic and samples taken with the geologists hammer. Boat positioning is usually done by measuring angles between three shore stations using the sextant held horizontally.

Three geologists, making six dives each, can make nine stations in a day at depths down to 150 feet; each station averages about 15 minutes underwater.

Aqualung divers are subject to the same time-depth limitations as are suited divers; decompression is frequently necessary after deep diving or prolonged diving at shallower depths.

Offshore mapping by diving geologists is a valuable supplementary technique to geophysical work at sea, land mapping along, the shore, and coring from ships, in waters from the shore line to depths of about 150 feet.

RECENT RESULTS OF MARINE SONOPROBE SURVEYS

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(Abstract)

The Marine Sonoprobe, developed by Magnolia Petroleum Corporation, a subsidiary of Socony Mobil Oil Company, has been used in fourteen surveys of sub-bottom conditions in eight different general areas in North and South America.

Slides are to be presented illustrating the equipment, installation techniques, and photographs of original Marine Sonoprobe records.

The records in 7 out of 8 areas surveyed show interesting and valuable information about bedding and structure (for petroleum structural search) and overburden thickness and distribution (for engineering surveys). The one "no-reflection" area was near the headwaters of a large river, where the current was very swift and the river bottom consisted of boulders; in this area no consistent sub-bottom reflections were observed.

Marine Sonoprobe surveying can apparently be successfully used in:

1) Reconnaissance surveying for structural evidence in water-covered sedimentary basins.
2) Detailed surveying in the solution of problems connected with marine construction, such as harbor development, channel dredging, tunnel locations, and location of offshore oil-drilling platforms, submarine cables and submarine pipelines.
3) Establishing weathering-correction data when used on the same boat in conjunction with marine seismograph surveys, as well as furnishing shallow structural information to supplement the deep seismic reflections.

AIRBORNE GEOPHYSICAL TECHNIQUES IN MINERAL EXPLORATION

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INTRODUCTION

If this paper is inaccurate or unbalanced, it is due to the defects in the memory of the writer who had to compose it hurriedly in Bangkok without the benefit of reference to relevant documents and results. Similarly illustrations submitted will not be consistent or entirely opposite.

Airborne Geophysics is a branch of Geophysical Science which uses aircraft as a traversing vehicle for instruments designed to measure variations of the physical characteristics of earth and atmosphere. This paper is confined to methods applicable to mineral exploration (i.e., the earth). In general, absolute measurements of physical quantities do not apply.

INSTRUMENTATION

Geophysical instruments designed for airborne traversing so far developed are the magnetometer, the scintillation counter, the electromagnetometer, and the gravity meter. In general, instruments are designed to be light in weight and to give continuous recordings.

MAGNETOMETERS

There are two types in current use: (1) Fluxgate, (2) Nuclear Precession.

The Fluxgate type uses a system whereby a measuring fluxgate is kept oriented in the direction of the earth's total field or a component of that field.

The total field fluxgate has the most universal application since it is instrumentally easier to maintain accuracy of relative measurements with it than with a component type. The component type has limited application, e.g., magnetic iron ore exploration in high magnetic latitudes.

The Nuclear Precession instrument uses the fact that the random distribution of nuclear orbits in a fluid can be modified by applying an electromagnetic field, and the rate at which the orbits precess to their random attitude, on removal of that field, is a measure of the ambient total field. The electromagnetic field is applied intermittantly and the fluid used is water possibly with some additives. Accuracies comparable to those possible with a fluxgate instrument are obtained and the instrument can possibly be developed to a higher degree than the fluxgate type in the directions of reduction of weight and speed of treatment of results. At the moment it is comparable to the fluxgate type in these respects. It has a slight disadvantage in that its record is not continuous and a slight possible advantage in that it measures absolute values.

SCINTILLOMETERS

These instruments are essentially one or more Sodium Iodide or synthetic phosphors connected through photomultipliers to ratemeters. In general, the larger the phosphor the better the sensitivity but too large a phosphor can give confusing results. Geiger counters are too insensitive.

GRAVITY METERS

One such instrument is in the development stage. The system employs two meters set a small distance apart to give measurement of gradient.

ELECTROMAGNETOMETERS

There are a number of this type of instrument. The principle in them all is to transmit a primary electromagnetic field powerful enough to affect the natural conductors beneath, and to record the characteristics of the resultant field at a detector, which is also airborne Instrumentation is designed to amplify the effect of the secondary field generated in the conductor at the detector and to measure its variation in relation to the primary field. In-phase, out-of-phase, and amplitude measurements are used. Obviously, the geometry of the system is important and the allowable tolerances in relative position of transmitter, detector and disturbing body influence instrument design and the survey plan. Lightness in weight is another design feature. Amplitude measurements call for a fixed distance between transmitter and receiver but phase measurements are not so critical in this regard. Hence "phase" type instruments use towed detectors with the advantage that the detector can be flown closer to the conducting body than is possible with "amplitude" instruments unless helicopters or very powerful light aircraft are used with the consequent increase in cost and limit to range.

One "phase" system uses two light aircrafts. Due to inadequate preparation time, the slides shown deal with only one type of E M instrument—a two frequency out-of-phase device—a highly successful instrument, by the way.

All the above instruments save one, i.e., magnetometer, scintillation counter, and electromagnetometer can be used in helicopters as well as fixed wing aircraft.

SURVEY TECHNIQUES

The aim in most geophysical surveys is to record measurements as consistently as possible. Two factors, in this connection, must be considered in aerial work, namely spatial accuracy of positioning (i.e., altitude and plan position) and stability of the measuring instrument enabling control systems to be flown.

Flight patterns must be designed to meet the exploration problem to be solved and the topography and yet must be capable of being controlled to give consistency of measurement.

If the exploration problem is one involving physical contrasts at depth, flight patterns flown at constant altitude above a datum (e.g., sea level) are used. If, however, the problem involves physical contrasts at or near the earth's surface, profile flying is generally called for.

The spacing, in plan, of traverses is dictated by the problem modified by economic and topographical considerations. Constant barometric altitude surveys generally have line spacing of from one mile to 20 miles whereas the spacing on profile flown surveys varies from one-eighth mile to one or two miles.

Since we are dealing with measuring differences in a highly variable medium—the earth's crust—it is difficult to pronounce on the proper relationship between altitude and line spacing. Some reasonably accurate relationship must be used if the results of the survey are to be contoured. If this is not required—i.e., only profiles are wanted—greater flexibility in spacing is possible since the dominant factor is the dimensions of the bodies or features it is designed to locate.

Spatial accuracy of positioning of traverses is, as earlier mentioned, important. Altitude measurements on constant barometric type surveys is usually by barometric altimeter, as its name implies. Relative accuracies within the envelope ± 150 ft. are normal; altitude measurement on profile type surveys is by radio altimeter accurate to ± 20 ft.

Plan positions of traverses are recorded by various radar systems; e.g., Shoran horac, Secca, Doppler or by tracking photography usually 35 to 90 mm. frame size, using existing topographic mapping or aerial photographs and mosaics. Such photography can be flown immediately previous to the geophysical work by a dual purpose aircraft. The relative accuracy of positioning under normal conditions is of the order of 100 m. where rader systems are used, while by using tracking, photography accuracy of positioning relative to ground detail is as high as 15 m. on profile surveys flown at 150 m. above ground control of measurements is effected by flying in such a way that a return to a reference datum is accomplished at intervals. The length of interval is determined by the normal time variation of the quantity measured and the stability characteristics of the instrument.

Tie Line or Tie Point Systems are used with a time interval of about 20 minutes for magnetic work—less if greater accuracy is required. Reference lines are flown on E.M. and radioactivity surveys where all three instruments are used, for instance, the control pattern is a combination of the above.

The traverse direction is important. Generally, radioactive and electromagnetic measurements are best taken on lines at right angles to the expected strike of the body or feature it is wished to map. Since, however, the E.M. method gives the best response when the instrument is flown in the direction of dip ideal flight patterns may be uneconomical.

In the magnetic latitudes where the dip is greater than about 40° traversing with the magnetometer at right angles to the strike direction is good. Where dips are less than 40° however, a consideration of the object of the survey is very important. If the search is for linear features, e.g., faults, shears, elongated bodies of relatively high magnetic character, etc., then the traverse direction should be at right angles to the strike or axis of those features.

If the search is for deep-seated disturbing bodies, again the traverse direction at right angles to their axis or strike is correct. If, however, the search is for near surface point sources, e.g., some magnetic iron ore deposits, etc., then the traverse direction should be in a northerly-southerly direction since the anomalies will have their largest dimension. East-west and the best record of them will be obtained north-south.

If the search is for many—apparently conflicting—features, a compromise traverse direction is used.

COMPARISON OF AIRBORNE AND GROUND BORNE TECHNIQUES

Airborn methods are limited to the magnetic (mainly total force), electromagnetic, radioactivity and possibly gravity. Such methods as self potential, resistivity & seismic cannot be adapted for airborne use.

Due to the fact that airborne instruments are operated some distance from the ground, two features in comparison with ground methods emerge:

1. Little or no interference from man-made disturbances and surface features such as float, drift, etc. Such parasitic disturbing bodies have to be relatively large to upset the record. It is true, however, that in well-developed areas electrical interference can be a problem in the magnetic and electromagnetic methods. Contamination by radioactive dust can upset a scintillation survey.
2. Since airborne instruments are positioned further from anomaly sources than ground borne instruments, some loss of resolution is encountered. This is not usually a major disadvantage when the proper use of aerial geophysics is considered, namely, the location of zones or points of interest for later detailed investigations by ground borne methods.

USES OF AIRBORNE TECHNIQUES IN MINERAL EXPLORATION

Airborne techniques may be used for both regional and detailed investigations.

REGIONAL INVESTIGATION

The speed and comparative ease of traversing makes airborne methods particularly suited to covering vast areas thus providing a regional picture which materially helps the exploration geologist in the major aim of his work. That is, the locating of areas of maximum interest in the search for ore or oil.

OIL EXPLORATION

In oil exploration it is of great use to the oil geologist to know as much as possible of the regional structure of his particular area. Airborne magnetometry helps in the determination of structure by giving information on the relative thickness of sediments above basement and on the trends in the basement topography.

You will be seeing the progress in oil exploration in Southern Thailand on Friday 29th and you will be shown the aeromagnetic map which located possible basement uplifts. The aeromagnetic survey was followed by gravity survey over one "high" and drilling is now proceeding. An immense amount of time and effort has been saved by the airborne survey.

Similar surveys in Australia, Papua, New Guinea, Philippines, and Pakistan come to mind.

Obviously the geological conditions must be there for the magnetic method to be useful.

Essentially, there must be a difference in magnetic character between basement and overlying sediments and the more uniform the magnetic character of the basement, the clearer is the interpretation of the results.

It is hoped the airborne gravity meter can be perfected since its use in oil exploration can be great.

MINERAL EXPLORATION

Regional aerogeophysical techniques are proving of great value in mineral exploration in positioning the major geological features of the area.

Mineral exploration, in the main, takes place in areas where igneous and metamorphic rocks outcrop at surface or relatively near surface. Since such rocks can have widely differing physical characteristics, all known airborne geophysical methods are usually applicable in mineral exploration. In fact, the three instruments magnetometer, electromagnetometer, and scintillation counter are often run together.

The scintillation counter technique is, for instance, useful in the location of minerals associated with granite intrusions since most granites are more consistently radioactive then metamorphics or sediments. Thus the junction of granite with country rock can often be found with scintillation counter. Again, mineralisation may be associated with shearing, when the electromagnetometer finds an application; generally, in association with the magnetic and radiometric methods whose results augment each other.

Faulting may be a major ore control when again the magnetic and possibly the E.M. and scintillation methods apply.

The ores searched for may be associated with ultra-basics when the magnetic methods is applicable.

In general, regional methods of aerogeophysics form an indirect approach to ore finding.

DETAILED SURVEYS

In areas where zones of mineralisation have been located either by regional aerogeophysics or regional geological methods, there may be justification for using airborne techniques as direct ore finders. Detailed surveys generally employ instruments directly applicable to the ore concerned or to minerals closely associated with ore. The magnetic method for iron ore location, the electromagnetic method for sulphides, and the scintillation counter for uranium and thorium mineralisation are obvious. Not so obvious are the magnetometer method for gold (e.g., South Africa) and the scintillation counter method for tin and columbite (e.g., Burma).

ABSORPTION OF ELASTIC WAVES IN ROCKS

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(Abstract)

1. One of the ways to perfect the methods of interpretation in seismology and seismic prospecting is to use the dynamical properties of the elastic waves propagation. To make a correct interpretation of the dynamic peculiarities, it is, firstly, necessary to know parameters characterizing the absorption proporties of rocks. The study of these parameters may be of help in determining physical and mechanical properties of the rocks.

2. A density decrease of the elastic wave energy during its propagation in rocks takes place mainly for three reasons;

(1) an increase of the wave front surface divergence;

(2) dispersion of energy in non-homogeneous rocks;

(3) energy absorption due to a non-ideal elasticity.

There are many theories dealing with the absorption of elastic waves in solid media; but there are none which would give a comprehensive explanation to the laws of seismic waves absorption in various rocks. The experimental studies of the absorption properties of rocks may be a decisive factor in forming such a theory.

3. To study the absorption properties of rocks, the so-called seismo-acoustic method has been used. It was elaborated by the author in collaboration with I.P. Pasechnik on G.A. Gamburtzev's initiative and is based on the study of a propagation nature of elastic harmonic motions in rocks with frequencies from 50 to 5000 cycles per sec.

Our methods of field observations with a proper treatment permit to determine a divergence index, decrement and absorption coefficient of stationary motions in rocks.

4. The results of the field determination of the parameters mentioned above make it possible to differentiate rocks in their absorption properties. The greatest absorption (value) for each given frequency of oscillations was observed in sedimentary rocks occurring near the day surface (sandy loam, sand); the least absorption—for metamorphic rocks at a depth of 200-300 m. (e.g. aegirine schists).

The values of the absorption coefficients for some rocks increase with the frequency of vibrations under the law, similar to a linear one, i.e. the absorption coefficient is proportional to the frequency. The value of the absorption decrement for the same rock does not practically depend on the frequency.

The comparison of the value of the absorption decrement and phase velocities V indicate that is inversely to V.

The experimental results of studying the absorption parameters for different rocks confirm, for the most part, some conclusions following from the theory of absorbing elastic waves due to an elastic after-action (B.V. Deryagin).

APPLICATION OF GEOPHYSICS TO THERMAL POWER PROJECTS IN NEW ZEALAND

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The geological structure of the active volcanic district of New Zealand is a mosaic of fault blocks that have subsided differentially in a complex graben between two stable blocks composed of dense ignimbrite sheets resting on a Mesozoic greywacke basement. Within the graben the ignimbrite is buried beneath younger flows, pumice, and sediment. The structure at depth is determined by detailed gravity surveys. The airborne magnetometer is used to distinguish between "structural highs" composed of non-magnetic ignimbrite and basement and "magnetic highs" formed by buried andesite and rhyolite volcanoes. The hot spring (thermal) areas are found at many scattered localities generally on structural highs within the graben or in areas of steep gravity gradient separating horsts from grabens.

Drilling at Wairakei over the past seven years has located extensive reserves of geothermal water stored in the permeable pumice formations overlying ignimbrite and discharging to an active thermal areas at the surface. It has also been proved by geological correlation of drill holes and by temperatures measured in drill holes that the geothermal reservoir is being fed from below through small linear fissures in the otherwise impermeable ignimbrite basement. These fissures are still active fault features and show on air photos as traces on the ground surface where recent pumice does not obscure them. Wells have been sited adjacent to the surface traces and drilled to intersect the fissures where they leave the ignimbrite basement. Such wells give double the production of wells sited at random, which have to be fitted with slotted liners to prevent erosion of the pumice and subsequent blockage. Some random wells do not produce because the pumice formations have been rendered almost impermeable by cementation and compaction.

As the best results are obtained by drilling fissured ground along faults cutting the ignimbrite basement, it has become important to locate these buried faults. So far no geophysical method has been successful because of the blanketing effect of the 2,000-3,000 foot pumice cover. Seismic waves are attenuated on passing through pumice. Reflections obtained at the surface are poor, and tentative interpretations have not been confirmed by later drilling.

Development at Wairnakei is in three stages. Stage I (69 MW) is under construction. Steam is already available for Stage II (150 MW), and drilling is now under way to prove State III (240 MW). It is not certain how long this rate of withdrawal can be maintained, but a close watch is kept for falling production in boundary wells. So far no decline has been definitely proved. The key problem, still unsolved, is whether the rate of heat supply to the reservoir can be accelerated by draw-off from drill holes. Present production is approximately double the natural heat escape before drilling started, so the answer to this problem may be decided in the near future.

Developmental plans include deeper drilling on the fissures at Wairakei and the investigation of the thermal area of Waiotapu 30 miles to the north. Scientific work of all kinds is being speeded up in an effort to solve some of these outstanding problems.

ON RESEARCH OF THE EARTH'S CRUST IN THE PACIFIC COAST AREA OF ASIA†

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The investigation of the crust's structure in different places of the world constitutes one of the most important problems relating to Geophysics and Geology.

It is essential to investigate the structure of the crust for purposes of geotectonic hypothesis, theories relating to the origin of continents and oceans, solution of isostasy's task, studies of seismicity, including tsunamis. It is also important to solve practical tasks, i.e. regional geophysical investigation when looking for mineral deposits.

In September 1955 in Brussels at a meeting of the Special Committee of the I.G.Y. the USSR recommended that special work in relation to the investigation of the crust's structure in the Northwestern part of the Pacific should be carried out. These researches had been planned long before by (my late teacher) Professor G.A. Gamburtsev. The main method proposed by him dealt with deep seismic sounding (SDS).

In order to get some information about the structure of the Earth's crust of the sea area in the USSR including the areas bordering the Pacific, Soviet scientists tried to use all of the main geophysical methods: gravimetry, magnetometry, electromagnetic methods, and the data relating to registration of earthquakes.

At the same time besides using the SDS method another method was applied. It was worked out at the Institute of Oceanography by M.M. Ondinzer and Lisizin to investigate the topography of the bottom and the velocity of the upper bottom layers. This method is similar to the seismic reflection method.

The technique of the SDS was first developed in the Caspian Sea. In this slide you can see the scheme of the profiles that were measured. The main seismic station was located in the center on the Artem Island. In the regions of Lencoran and Krasnovodsk there were established seismic stations to get the full systems of time-distance curves of refracted waves. The observations were carried out in the following way. The ship sailed along a line connecting two seismic stations; at equal intervals of distance the ship detonates explosive charges.

250-300 km. of profiles were thus covered per day. There, and in the Black Sea as well, some technical questions were solved: the effect of the sensitivity of geophones, placing of geophones in the deep sea etc.

As a result of these researches we obtained a map of the structure of the Earth's crust in the Southern part of the Caspian Sea. The structures of the submarine mountain area bounding the Caucasus with Turkmenia was thus investigated as well as the observation of the increase in thickness of the Earth's crust in southern direction.

In 1957 similar work started in the Pacific. A number of the longitudinal profiles were planned, i.e. across the direction of the main structural trends in that area. In the western direction the lines of observation enter the Okotsk Sea in shallow water, where the structure is very similar to that of the continent. In the eastern direction the lines above mentioned cross a deep depression and enter the area of the Pacific basin. The profiles are located in the region of South Sakalin and the southern part of the Kurile Islands. This year researches have been carried out relating to four profiles (total 3000 km.). They were finished only a month ago and the field materials are not interpreted as yet. But we have already established the demarcation line between the three-layered continental crust and the two-layered oceanic crust in the Okotsk Sea in the vicinity of the Kurile Islands. The thickness of the crust on the bottom of the Pacific Ocean is far less and the granitic layer seems to be absent.

Basing our work on the results of the complex investigations carried out by use of different geophysical methods one can give a preliminary description of the area as follows: existence of the Kurile Island arc, one of the deepest depressions in Pacific (10 km.), high seismicity of that area, where actually tsunamis are occurring testifying to the tectonic activity, actual volcanism which

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† Presented by E. V. Karus,

cannot be observed in any area of the USSR but there; existence of a positive gravity anomaly of 500 mlg. The Kurile-Kamzatka area is in fact a modern geosyncline. There we observe one of the largest faults, which seems to appear in the region of the oceanic depression. It dips steeply under the continent, showing itself at depths of 700 km. where the hypocentres, origin of deep earthquakes, are located.

In 1958 investigations will be carried out in the northern part of the Pacific area, including the Shanter Islands, the northern part of Sakalin Island and the southern part of the Kamchatka Peninsula.

Symposium: *Geology of Coral Reefs.*

Convener: Rhodes W. Fairbridge (U.S.A.)

THE ROLE OF MECHANICAL ABRASION IN THE EROSION OF CORAL REEFS AND LAND AREAS

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During the past three years of study of atoll phenomena, the writer's travels to some twenty atolls and reef islands in Micronesia and his examination of several hundred serial photographs of atoll features have impressed him with the erosive power of ocean waves and the abrasive materials which they transport. This has led him to the belief that mechanical abrasion as an agent of destruction of coral reefs and atoll land may be more important than some students of atoll problems have allowed. In the present paper therefore the writer wishes to examine the role of mechanical abrasion in the erosion of coral reefs.

The writer agrees with Kuenen (1950, 465) and numerous other atoll scholars that mechanical denudation is not a satisfactory explanation for glacial low level bevelling of the raised reef (if in fact there was such bevelling) but that the destruction of the exposed limestone is largely accomplished through chemical solution by rainwater. The highly eroded and honey-combed so-called *makatea* surfaces of raised atolls give ample evidence of this process. On the other hand, "there is no compelling evidence (Newell, 1956, 324) "for extensive planation during the short duration of the low levels as Kuenen would have us believe." Newell pointed out that Pleistocene low level terraces in the Bahamas are rarely more than half a mile wide, and the felt that only the smallest limestone islands were truncated during Pleistocene lows.

In regard to subaerial and intertidal reef reduction, there is less agreement on the role of solution versus mechanical erosion. In their brief review of the Problem of Coral Reefs, Ladd and Tracey (1949) cited the observations of Murray and Gardiner in an earlier day, and of Kuenen, Umbgrove, Fairbridge and Teichert more recently concerning the importance of the geological evidence of widespread solution that is limited to the intertidal zone and particularly effective at low tide level. They pointed out that water on reef flats varies considerably in its composition from that of normal sea water as shown by biochemists on the Great Barrier Reef and at Bikini, concluding that "the possibility of solution on a large scale as a result of this variation must be considered". Fairbridge (1952) contended that horizontal platforming such as that which produces a coral reef flat is not the result of mechanical erosion operating at wave-base, but through subaerial cutting in the inter-tidal belt.

Emery (1946) argued that in tide pools during the night the increase in carbon dioxide in solution increased the amount of calcium ions that can be held in solution and this led to the dissolving of the rock walls of the basin. During the day by a reverse process calcium carbonate is deposited as a fine precipitate to be flushed out by high tide waves, thus leading to a gradual erosion of the reef flat.

Kuenen (1950, 436) asserted that "the testimony of geological observations appears to establish beyond doubt the solvent action of tropical *surface* waters on reef limestone". Kuenen's arguments were endorsed by Fairbridge (1952) and Emery, Tracey and Ladd (1954, 26-30). While accepting the thesis of the solvent power of tropical surface water on limestone, Newell alluded to the fact that Robert N. Ginsburg (1953) Gilbert Ranson (1955) as well as Newell (1951) had concluded that bio-mechanical and bio-chemical activities are adequate to produce most of the distinctive erosion forms of the intertidal zone on certain limestone coasts, and that solution by sea water is not the dominant process. Emery himself had shown that intertidal gastropods probably play an important role in the erosion, and in his study of Johnston Island (1956, 1513) he wrote that "The myriads of fishes that scrape and break off bits of coral and coralline algae during their feeding result in the production and transportation of sediments in quantities that may rival the amounts produced and transported by waves and currents." Moreover, "If it be assumed that the growth of blue-green algae on and below the surface initiates erosion by biochemical action and penetration of algal filaments into the rock (as found by Doty, Newhouse, Miller, and Wilson, 1954) it may be safely concluded that the rasping of the softened surface rock by gastropod radulae accelerates the process of limestone removal." (Newell, 1956, 360). Estimates of rock removal through marine solution were made by Emery (1946, p. 227) in a study of tide pools averaging 5 cm. deep. He calculated that it probably required 200 years to excavate the pools to this depth. The process thus appears to be relatively slow.

From the preceding discussion, it is evident that there is as yet no complete agreement on the dominant processes of erosion. Fairbridge (1952) and Kuenen appear to emphasize marine solution as the dominant process. Newell (1956, 360) admitted that direct solution by sea water may be a factor and that algal penetration of the rock doubtless is significant, but he denied they are the dominant current factors. By contrast Newell placed greater emphasis, and the writer believes rightly, on mechanical and bio-mechanical abrasion as present tools of erosion of the reef flat and in the cutting back of the old ledgerock or island rock that forms the protective foundation of atoll islets.

Possibly, some of the general disagreement over the dominant process arises from the differences in the particular zones or areas of the atoll considered. The erosion in the grooves of the margin differs from that of the reef flat, and both differs from that of the island ledgerock and of the loosely consolidated island sediments. The fracturing and breaking off of reef blocks along the windward reef margin is of still another order. In considering the dominant process of erosion of atoll reef and land, all the multiple processes must be considered as a whole and an evaluation made of the bulk contribution of each process. Unfortunately, sufficient data is lacking for evaluation on a quantative basis.

Although no data has been gathered for quantitative evaluation of the role of mechanical abrasion of the reef front, reef surfaces, and ledgerock through wave fracture and transport and gravel and sand scour, some observable evidences of its importance can be presented. The excellent observations of Emery, Tracey and Ladd in the northern Marshalls and of Newell at Raroia provide direct evidence to which the writer would like to add his own. These, in the main are corroboratory of theirs. It must be recognized, of course, that mechanical abrasion is accelerated by disintegrative forces such as algal undermining of rock by boring worms, urchins, gastropods and other organisms.

An aerial photograph examined by the writer showing the lagoon reef off Aineman Islet of Jaluit Atoll illustrates a type of exfoliation of the lagoon reef flat producing a slight terrace and which could be affected by the hydraulic pressure of storm waves in a process of undermining of reef rock layers. This type of erosion through which layers of consolidated rock separated by a thin layer of loose sand could occur where a "sheet" of heliopora expands laterally upon a previous lagoon reef flat following a rise in sea-level. On the lagoon reef flat at Ebon Atoll the writer observed and photographed an area of several thousand square yards covered by a continuous "sheet" of this coral only a few inches thick and stopped in its upward growth after reaching the sea surface but spreading laterally from the peripheral. Probably the "sheet" comprised the coalescence of numerous separate colonies. Because of the foraminiferous veneer underlying it, it would appear to require no great violence of wave power to hydraulically scale off parts of such a rock layer.

More impressive are the examples of seaward wave-erosion. The results of this are represented by the huge blocks broken off the reef front and tossed onto the reef flat. At Bikini (Emery *et al.*, 1954) they were normally 5-10 feet cubed, but some blocks were 20-30 feet long and more than 10 feet thick. Many of these blocks have been washed 100-300 feet shoreward by hurricane waves. Newell (1956) furnished a photograph of one such enormous block thrown up on the reef flat at Raroia. Its comparatively old age is shown by the intertidal undercutting that has taken place. Fosberg and Stearns (manuscript 1954) asserted that occasionally they are aggregated into large block-fields, areas of the reefs completely covered by enormous fragments. While sailing by the leeward side of Lugagi Islet of Namu Atoll in 1956, the writer saw a large area of the reef flat several hundred feet across mantled with boulders from 3-5 feet in diameter. On the reef adjacent to the ship's pass there stood a block the dimensions of which was estimated to be 10 by 20 by 7 feet by the writer. Two blocks each about six feet cubed were seen at Jaluit washed 150 feet from the reef margin to the beach edge. The relative recency of this breakage was shown by the lack of intertidal erosion such as that shown in Newell's photo from Raroia (Plate 41). An aerial photo of the reef at Namorick shows numerous such boulders appearing between 10-20 feet wide and long by 5-10 feet thick. While relatively few of the larger blocks are tossed up onto the reef flat, undoubtedly these few represent but a small fraction of what is broken off to sink down onto the atoll slopes. At Bikini slumped sections of the reef as much as 40 feet long lie on the shallow terrace that fringes the seaward edge (Emery, Tracey and Ladd, 1954, p. 32) At the margin (p. 30) collapsed sections of the reef that rest on submarine terraces are indicated by matching reentrants up to 500 feet wide and extending 25-200 feet into the reef. The attrition through this mechanical and hydraulic erosion of the reef must be enormous, even though much of it may require the rare storm waves to accomplish.

At Raroia, Newell spoke of angular clefts or notches in the reef which he terms incomplete channels. He said that these "clearly are being lengthened headward as storm waters cross the islets towards the lagoon." Several aerial photos shown clearly indicate the mechanical nature of the erosion. They do not occur on the reef at Kapingamarangi Atoll in the Carolines. In a check of Emery, Tracey and Ladd's studies of Bikini, Eniwetok, Rongelap and Rongerik I find no mention of similar features, nor have I, in my examination of the aerial photographs of numerous reefs in the Marshalls and Carolines observed such features except for the far northern atoll of Taongi. In the latter, however, the triangular notches on the lagoon reef edge were cut into the lagoon side of large vegetated islets and did not run across from the seaward reef flat but large gravel and boulder fans extended into the lagoon. They could be accounted for by headward erosion by storm waters running across islets at an earlier date subsequent to which storm-washed gravels and sands again closed the gaps and reconstituted the vegetated land. Newell concluded from his observations that the shallow channels between islets all are of very recent origin, although the deep ship passage probably is inherited from an earlier gap in the rim.

Although such incipient shallow channels appear to be rare, their advanced stages, cutting across the islets and forming numerous small slivers of islets, are familiar occurrences on most atolls. According to Newell (1956, 328) "Topographic forms of the islands, including conspicuous flow lines in the coarse coral rubble, generally at right angles to the atoll rim, strongly suggest that the land has been inundated many times, indeed built up in places, by translation waves that sweep across the atoll rim to the lagoon." These flow lines obviously are the results of wave transport of sediments scoured loose by mechanical erosion.

The flow lines are associated with another erosional feature mentioned by Newell but which is not mentioned in the Bikini study (Emery, *et al.*, 1954). On Raroia the excurrent areas of the reef flat (Newell 1956, 350) commonly were found to be furrowed by irregular shallow grooves converging, fan-like, towards the gaps in the algal ridge. The grooves are discontinuous and erratic. Their floors are scoured clean by gravel and sand but are very uneven and interrupted here and there by gravel-filled pot-holes. Newell regarded these grooves as incipient surge channels and said that like the latter they led to outer grooves. Because of their shallowness, such grooves on the reef flat are not always obvious to the ground observer. They did not come to the writer's attention during the traverse of long stretches of reef flats on both lagoon and seaward sides on numerous atolls. However, prior to reading Newell's monograph on Raroia, and during the course of the examination of aerial photographs, the writer had noticed the occurrence of these shallow grooves on the seaward sides of certain reef stretches, and had come to the same conclusion as Newell in relating them to developing surge channels. Nevertheless, they are not conspicuous for most reef flats even on aerial photographs, or for all or most sections of those atoll reefs on which the writer found them to occur.

The flowlines showing the excurrent movement of gravels along these shallow troughs furnish support for the contention that the development of surge channels and of the outer groove and spur system of windward reefs is chiefly the result of mechanical scour. The origin of the groove and spur system and the role of erosion in their formation have been points of controversy. The importance of this outer front of the atoll reef has long been known. Darwin (1889, 86) wrote that:... "Should the outer and living margin perish, of any one of the many low coral islands, round which a line of great breakers is incessantly foaming, the whole, it is scarcely possible to doubt, would be washed away and destroyed in less than half a century." Although the writer joins with Newell in regarding the groove and spur system as the result primarily of erosion, paradoxically, it appears that the grooves dissipate the enormous energy of ocean waves and "play a vital part in the function of the coral reef as a breakwater. Near their outer ends, which extend to the maximum depth of appreciable wave action. . .they interfere with the normal orbital water motion associated with waves on a sloping bottom by "taking the bottom out from under the waves"; at the inner end they pursue a "divide and conquer" policy. The resulting effect upon waves is remarkable." (Munk and Sargent, 1954, 276).

In their study at Bikini, Munk and Sargent found that the distribution of the grooves can be correlated with the distribution of wave power around the atoll, being most developed where wave power is greatest. They wrote that "Most of the grooves begin at a depth of 35 - 50 feet, then run up the reef slope into and through the surf zone. At the inner end they may end abruptly or be continued as surge channels, or as tunnels with blowholes under the reef platform. Just inside the surf zone, around the blowholes and the heads of grooves and channels, colonies of Lithothamnion and corals rise about 2 feet above the general reef level. The upper faces of the spurs are paved with living Lithothamnion which present an extremely rough surface. The sides of the grooves are covered with projecting, often bracket-like colonies, The bottoms of the grooves consist of relatively smooth rock and sand." It was found at Bikini that between Bikini and Aomoen islets the grooves are spaced about 25 feet apart, are about 16 feet deep at their inner ends, and vary in width from 3 to 6 feet. Newell (1956) described the groove and spur zone at Raroia as very like the one at Bikini.

In explaining this phenomenum (1950, 431) Kuenen wrote: "At first the trenches might be explained as erosional forms, scoured by the waves in the rock of the reef. Several observations show, however," he claimed, "that they have been formed by growth. The covering with live nullipores, the formation of tunnels, the transverse connections at right angles to the rush of the waters, and finally the absence of sane or other erosion tools around the blow holes, all testify to the absence of mechanical wear." Emery, Tracey and Ladd (1954, 26) appear to agree with Kuenen in stating: "Probably there is mechanical abrasion during periods of exceptionally heavy weather, but this does not seem adequate to explain the grooves as erosional features". With Kuenen, they took the position that the phenomenum represents a constructional form developed by outward growth of Lithothamnion. But, as Newell pointed out, "it is not at all clear just how processes of organic accretion could produce the serrate reef front." In fact Kuenen's statement has certain weaknesses that defeat its argument.

In the first place, if these features resulted chiefly from growth, the grooves would all terminate at the reef front instead of transgressing the reef edge to continue inward as surge channels or as tunnels trenched in the reef flat. The surge channels sunk in the reef flat certainly could not be regarded as constructional features. Secondly, the covering with live nullipores is over the ridges or buttresses between grooves and along their sides, not along the bottom of the grooves where active erosional tools in the form of gravels and sands operate. Moreover, Kuenen himself stated (1950, 422) that "despite the strengthening influence of encrusting Lithothamnion on the reef structure in the breaker zone, there can be little doubt that, for the reef mass as a whole, growth is greatly retarded by the presence of *these almost stationary veneers.*" Since the live nullipores prevent the growth of coral, the only significant growth agency comprises the nullipores which Kuenen said constituted almost stationary agents.

The formation of tunnels may be because of algal growth covering the troughs but the trough itself must have been scoured out by erosion posssibly during an emergent period, and, if such were the case, solution erosion by fresh water runoff must be postulated to account for the furrows. Roofing over of the troughs occurs only where they are narrow and the roof of algae is but a small part of the space resulting from erosion. The absence of sand or other erosional agents around blow-holes most likely may be attributed to inadequate or inopportune observation, since this observation generally is only possible at low tide stage when the force of the surge might not carry sands and gravels from the bottom of the grooves through the blow-holes. During high tide when the deeper water movement might bring sands out of the blow-holes, such sediments would be removed from their vicinity by the tidal currents. Moreover, it is likely that most of the abrasion is accomplished in the downward and outward transport of sediments, from the reef flat rather than in upward heaving of materials, although this also must occur. In both events, the movement represents a back and forth surge of abrasive materials with the waves. Emery *et al.* (1954, 25-26) stated that "there is no evidence that the algae are roofing over or otherwise filling the grooves", whereas "the waves remove much material from the reef in small pieces which are transported down the grooves and down the terrace". Such a movement undoubtedly would rasp out troughs across the reef flat that would lead to the development of surge channels and grooves as was pointed out earlier. The writer also has been seen sands and gravels in surge channels and pools which were connected by tunnels with the grooves on the windward reef opposite Uliga Islet on Majuro Atoll. Newell (1956, 346) wrote that "The surge channels (at Raroia) are headward extensions of the outer grooves, and they are being cut and deepened by gravel scour. All the Raroia examples contain potholes filled with rounded cobbles and pebbles. Many extend within 15 meters of shore." He stated that while the channels are lined at the rim by small corals and blisters of *Porolithon onkodes* (Lithothamnion), "the lower walls and floors, however, are scoured by sand and gravel as are those of the outer grooves. . . The coralline algae are not . . . very active in the gloomy recesses of the caverns where erosion clearly is dominant and accretion is at a minimum."

Another interesting bit of evidence refuting the idea of growth as the causal factor in the development of the grooves system is the fact that, according to Munk and Sargent (1954), the surge channels at Bikini are "properly turned to the average wave characteristics. An average depth of 15 to 20 feet and a length of about 200 feet between the outer end of the platform (Lithothamnion ridge) and the inner ends of the channels correspond to a fundamental period of oscillation of 8 seconds, which is also the prevailing period of the waves of the trade winds." It would be odd indeed for a growth agent such as Lithothamnion to adjust its growth to such a point of correlation. On the other hand, it is entirely conceivable for a mechanical erosion process to develop on a sea-level reef flat until it reaches a point of adjustment with average wave oscillation periods. While Munk and Sargent declared an inability to clarify the reef molding process, they assert that "It is clear in general that the reef form represents some kind of equilibrium between the erosive or destructive power of the waves and the growth potential of the reef-building organisms. It is generally apparent that in areas where the wave action and hence presumably destructive power is greatest, growth of reef builders is also most rapid. (Yonge, 1940, 355, 374). Hence windward reef faces may be nearly in equilibrium under conditions of rapid growth and erosion, leeward ones under slow growth and erosion". The arguments against this conclusion may be seen from the following comments.

The grooves are not all of the same length. Newell (1956, 342-343) stated that "Where dissection is incomplete, not all the grooves extend to the outer edge of the (8 meter) terrace. This and the fact that the terrace has a very regular outer margin suggest that the form of both spurs and grooves is the effect of erosion rather than construction. There is very little roofing of the grooves by algal deposits on Raroia. On the other hand, the spurs are quite unequal in breadth. If they were simply buttresses of algal deposits being extended seaward against the surf, they would probably advance at unequal rates, and this would produce a lobate or irregular margin." As a matter of fact, this is the character of the leeward reefs which have little Lithothamnion and which develop no surge channels and grooves.

One final interesting phenomenon pointed out by Emery, Tracey and Ladd (1954, 26, 29-30) provides a clue to the importance of mechanical erosion versus lithothamnion upbuilding. At Bikini, Eniwetok, Rongerik, and Rongelap in the northern Marshalls on the windward reefs (e.i., where lithothamnion is most vigorous and important) a shallow terrace "slopes gently seaward, from a depth of 15-25 feet at the reef edge to a depth of about 50 feet at the outer edge. Where well developed, the terrace is rather flat for a distance of several hundred yards from the reef edge; in other places its slope is 10-15 degrees. The living reef rises from this terrace". By contrast, "the most striking feature of the western reef is the steepness of its seaward slope . . .The visible part of the seaward slope is indeed a steep submarine cliff. . . .From a depth of 100 feet to an undetermined depth, greater than 180 feet, the cliff is vertical". . . .They go on to point out that on the western side of the atoll the reef flat is wider than to windward. Newell (1956, 334) points out a similar terrace at Raroia and also in the Bahamas (Newell and Rigby, 1957, 24).

It is generally agreed by students of coral reefs that the windward sides of coral atolls provide the best conditions for coral growth. Thus, lacking destructive agencies, one would expect the reef wall on the windward sides to be cliff-like rather than comprising a gentler slope supporting sediments brought down from reef surface erosion. Such terraces appear to be most explicable as a result of erosion of the windward side by mechanical scour, leading to a gradual retreat of the reef edge through headward erosion in the surge channels (Newell, 1956, 346) and the breakage of the spur projections during heavy storms. Recent studies in the Bimini area of the Great Bahama Bank (Newell and Rigby, 1954, 68) "are suggestive that the 3-fathom depth may correspond rather closely with the base level of marine planation for the present sea level". Umbgrove (1947, 104) estimated the limit of wave abrasion of hard rock at 40 fathoms and Barrell (1917, 779-780) placed it at 50 fathoms. Emery, Tracey and Ladd (1954, 30) concluded that the Bikini terrace probably is erosional but thought that it might antedate the present reef.

The foregoing account and the evidences provided by aerial photographs of the Marshalls and other atolls make clear the vast importance of mechanical erosion through the abrasive power of sands and gravels and the hydraulic power of waves. Although no quantitative values can be given for its role as compared with marine solution and bio-mechanical and bio-chemical erosion, the writer is persuaded that mechanical scour occupies one of the dominant roles if not the dominant role in the destruction of coral reefs and atoll land.

REFERENCES

Barrell, J., 1917, Rhythms and measurements of geologic time. *Bull. Geol. Soc. Am.* **28** : 776-785.

Darwin, Charles, 1889, The structure and distribution of coral reefs, 3rd ed., Appleton and Co., New York, p. 334.

Dietz, R.S. and Menard, H.W., 1951, Origin of abrupt change in slope at continental shelf margin, *Bull. Amer. Assoc. Petrol. Geol.* **35** : 1994-2016.

Doty, Maxwell S., Jan Newhouse, Harvey A. Miller and Kenneth Wilson, 1954, Floristics and plant ecology of Raroia atoll. *Atoll Research Bulletin.* **33** : 58.

Emery, Kenneth O., 1946, Marine solution basins *Journal of Geology.* **54** : 209-228.

Emery, K.O., J. I. Tracey and H.S. Ladd, 1954, Geology of Bikini and nearby atolls, *Geological Survey professional paper* **260-A,** U.S. Gov't Print. Off., Washington, D.C., p. 265.

Emery, K. O., 1956, Marine geology of Johnston Island and its surrounding shallows, Central Pacific Ocean. *Bull. of the Geol. Soc. of Amer.* **67**: 1505-1520.

Fairbridge, R.W., 1952, Marine erosion, Seventh Pacific Science Congress, Vol. III.

Fisk, H.N., 1944, Geological investigation of the alluvial valley of the lower Mississippi River, War Department, Corps of Engineers, U.S. Army.

Flint, Richard F., 1957, Glacial and Pleistocene Geology, John Wiley and Sons, inc., New York, p. 553.

Fosberg, F.R. and MacNeil Stearns, 1954, The geography of the northern Marshalls, preliminary typed manuscript, 1954.

Ginsburg, Robert N., 1953, Intertidal erosion on the Florida Keys. *Bull. Marine Science of the Gulf and Caribbean, Contr. Marine Lab., Univ, of Miami,* **98** : 55-58

Kuenen, Ph. H., 1950, Marine geology, John Wiley, New York, p. 551.

Ladd, H. S. and J.I. Tracey, Jr., 1949, The problem of coral reefs. *Scientific Monthly,* **69**, (5) : 1-8.

LeBlanc, Rufus J. and Hugh A., Bernard, 1954, Resumé of recent geological history of the Gulf Coast. *Geol. en Mijnbouw,* **16** : 185-194.

Munk, Walter H. and Marston C. Sargent, 1954, Adjustment of Bikini atoll to ocean waves. Bikini and nearby atolls Marshall Islands, *U.S. Geol. Survey, Prof. paper* **260-C,** U.S. Gov't Print. Off., Washington, : 275-280,

Newell, Norman D., 1956, Geological reconnaissance of Raroia (Kon Tiki) atoll, Tuamotu Archipelago. *Bull. Amer. Ms. of Nat. History,* **109**, (3) : 55.

Newell, Norman D. and J. Keith Rigby, 1957, Geological studies on the Great Bahamas Bank, In Regional aspects of carbonate deposition, edited by Rufus J. LeBlanc and Julia G. Breeding, *Amer. Assoc. of Petrol. Geol. Spec. Public.* **5** : 70.

Ranson, Gilbert, 1953, Observations sur les principaux agents de la dissolution du calcaire sous-marine dans la zone cotiere de iles coralliennes de l'Archipel des Tuamotu, *Compt. Rendus Seances Acad. Sci. Paris.* **240** : 806-808.

Yonge, C.M., 1940, The biology of reef-building corals, In Great Barrier Reef Expedition, 1928-29, *Science Reports, London British Museum,* **1** (14) : 353-391.

THE EVOLUTION AND DESTRUCTION OF ATOLL LAND

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My purpose in this paper is briefly to review the relationship of eustatic changes in sea level to the morphology of atoll reefs and land areas and to show the present stage and the future in the evolution of atoll land. In this exposition the writer still accepts the debated conclusions that relatively permanent islets are formed on reefs chiefly during a period of falling sea levels, while rising sea levels gradually plane them off and eliminate them. The recent stage of rising atmospheric temperatures and rising sea levels (Fairbridge, 1957) thus is a period of shrinkage and destruction of man's habitat on coral atolls. The long term glaciation prospect (Emiliani, 1955) promises reinstatement and enlargement of man's atoll habitat.

In the study of the morphology of coral atolls and their vegetated land, one always is driven first to discuss the question of the origin of coral reefs and atolls, since so much of the argument depends upon the premises made. Numerous studies have been made of this question since Darwin in the mid-19th century first propounded his subsidence theory to account for the construction of coral reefs and atolls. Various alternate theories developed by opponents of Darwin's views have been summarized by different authors, especially carefully by William Morris Davis (1928), J. Stanley Gardiner (1931), Francis P. Shepherd (Submarine Geology, 1948), and Ph. H. Kuenen (1950). Probably most students concerned with the coral reef problem now accept the main premise of Darwin's subsidence theory, especially since the recent borings at Bikini Atoll (1946) and Eniwetok Atoll (1951) confirmed the earlier (1896) boring studies at Funafuti Atoll showing the great thickness of coral and algal lime structures. At Funafuti, coral and coraliferous algal deposits were found to a depth of over 1,100 feet (Shepherd 1948), while at Bikini they were found down to 2,556 feet (Dobrin 1954) and at Eniwetok down to basalt at 4,222 and 4,610 feet in two drill holes. Since reef building corals will not grow significantly under a depth of about 200 feet (MacGinitie 1949 and others), the inference is that these deep cores once stood less than 200 feet from the surface of the sea, and that only subsidence could explain their present position relative to sea level. Ekman (1953) thought that isostatic depression of the earth's crust could occur over a period of less than one or two million years from the weight of limestone produced in such a group of coral islands as the Maldives. However, since reefs do not develop from depths greater than 50-85 fathoms, a layer of limestone developed from these depths up to the surface probably would be insufficient to initiate subsidence or overcome crustal resistance to down -warping. Therefore, subsidence must be explained without consideration of the reef limestone cap, although with subsidence, the increasing thickness and weight of limestone may continue or accelerate the subsidence. Emeliani (1954, p. 854) wrote that . . ." all that is known about the Pacific basin indicates that most of it is an area of great stability and has been such for a long time. Therefore, subsidence on a regional scale, such as would be needed here, can be excluded with confidence." Thus, he concluded, "All cases of subsidence in the Pacific basin appear to be strictly local phenomena connected with volcanic intrusions and extrusions and subsequent isostatic adjustments. . . "

In discussing the origin of the Northern Marshalls guyots or flat-topped seamounts, Hamilton (1956, p. 3-4) wrote that Emery *et al.* (1954) postulated some regional subsidence and individual sinking of the volcanic masses to explain submergence. "Most writers," said Hamilton (p. 47-48), "in considering the increase in ocean volume in geologic time, hold that the ocean basins sank as the volume of oceanic waters increased (because of release of waters from the interior of the earth). Thus, the present position of the sunken islands (and the atoll foundations) must be partially due to isostatic adjustments under the volcanic ridge but also to a general sinking of the ocean floor..." However, "Inasmuch as appreciable increase in ocean volume, sedimentation, compacting of soft sediments, and isostatic adjustments have been discounted as major factors which could completely explain the submergence of the guyots probably only tectonic activity or crustal movement, together with the preceding factors, would have caused deep subsidence of the area of the Mid-Pacific Mountains. Both Schuchert (1932, p. 537-561) and Kuenen (1950, p. 549) postulate crustal movements to explain great eustatic changes. There is little large-scale faulting in the Mid-Pacific Mountains."

Hamilton (1956, p. 47-48) found several writers favoring the explanation of Griggs (1939) and Vening Meinesz (1944; 1948) proposing deep subscrustal convection currents as causing significant subsiding movements of the crust. Agreeing with this view, Hamilton stated that in his opinion "isostatic adjustment, sedimentation, compaction, and rise of sea level are not adequate to account for the great depths to which the Mid-Pacific Mountains and their Guyots have been submerged." However, he felt that if one is prepared to accept the ideas of Meinesz and Gunn "that the great loads on the Pacific crust are borne partly by the elastic strength of the downbowing crust and partly by hydrostatic pressure of the underlying lithosphere, then the idea should be carried to its ultimate conclusions under an excessively great load a point might be reached beyond which the strong crust would reach its elastic limit and the mass previously supported in part by the crust would founder and seek its isostatic level..." In any case, he wrote: "it appears proven that a subsidence of the Pacific Basin of several hundreds of fathoms did take place in the area of the Mid-Pacific Mountains."

Newell (1956, p. 324-325) felt that subsidence is not invariably involved in the origin of atolls and thought that Hoffmeister and Ladd (1944) had "satisfactorily demonstrated that some atolls of the Fiji and Tonga Islands have been formed over platforms not subject to extensive and long continued down-warping." With favorable ecologic factors of reef coral-growth, including a foundation whose top was within the depth zone of reef growth, a coral reef will grow to the surface regardless of still-stand or submergence (granted slow subsidence or submergence) (Hamilton, 1956, p. 50). This essentially summarizes the so-called "antecedent platform" theory of atoll formation proposed by Wharton (1897) and elaborated upon by Hoffmeister and Ladd, although the original idea also must be credited to Darwin (Hamilton, 1956, p. 49).

An alternate theory of atoll origin, termed the glacial control theory, proposed by Professor Daly (1910) of Harvard University also has active proponents. In characterizing the rival supporters of the subsidence and glacial control theories respectively, Ladd and Tracey (1949) humorously termed the famous 3 decades of controversy between William M. Davis and R. A. Daly as the 30 years' war. According to the glacial control theory, during glacial epochs the sea level was lowered to a vast extent so as to truncate through wave abrasion presently submerged seamounts and provide platforms accessible to reef-building corals. Then as the ice melted, the corals built up reefs as the sea level rose. The supposed flatness of lagoon bottoms presumably resulted from wave planation. Daly, however, viewed the glacial lowering as on the order of a few hundred feet.

In their book on the Natural History of Marine Animals, 1949 (p. 135-143) MacGinitie and MacGinitie appeared to favor this upward growth theory as against the subsidence theory and inferred that Shepard's study of submarine canyons suggested that the ocean level may have been lowered nearly a mile during glacial epochs, thus supporting Daly's theory and explaining the great depth of the volcanic base. Daly did not assume the thousands of feet lowering of sea-level that the MacGinities appear to have inferred to him, however, and Shepard stated that "There is virtually no evidence.... that the waves beveled off volcanic island platforms to Daly's -250 foot level" (p. 275).

Hess' fathometric survey in the Pacific indicated the existence in the area of his survey of at least 160 flat-topped truncated and beveled cones which he called "guyots" ranging in depth from 3,000 to 6,000 feet (Dobrin, 1954). If the ocean level had indeed dropped to such an extent, Daly's theory might provide a better overall explanation for such phenomena as coral reefs and islands, the Great Barrier Reef and the numerous submarine canyons at great depths on the continental shelves. Shepard (1948, p. 268), however, was cautious in interpreting his findings on glacial sea-levels.

Moreover, seismic refraction studies at Bikini (Dobrin, 1954) indicated a minimum depth to the igneous base of the atoll of 3,000 feet but a possible maximum of 13,000 feet, and Dobrin asserted that "if, as seems logical," the identity of the 11,000 fps refraction layer under the surface of the atoll consists of calcareous material like that now being deposited "then the atoll must have formed somewhat in the manner Darwin proposed, with a total subsidence of more than two miles." Shepard also concluded that although "It may be too soon to say that 'Darwin was right,'... there is no denying that the major tests have indicated that submergence on a large scale has taken place."

Flint (1957, p. 261) described various factors capable of causing sea-level change and wrote that "We must admit that we know little as yet concerning the glacial control of sea-level. All we can discern at present is that the inferred fluctuations of sea-level seem to fit the pattern of the more recent fluctuations of glaciers and to promise closer comparisons as future study adds to our knowledge."

An interesting correlation has been drawn by Emiliani (1955, p. 561) between high carbonate stages in deep sea sediments and low general temperatures of the sea water. This appears to provide a method for ascertaining past climatic changes. From variations in carbonate content and variations in relative abundances of cold and warm water pelagic Foraminifera as indicated by their tests in ocean sediments it has been found (Emiliani, 1954, p. 854-855) that "A temperature decrease of some 8°C from the Middle Oligocene to the end of the Pliocene in the deep waters of the Equatorial Pacific reflects and emphasizes the general temperature trend during the Tertiary which resulted in the ice age."

Moreover, in studying the deep-sea cores Emiliani (1955, p. 567) found that the demonstrated correlation of at least five core stages (in low latitudes) with glacial and interglacial events in high latitudes "strongly indicates that the climatic pattern in high latitudes, and that wet and dry phases in equatorial and tropical regions correlate with glacial and interglacial ages. Also, contemporaneity of colder and warmer ages the world over is indicated." Further (p. 569) the "General agreement between ages of insolation minima and the even core stages (studied by Emiliani) supports the conclusion that summer insolation at high northern latitudes and Pleistocene temperatures may be related... a time correspondence seems to exist between temperature and insolation, but correspondence in amplitude is not exact. A causal connection is suggested but not proved."

It is clear that whatever the cause or causes, relatively rapid changes of sea levels have taken place during Pleistocene times. Since both subsidence and glacial sea-level changes appear well-established in the atoll evolution processes, Kuenen (1947) proposed a combination of the subsidence theory with the glacial control theory. He felt that such a theory met the objections to either when applied separately and that it explains "some matters that neither of these theories can account for", such as the absence of deep passes, the uniformity of lagoon depths, and the basin character of lagoons. The latter, he felt, did not accord with atoll formation as explained by the antecedent platform theory, because wave planation of large atoll foundations would result in a domed platform with higher center than peripherals and hence with lagoon centers shallower than lagoon fringes. Such situations do not prevail on large atolls. Fairbridge (1957) contended on the other hand that "from multiple sources of evidence there seems general support for Zeuner's theory (1952) of a non-glacially controlled eustatic drop of sea level which lowered the relative world ocean several hundred feet during the course of the Pleistocene. Any climatically controlled hypothesis must allow for this additional factor."

However, as Hamilton (1956, p. 50) citing Stearns (1946, p. 262) concluded: "It is theoretically possible to get all the various kinds of reefs with and without submergence. No theory is all-embracing, and attempts to explain all reefs with one theory are destined to failure. The happy conclusion here is that almost everyone is right at some time and in some places."

Assuming the premise of subsidence and glacial control, then, as jointly being responsible for the present structure of most coral atolls in the Pacific, one should proceed to examine the latter factor more closely, since glacial control is the more important of the two in the morphology of the superstructure of present-day atolls. Kuenen (1947) pointed out that only vague evidence of the rate of subsidence is available and that it most probably is not more than a few tenths of a millimeter per year while the Pleistocene rise of sealevel probably was at least ten times the average pre-glacial subsidence of atoll foundations.

The extent of Pleistocene sea-level drops and rises is uncertain, and different scholars have come to varying conclusions. Antevs (1928) stated that if glaciation climaxes in both hemispheres were reached simultaneously, the sea level was lowered by some 305 feet. If the contemporaneity was only partial the sealevel may at most have been lowered 290 feet. The topography of the shallow Sunda Sea, he wrote, suggests that it has partly been carved out at epochs when the sea level stood at least 240 feet lower than at present. Kuenen (1947) referred to Daly's estimate of 75 meters lowering of sea level during the last (Würm) glaciation. To this amount, he wrote, must be added 5 meters for the recent world-wide sinking of ocean level, thus making a total of 80 meters. In his earlier book on Glacial Geology and the Pleistocene Epoch (1947) Flint wrote that "it is now believed that at the time of the most extensive glaciation the sea level was reduced 350-400 feet, that in the 4th glacial age it was reduced 230-330 feet and that if all the existing glaciers were to melt, the sea level would be raised 65-165 feet above its present position." In his more recent book (1957) he is doubtful of the value of the estimates on ice volumes of past glaciations owing to the inadequacies of data on thicknesses of the large ice sheets. He wrote that "Published values for the position of sea level at glacial maxima relative to existing sea level, deduced from assumed glacier volumes, range from -85 meters to -120 meters. The best that can be said for them is that they are of the same order of magnitude as the values inferred from geologic data, which have greater validity." But he placed the post-Tyrrhenian regression of sea level tentatively at a minimum of -90 meters. "This implies that in Boreal time, 7,500 to 8,500 years before the present, sea level was at least 36 meters lower than now, with respect to the land." An important question which is the crux of the problem of atoll land formation is whether there has been a sea-level during the Recent Epoch higher than the present.

Shepard and Suess (1956, p. 1082-1083) estimated that 11,000 years ago sea level stood about a hundred feet lower than at present that, and except for a possible temporary halt some 7,000 or 8,000 years ago, sea level has continued to rise, though of late at a slower rate, without "any indication of a post-glacial sea level higher than that of the present." This statement seems to represent a change from Shepard's view in 1948 when in his book "Submarine Geology" he referred to wave-cut benches standing at uniform height around some coral islands. He then pointed out that "Investigations of the islands of Oceania by Ph. H. Kuenen, C.K. Wentworth, H.S. Palmer, H. T. Stearns, G.A. MacDonald, H. S. Ladd, J.E. Hoffmeister, and many others have shown that these terraces occur with amazing regularity. These terraces have been recognized also in the Atlantic and Indian Oceans. Probably one stand of the sea was about 25 feet above the present. A well-developed bench at about 5 feet is also recognized and has great regularity around the Hawaiian Islands. "Obviously," he concluded, "a sea-level change could alone account for these benches."

Cloud (1952, p. 47) claimed that "the recent world-wide 6-foot fall of sea-level" may be amply documented, and he cited as one example the remnants of an elevated Heliopora reef flat on Onotoa Atoll occurring up to 2 ½ feet above the inner edge of the present reef flat, as well as what he terms "elevated cobble stripes" 6-7 feet above the present reef flat. McKee (1956, p. 11) found on Kapingamarangi Atoll "high-level remnants of stratified rock considered to antedate the latest fall in sea level." Couthouy (1843-44 p. 140-141) long ago wrote: "At almost every Paumotu (atoll) visited, I found the shore of the lagoon raised from 18-30 inches, containing imbedded shells and corals standing as they grew." Couthouy specifically mentions Clermont Tonnerre, Raraka and King's Island (Taiaro) Atolls as having such reef rock with shells *in situ*. Friederici (1910) found marine shells *in situ* elevated one or two meters on Niau and Maria Atolls, thus indicating an emergence or a former higher sea-level stand but he did not attempt to date the emergence.

After his field study of Raroia, Newell's opinion on recent changes (1956, p. 351) was that "The evidence of the erosion of the reef flat taken in conjunction with the general sterile appearance over great areas, suggest an appreciable very recent uplift or drop in sea level of perhaps 15 or 20 cm." He was unable to find evidence on the atolls he visited of a terrace 5-6 feet above the present level.

Flint (1957, p. 263) apparently did not accept these interpretations of the evidence when he stated that certain "very scattered data" which he cited "suggest that the theory of a Hypsithermal (Climatic Optimum) sea-level higher than the present one is improbable, and that emerged undeformed strandlines which have been correlated with the Hypsithermal may be in fact very much older." Newell also pointed out that H.N. Fisk, Rufus LeBlanc and Hugh Bernard have marshalled an impressive body of evidence from the Gulf Coast region of North America that casts doubt on an appreciably higher sea level during the Recent than that of the present.

However in a study summing up a great array of data establishing tentative correlation of Postglacial radiocarbon dates and sea level changes Fairbridge (1957) demonstrates convincingly that there were several stands of sea level during the last 5000 years higher than that of the present. He showed a definite 10-foot higher level during the middle of the Climatic Optimum at about 3,600 years B.P. (the so-called Peron emergence).

During the so-called Abrolhos Emergence, about 2,300 B.P., he indicated a 5-foot level higher than that of the present, and he also showed a 2-foot higher level (the Rottnest Emergence) at 1,200 A.D.

During travels among the Marshalls atolls in 1956 the writer found elevated remnants of what appeared to be island ledgerock resting on the lagoon reef flat of Ebon Atoll (Wiens, 1956, p. 6). These rose 5-6 feet above the reef flat at intervals in a line stretching over half a mile long. Individually, these "pedestals" were 30-40 feet long, 10-20 feet wide. At one end of the line one of the large blocks of rock was connected with the rock underlying the main islet of Ebon. Others were isolated 100-300 feet from the islet, with the intervening flat apparently scoured away by storm or other means of erosion. Some supported a growth of halophytic *Pemphis acidula.* While it was not ascertained whether they were of reef rock or conglomerate structure, it did not appear possible that they could have originated except at a higher stand of sea-level than the present. Their surfaces appeared to conform to a five or six foot terrace above present mean sea-level, although the heights were estimated by eye measurement.

Lowering of sea level was undoubtedly an important factor in producing the atoll islands. "Gardiner expressed the opinion that all habitable atolls are the result of this shift. Some writers have suggested that the emerged atolls have resulted from the piling up of coral debris by the waves, but it seems more likely that most of them have been exposed by the lowered sea level. It has been recognized by most students that the atoll islands show abundant evidence of having emerged." (Shepard 1948).

Newell (1956, p. 332) nevertheless asserted that the conglomerate rock platform underlying the loose sediments on the islets of Raroia which rose to between 0.5 and 1.0 meters above average high water comprised entirely bioclastic material which could have been formed near the present sea level. He found no *in situ* reef material and did not consider it an elevated platform, but rather a depositional surface of cemented coral rubble. He thought it improbable (p. 346) that "atoll islets invariably rest on a pre-existing reef flat", and that islets may be formed on reefs by hurricanes without the necessity of negative movements of sea level.

The writer's observations on coral reefs in the Marshalls and eastern Carolines have been that in reef sectors where corals and coralline algae have just reached the water surface at low tide, there appears to be little sand, gravel and boulder accumulation, and islets do not occur. Their formation appears to occur invariably in the middle and highest parts of the dead reef. The reef here has died and become planed flat in large part by erosion because the once live corals and algae have been killed by a lowered sea level (Newell, 1956, p. 341). It is precisely at these elevated parts that sediments are heaped by hurricanes to form or to enlarge islets. Since different reefs may grow at different rates owing to local conditions, in some areas elevated reef remnants may form the base of islets. At other places on a reef the islets may have resulted from depositional activities of storms. The latter occurrences need not invalidate the contention supported by Kuenen (1950) that "practically no cays and ramparts could have been formed but for the preceding emergence" of the reef. "Elevated islands" or reef islets that rise on most reef flats may be of sand or debris or of solid rock. The writer believes with Kuenen that "they have evidently been formed during a recent relatively higher stand of sea level."

Kuenen (1950) took the view that erosion of exposed reef rock through chemical solution resulting from rainwater is so rapid that the "pre-existing atoll and barrier rims must have suffered severe attack during the retreat of the Pleistocene oceans, and not improvably were entirely beheaded at sea-level". While he concedes that this conclusion is still highly speculative, he asserts that the amount of destruction gives an indication of the right order of magnitude. Thus, Kuenen and others who believe this with him are convinced that the present emerged ledgerock could not have remained from prior to the last Pleistocene glaciation as Flint's interpretation places it, but has formed since the last glaciation. This would be particularly true where marine shells persist *in situ.*

Once land is formed, whether through reef emergence or subsequent deposition of storm debris, its preservation is greatly aided by the growth of terrestrial vegetation and the development of beach rock. The roots of vegetation help to hold the loose debris together. Marine birds roosting in bushes and trees drop guano which in time may develop phosphatic cementation of underlying loose sediments, thus further consolidating the land.

Beach rock originates from sand and gravel laid down in successive layers mostly on the lagoon sides of islets. It generally has a lagoonward dipping character at such sites and shows a stratification indicating the nature of its origin. Consolidation of beaches into rock through cementation processes provides a protective armor for the loose sediments of atoll land, slows down wave erosion, and reduces danger of storm-scour of islet soils.

Beach rock is abundant around islets of atolls and relatively rare around high islands of moderately great rainfall such as Guam (Emery and Cox, 1956, p. 399). In discussing the origin of beach rock Emery and Cox summarized several theories currently held. One is that beachrock develops where the interstitial water of beaches is sea water, which is already saturated with calcium carbonate, and that it should be absent where the interstices are occupied by ground water that has passed only through volcanic rocks and is presumably not saturated with calcium carbonate. Water left by falling tide or rising through capillary action evaporates near the sand surface, precipitating salts that serve a cement. Readily soluble salts such as sodium chloride are removed by the next high tide, but salts such as calcium carbonate may remain to form a more permanent cement.

Emery, Tracey and Ladd (1954, p. 45-46) suggested that sun heating of the beach during the day reduces the solubility of CO_2 in the interstitial water close to the surface, so that its pH rises. If the water is initially near saturation, calcium carbonate is precipitated. However, Emery and Cox's study of beachrock in the Hawaiian Islands (1956) revealed no unequivocal preference of beachrock for beaches having interstitial water composed of sea water, ground water from limestone plains, or ground water from volcanic rocks (p. 401). They also rejected a suggestion by Cloud that the cementing might result from the biochemical activity of blue-green algae. Since these algae are probably restricted to the topmost fraction of an inch, their activities could not explain cementation of individual layers two feet or more thick. Bacterial action depositing amorphous calcium carbonate suggested by Nesteroff and by Ranson did not appear as a satisfactory explanation because of the insufficient amount of organic material in the sand. Emery and Cox also found that stable beaches (Merrin, 1955) were not essential for beach rock formation. In short, their conclusion was that although beach rock is abundant in many places, we do not know how it forms (p. 402). It is known, however, that the cementing material that binds sand into beachrock consists of calcite with some aragonite (Ginsburg, 1953, Emery, Tracey and Ladd, 1954, Illing, 1954, Ranson, 1955) or of calcite without aragonite (Emery and Cox, 1956, p. 383).

Although many examples of old beachrock occur on atolls, not all is of old formation. Kuenen (1950, p. 434) asserted that cases have been known in which beach sandstone has formed in one year's time. That the cementing acting is rapid on reef flats is clear. In 1954 the writer saw shell cases from World War II cemented firmly and partially imbedded in the reef surface. In 1956 the writer found an example of dipping, well stratified and partially consolidated beachrock on the seaward and windward side of an islet on Kwajelein. This undoubtedly showed beachrock in the formative process, since pieces could be kicked off by foot or broken off by hand, although the sand was firmly enough welded together to preserve the shape of the pieces broken off.

Much of the beachrock observed by the writer in the Marshalls and Carolines atolls were of old origins. McKee (1956, p. 11) wrote that the relatively old age of the beachrock observed at Kapingamarangi Atoll is suggested by the presence of typical beds preserved as relic deposits standing above present high-tide level on several islands, by the bevelled remnants of typical beachrock extending seaward a few hundred feet across the reef flat from the present island shores, and by evidence of replacement of calcium carbonate by apatite in strata both in the interiors and on the shores of several islands. He found little evidence of beachrock forming currently, although evidences of cementation of loose debris on the seaward side of reefs were abundant. Beach rock presently observed around islets on atoll reefs thus appears to be mostly of earlier origin.

Emery and Cox (1956, p. 389) found that in the Hawaiian Islands the beachrock appeared to extend about the same distance above high tide as the wash of the waves, but in several places it extends as much as 3 feet below low tide. Thus, the position and attitude of most beachrock there is closely accordant with present beaches. Some beach rock was found discordant with present beaches owing to retreat of beaches, or to coastal elevation or submergence after the beachrock was formed (p. 390).

Both beachrock presently located on current shores of islets and relic beach rock off the seaward shores of present islets serve the important role of protecting the accumulations of loose sediments on islets from storm scour and erosion. The relic bands of beachrock often found some distance from seaward shores of atoll islets act as a breakwater, a second line of defense after the reef margin and algal ridge.

Another important role of beachrock remnants relative to atoll land is the trapping of sand and other sediments carried lagoonward toward their lee sides by high-tide or storm waves from the ocean side. Man can copy from nature in creating land artificially through application of the same principle. This was done at Kapingamarangi by the building of a wall of large boulders gathered from the reef in the middle and higher portions of the reef, probably on a remnant of beachrock or island ledgerock awash at high tide (Wiens, 1956). Pepeio Islet with 0.7 acres of planted coconut land in 1954 was asserted to have been built up in this fashion since 1919. Tipae Islet on the same atoll also was man-aided to develop to its present 1.6 acre area at an earlier time. Causeways built between islets have led to similar land accretions. Such sediment accumulation can be relatively rapid. On Ringutoru Islet of Kapingamarangi the lagoonward land-building during the last forty years or so has been at the rate of about a foot per year. The writer observed a similar movement of land lagoonward although at a somewhat slower rate at Likiep Village in the northern Marshalls where the edge of an old wharf now is 20-30 feet from the deep water which it once bordered.

The nature of the building of atoll land deserves a brief mention. Those who have examined atoll islets often have found their topography to exhibit interior depressions which lead to higher rims. These simply have resulted from the formation of surrounding beach ramparts and ridges. On the seaward side and the exposed channel sides the stronger ocean waves throw up ramparts of coarse boulders and gravels that generally form the highest natural parts of the land surface. Sometimes, two or more parallel or concentric ramparts may occur. The writer has seen the ramparts described by McKee (1956, p. 8-9) for Kapingamarangi Atoll and containing blocks up to 36 inches in diameter and similar ramparts at Ebon and Utirik. Hedley (1896, p. 14-15) refers to an island in the Gilberts formed of successive parallel ramparts 30-50 feet across described by the missionary, Whitmee, who ascribed each rampart to the result of a single storm. Hedley uses this example to bolster his argument based upon the more decomposed state of the rubble in the interior of the islet that islets grow peripherally seaward as well as lagoonward.

As applied to relatively permanent atoll islets during the current stage of atoll land morphology this appears incorrect. There is no indication that the ramparts were not piled onto an already existing land surface. In fact seaward parts of the existing land may have been scoured away and added to storm debris piled in ramparts farther inland. Newell (1954, p. 14) and McKee (1956, p. 6-8) provide carefully gathered evidence that the seaward sides of the islets on Raroia and Kapingamarangi have been wearing away rather than building seaward. However, in a personal letter to the writer Newell emphasized his belief in the importance of storms in the atoll land-building process, and he expressed the view that most of the island building at Raroia during the last 800 years had been accomplished by hurricanes. However, he does not suggest seaward extension of land-building. He thought, moreover, that this cycle was initiated by a slight drop in sea level. Hedley's thesis would conform with conditions during a period of falling sea-levels, but not with the recent stage of rising sea-level. Aerial views of a number of widely scattered reefs provide convincing evidence of the net erosion on seaward sides of islets.

While the retreat of the seaward shoreline may be a geologically rapid process, this retreat is relatively slow compared with the current land-building lagoonward. Land owners on Kapingamarangi informed the writer that they had not observed any notable retreat of the seaward shore due to erosion during the last several decades, while no informants with whom the writer talked in the Marshalls had observed such a retreat. This does not apply to the washing away of soil and vegetation and the destruction of some individual islets by occasional hurricanes, however. Vast land destruction can be done within a few hours by a hurricane. Friederici (1910, p. 139) described the razing of 1-2 meter thick layers of sedimentary land on the principal inhabited islet of Anaa Atoll in the Tuamotus in 1906 together with all their houses, the stone church, and 85 inhabitants. Matukerekere on Kapingamarangi (Wiens, 1956) prior to 1858 was said to have had an area of about 0.7 acres most of which was lost in a typhoon of that year. The storm of 1905 on Arno (Stone, 1951) washed away large parts of Namej and Ine Islets, and the storm of 1918 washed away a part of Arno Islet in the Marshalls. Nevertheless, Stone observed that examination of the areas once destroyed indicated the rapidity of the rebuilding of the land. A typhoon (presumably that of 1905, blowing across the lagoon at Utirik in the Northern Marshalls (Wiens, 1957, p. 22) destroyed at the south end of Utirik Islet a vegetated land area which the writer estimated to be a mile long narrowing to a point from a base 500 feet wide. Here a high sand ridge subsequently developed over a line of beachrock on the lagoon-shore facing the wind. This appears to have prevented the sand deposits from recovering the interior of the area which lies as a desert waste. A line of beachrock bordered this on the seaward side.

Most of the recent land additions observed by the writer in the Marshalls and Carolines were constructed of foraminiferous sands and small sized gravels added along lagoon shorelines. Moderately strong wind-driven currents and waves are able to accumulate and pile up such sediments. The dozens of concentric sand ridges that have pushed lagoonward on some islets show this type of land building without major storms, while land-building has been going on steadily at Kapingamarangi in the absence of typhoons.

One facet of this development that the writer has not seen mentioned in publications is that, on a long-term basis, a continuing rise of sea level also brings into this land building process gradually rising beach ridges on the lagoon side as the land pushes outward toward the lagoon. The general average of beach ridges on this side of an islet therefore, should be higher in their more recent occurrences and lower as one approaches the older ridges nearer the center. Thus, the succession of beach-ridge additions on the lagoonside results ultimately in a gradual slope of the land from the top of the present lagoon beach ridge toward the central depression. During a period of dropping sea levels, these ridges conversely should produce a topography that slopes from the beachridge marking the downswing of sea level toward the lagoon shoreline. In practice, however, the differing results of unequal storms produce no such conformity to theory, although in the present stage the general slopes inland from the lagoonside beach ridges appear to run downward toward a depression.

With a topography that falls inward from the rims to a central depression, most islets of sufficient size during a period of rising sea levels ultimately would develop swampy interiors. In some of the atolls this already has occurred as on Taringa Islet on Kapingamarangi Atoll. In others, man has hastened the process by excavating pits in low areas to reach the fresh-water lens in order to grow swamp taro.

In looking at the past record of fluctuating sea-levels, one can see Pleistocene levels as much as 100 feet above the level of present atoll land surfaces (Flint, 1957, p. 270). During as recent a time as only 3,600 years ago the 10-foot higher sea-level (Fairbridge, 1957) would have submerged most present-day atoll land surfaces. We may still be in the midst of an interglacial period that has had a long time trend toward a warmer earth (Carson, 1954, p. 144) or we may have reached a leveling off plateau of climatic fluctuations that will see little change in sea-level for many centuries. Looking toward the future climate, Emiliani (1955, p. 571) thought that a prophetic glimpse might be had by extending toward the future the insolation curve he obtained in his study of Pleistocene temperatures. "...if its trend during the last 10,000 years continues, an insolation minimum may be expected to occur in about 10,000 years, when the northern lands will have completed their isostatic recovery. Conditions will then be favorable for the inception of a new ice age."

Projecting these facts and speculations in terms of the future of atoll land, the writer finds man's habitat on Pacific Atolls facing an uncertain and probably gloomy "short-term" prospect, but a much enlarged and perhaps improved "long term" prospect. In the next 5,000-6,000 years it is possible that periods of rising sea-levels may inundate most present land on atolls and possibly destroy most present reef islets. During the first half of this century the rise in sealevel has amounted to 2-3 inches (Russell, 1957). Were the earth's temperatures to increase and the sea-level to rise at the same rate, within a thousand years most atoll islets would be awash or at least largely comprised of saline swamps. While temporarily the rate of land-building lagoonward exceeds the rate of land erosion on the seaward shore the migration of the land area lagoonward that is taking place "will probably end with their being pushed back across the reef into the depths of the lagoon" (Kuenen 1950, p. 447).

On the other hand, with the definite onset of continually decreasing earth's temperatures as forecast by Emiliani for the long-term future, the renewed glaciation then will result in ever-emerging land area, a much enlarged and safer habitat for man and other terrestrial life. Enlargement will result from the availability of the entire present reef flat and much of the lagoon slopes of atolls for vegetation growth, although a "makatea" surface may render parts of it productively unusable. Greater safety will result for man and other terrestrial animal and plant life because the increasing elevation above sea-level will make such land less susceptible to destruction by typhoon and tidal waves. Moreover, now fragmented and isolated land will become more or less continuous around the central lagoons which will become progressively smaller. Passes into lagoons will become shallower and most lagoon bottoms eventually may also emerge to become dry land. Except for now submerged or drowned atolls and reefs which may then emerge and add to the land area, present atolls then will cease to exist by definition, and will become "high" limestone islands.

REFERENCES

Baden-Powell, D.F.W., 1953, Correlation of Pliocene and Pleistocene marine beds. *Nature*, Oct. 24 : 762-763.

Carson, Rachel, 1951, The sea around us. The New American Library, New York, pp. 166.

Cloud, Preston E., 1952, Preliminary report on the geology and marine environments of Onotoa Atoll. Gilbert Islands, Atoll *Research Bulletin*, **12**.

Daly, R.A., 1910, Pleistocene glaciation and the coral reef problem, *Amer. Journal Science*. **30** : 297-308.

Davis, William Morris, 1928, The coral reef problem, *Amer. Geog. Soc., Spec. Pub.* **9** New York, pp. 596.

Dobrin, M.B. and B. Perkins, Jr., 1954, Seismic studies of Bikini atoll. *U.S. Geolog. Survey Prof. paper* **260-J,** U.S. Gov't Print. Off., Washington, pp. 17.

Ekman, Sven, 1953, Zoogeography of the sea. Sidgwick and Jackson, Ltd., London, pp. 417.

Emery, K.O., J.I. Tracey, Jr. and H.S. Ladd, 1954, Geology of Bikini and nearby atolls. *U.S. Geol. Survey Prof. paper* **260-A,** U.S. Gov't Print. Off., Washington, pp. 265.

Emery, K.O. and Cox, 1956, Beachrock in the Hawaiian Islands. *Pacific Science,* October : 382-402.

Emiliani, Cesare, 1955, Pleistocene temperatures. *Journal of Geology*, **63** : 538-578.

Emiliani, Cesare, 1954, Temperatures of Pacific bottom waters and Polar superficial waters during the Tertiary. *Science* **119.**

Fairbridge, R. W., 1957, Personal communication.

Flint, Richard F., 1957, Glacial and Pleistocene geology. John Wiley and sons, inc., New York, pp. 553.

Friederici, Georg, 1910, Ein Beitrag zur Kentniss der Tuamotu Inseln. *Gesell. für. Erdk. zu Leipzig*, : 97-176, Mitt. gen., Leipzig.

Gardiner, J.S., 1931, Coral reefs and atolls. MacMillan Co., New York, pp. 181.

Griggs, D., 1939, A theory of mountain building. *Amer. Jour. Science* **237**: 611-650.

Gunn, R., 1943, Quantitative aspects of juxtaposed ocean deeps, mountain chains, and volcanic ranges. *Geophysics.* **12**: 238-255.

Hamilton, Edwin L., 1956, Sunken islands of the Mid-Pacific Mountains. *Geol. Soc. of Amer., Memoir* **64.**

Hedley, Charles, 1900, General account of the atoll of Funafuti. *Australian Museum Memoir* 3, 1896-1900, Sydney, pp. 18.

Hoffmeister, J.E., and Ladd, H. S., 1944, The antecedent platform theory. *Jour. Geol.* **52**: 388-502.

Illing, L. V., 1954, Bahaman calcareous sands. *Amer. Assoc. Petrol. Geol. Bull.* **38**: 1-95.

Kuenen, Ph. H., 1947, Two problems of marine geology: Atolls and Canyons. *Verhand. der Kon. Ned. Akad. van Wet. Afd., Naturkunde*, Amsterdam, **43**: 69.

Kuenen, Ph. H., 1950, Marine geology. John Wiley, New York, pp. 551.

MacGinitie, G.E. and Nettie MacGinitie, 1949, Natural history of marine animals. McGraw-Hill Book Co., New York, pp. 473.

McKee, Edwin D., 1956, Geology of Kapingamarangi atoll, Caroline Islands. *Atoll Res. Bull.*, June 30, **50**: 37.

Merrin, S., 1955, Beachrock in northeastern Puerto Rico, *First Caribbean Geol. Congress*, Antigua, British West Indies, 155 pp. (mimeographed).

Newell, Norman D., 1956, Geological reconnaissance of Raroia (Kon Tiki) atoll, Tuamotu Archipelago. *Bull. Amer. Mus. of Nat. History* **109** (3): 55.

Ranson, G., 1955, La consolidation des sédiments calcaires dans les regions tropicales (Paris). *Acad. des Sciences, Compt. Rend.* **240**: 640-642.

Russell, Richard J., 1941, Climatic change through the ages, In Climate and Man. *Yearbook of Agriculture* : 67-97, U.S. Department of Agriculture, Washington pp. 30.

Russell, Richard J., 1957, A Lecture reported by the New York Times, May 5.

Sauer, Carl O., 1957, The end of the Ice Age and its witnesses. *Geographical Review*, January 1957: 31-32.

Schuchert, C., 1932, The periodicity of oceanic spreading, mountain making and paleography. *Bull. Nat. Res. Council* **85**: 537-561.

Shepard, Francis and Suess, H. E., 1956, The rate of post-glacial rise of sea-level. *Science*, **123**: 1082-1083.

Shepard, F.P., 1948, Submarine geology. Harper and Bros., New York, pp. 348.

Stearns, H. T., 1946, An integration of coral-reef hypotheses. *Amer. Jour. Sci.* **244**: 245-262.

Vening Meinesz, F. A., 1948, Major tectonic phenomena and the hypothesis of convection currents in the earth. *Quart. Jour. Geol. Soc.* **103** : 191-207.

Vening Meinesz, F. A., 1944, De verdeling van continenten en oceanen over het aardoppervlak. *Versl. Kon. Akad. v. Wetensch, Amsterdam, Afd. Nat.* **53**: 151-159.

Wharton, A.J. L., 1897, Foundations of coral atolls. *Nature* **55**: 390-393.

Wiens, Herold J., 1956, Field notes on atolls visited in the Marshalls. *Atoll. Res. Bull.*, **54**.

Wiens, Herold J., 1956, The geography of Kapingamarangi atoll in the Eastern Carolines. *Atoll. Res. Bull.*, **48**, Washington, pp. 84.

Zeuner, F.E., 1952, Dating the past; an introduction to geochronology. London, Methuen Co., 3rd ed.

MARINE TERRACES IN THE WESTERN PACIFIC AND THE ORIGIN OF CORAL REEFS†

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(Abstract)

During the diastrophism due to a sudden total displacement of the solid earth shell a region shifted from a lower latitude to a higher would be relatively uplifted and the continental slope or insular slope brought above sea level would gradually resume normality through intermittent adjustments and leave marine terraces wherever a place tarried at sea level before final submergence. Terraces of such origin are preserved below present sea level. In a region that was shifted from a higher latitude to a lower the terraces formed would be now situated above sea level. While a place tarried at sea level, if the environment fitted for the survival of reef corals coral reefs would have been built to be submerged below or uplifted above the permanent sea level environment. When the earth surface has resumed normality after diastrophism there is only uplift of crustal masses due to their shifting along the shear planes marked out by earthquake foci and coral reefs would be continually brought out of the sea. On the forward edge of moved crustal masses as along the island chains and geanticlinal ridges in the Western Pacific there is this continuous bringing of coral reefs above sea level. Therefore the coral reefs formed during a quiet geological timeperiod as the present would mainly grow downward as the deeper sea bottom is uplifted within the depth for the flourishing of reef corals.

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Symposium: *Tin and Tungsten Deposits in the Pacific Area*

Convener: Vija Sethaput, Thailand.

THE OCCURRENCE OF TIN AND TUNGSTEN IN MALAYA†

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(Abstract)

The occurrence of tin and tungsten minerals in Malaya is described.

Introductory chapters deal with the tin and tungsten minerals found in Malaya; the description and age of the host rocks to mineralization; the different types of deposits that occur; and the mineral associations and genesis of the deposits.

The major portion of the paper is devoted to descriptions of the geology of the principal deposits of tin-ore and tungsten-ore in Malaya, arranged geographically and subdivided into the different States. Perak and Selangor are the principal States where tin-ore is mined and together account for 31% of the world's total tin production. The Malayan tungsten-ore deposits are economically of little or no importance: most wolframite mined at present comes from Kedah and Selangor, while scheelite is chiefly produced in Perak and Pahang.

The paper concludes with a summary of production statistics and a short bibliography.

TIN AND TUNGSTEN MINERALS OCCURRING IN MALAYA

Only cassiterite, wolframite, and scheelite are or have been of economic importance in Malaya. However, a number of other tin and tungsten minerals have been identified and will be chiefly mentioned below.

TIN MINERALS

Cassiterite (dioxide of tin):

Detailed mineralogical studies of Malayan cassiterite are regrettably scarce. The only recent paper giving spectroscopic and chemical analyses is that by Pryor and Wrobel (1951) where the following data are given:

Locality	Percentage Sp determined		Spectroscopic Analysis										
	Spectroscopic	Chemically	Ta	Nb	Mn	W	V	As	Ti	Fe	Zr	Si	Sb
Tambun, Kinta	73.1	73.0	2.2	1.3	0.2	tr	tr	tr	0.2	0.9	tr	0.2	nil
Pulai, Kinta	70.9	71.6	0.2	0.2	tr	0.1	nil	nil	0.3	0.8	tr	0.6	nil
Tekka, Kinta	73.8	74.0	0.1	tr	tr	0.2	nil	nil	tr	0.8	tr	0.5	nil
Kacha, Kinta	75.0	75.2	0.1	tr	nil	0.1	nil	nil	tr	0.5	tr	0.3	nil
Siputeh, Kinta	74.8	75.0	tr	tr	nil	0.2	nil	nil	0.2	0.7	tr	0.2	nil
Sg. Way, Selangor	74.6	74.5	nil	tr	tr	tr	0.3	nil	nil	0.7	tr	0.5	0.2
K. Tinggi, Johore	61.2	60.8	6.9	1.1	0.1	tr	nil	nil	tr	0.5	nil	0.2	nil

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Other properties of certain varieties of Malayan cassiterite, which have been briefly referred to in the literature, are strong pleochroism and magnetic susceptibility. Neither of these properties has been fully investigated, but a few recent observations may be noted here. Thus a striking form of red-green pleochroism of cassiterite appears to be particularly common in concentrates from Gunong Jerai (Kedah) and Bakri (Johore), where the local mineral suite contains columbite-tantalite. With regard to the magnetic properties of cassiterite, two different types have been distinguished: a ferromagnetic type which is destroyed by heating and is found in areas where cassiterite occurs in close association with iron-ores; and a paramagnetic type which is persistent after heating, occurs together with columbite-tantalite minerals, and may be due to the presence of tapiolite in solid solution in the cassiterite.

Stannite (Sulphostannate of copper and iron):

This mineral has been recorded in insignificant quantities from a few localities in Kinta (Perak), and Selangor. It is possible that some tin is present in an acid-soluble form in many ores rich in metallic sulphides, and early experiments suggested that stannite may make up as much as 1.3% of such ores. No detailed work has been done on this problem.

Varlamoffite (hydrated dioxide of tin):

This mineral, consisting of SnO_2 with varying amounts of H_2O, has been tentatively identified in a yellow coating on cassiterite crystals obtained from Chenderiang (Perak). Associated with it there occurs another *secondary tin mineral* of the approximate composition ($CaO.SnO.SiO_2$) which does not correspond to any known mineral. Preliminary work at the Mineral Resources Division, Overseas Geological Surveys, showed that the mineral fluoresces yellowish-green with short-wave ultraviolet light, and a chemical analysis gave the following results:

		Per cent
CaO	...	19.14
SnO_2	...	58.48
$Si\ O_2$	...	21.26
Loss on ignition		0.50
		99.38

Further work on this unknown mineral is in progress.

TUNGSTEN MINERALS

Wolframite (tungstate of iron and manganese):

No detailed mineralogical data on Malayan wolframite are available, and its exact postion in the isomorphous series has not been determined.

Scheelite (tungstate of calcium):

Scheelite ore from Pulai (Perak) was analyzed with the following results:

		Per cent
WO_3	...	79.52
CaO	...	19.50
SiO_2	...	0.36
TiO_2	...	trace
Al_2O_3	...	0.07
Fe_2O_3	...	0.23
MnO	...	trace
MgO	...	trace
H_2O	...	0.14
P_2O_5	...	nil
Ta_2O_5 and Nb_2O_5		0.05
As_2O_3	...	trace
CoO	...	nil
CuO	...	nil
PbO	...	nil
SnO_2	...	0.25

(Analyst: J.C. Shenton)
(Geological Survey F.M.S.)

Ferberite (tungstate of iron):

This mineral occurred as black blocks and fragments in a fault fissure in weathered granite at Pulai (Perak), and appeared to be secondary. It was found together with another tungsten mineral, yttrotungstite, described below, and an analysis by the Mineral Resources Division of the Overseas Geological Surveys gave the following result:

		Per cent
WO_3	...	73.26
FeO	...	18.54
Fe_2O_3	...	4.56
MnO	...	0.78
Al_2O_3	...	1.16
SiO_2	...	0.65
CaO	...	not detected
MgO	...	0.14
H_2O-	...	0.10
H_2O+	...	0.75

Rare earth metals, Th, Cb, Ta, Zr, Ti, Mo, P, As, S, Bi, Cu, Pb, Sn	not detected
	99.94

(Analyst: L.C. Chadwick)
(Overseas Geological Surveys)

Stolzite (tungstate of lead):

This mineral has been found in small quantities at Lahat and Pulai in Kinta (Perak), and at Tui Gold Mine, Kuala Lipis (Pahang). The Lahat material is remarkable for a bright to medium fluorescence in short-wave ultraviolet light, the colour ranging from white tinged with green to greyish-white. It is believed that the fluorescence is not that of the tungstate itself, but is due to the presence of an activator.

Yttrotungstite (tungstate of rare earth metals):

A mineral unique to the Kinta District (Perak), found at Pulai. It was first discovered in 1921 and originally believed to be thorotungstite. The mineral is pale yellow and occurred in small quantities as shapeless blocks at the base of an eluvial cassiterite deposit overlying granite on a hillside. The mineral consists essentially of a tungstate of the rare earth metals, the yttrium group preponderating over the cerium group in the ratio of about 3:1. Handpicked crystalline aggregates of the mineral gave the following analysis:

	Per cent
WO_3	71.45
Y_2O_3 etc	15.52
Ce_2O_3	2.21
La_2O_3 etc	3.80
ThO_2	not detected
ZrO_2	not detected
Fe_2O_3	0.36
Al_2O_3	0.87
TiO_2	0.01
MnO	not detected
CaO	0.32
MgO	0.17
$H_2O - 105°$	0.07
$H_2O + 105°$	4.96
SiO_2 (probably due to quartz impurity)	0.37
	100.11

(Analyst: L.C. Chadwick)
(Overseas Geological Surveys)

Tungstite (trioxide of tungsten):

This secondary tungsten mineral has been reported as minute but well shaped crystals at Pulai (Perak), associated with scheelite; it has also been reported from Manchis (Pahang).

THE HOST ROCKS FOR TIN AND TUNGSTEN MINERALIZATION

Tin and tungsten ores have been found in most of the rocks occurring in Malaya. All such deposits are genetically related to granites which are intrusive into the country's sedimentary, volcanic, and metamorphic rocks of Ordovician-Silurian, Carboniferous, Permian, and Triassic ages. These sediments were folded and arched along a north-northwest axis during a period of mountain building in the Mesozoic era, when the Main Range granite was emplaced.

The exact age of the Malayan granite is not definitely known, but recent evidence suggests that at least some, if not all of it, was emplaced in Upper Triassic or Jurassic times. The different phases of the Main Range granite emplacement have been studied in the Kinta and Tapah areas of Perak and appear to be as follows:

11. Weathering and kaolinization.
10. Hot springs.
9. Hydrothermal intrusions of vein quartz.
8. Late pneumatolytic stage, carrying gold, especially where sheared granite is found (Changkat Rembian).
7. Aplitic and pegmatitic intrusions, often contemporaneous with (6).
6. Main pneumatolytic stage, carrying tin, tungsten, etc. especially in the unsheared part of the intrusion; kaolinization of some granite.
5. Solidification of granite in contact with sedimentary cover.
4. Further shearing of quartz porphyry, shearing of earliest consolidated granite (Changkat Rembian), and continued intrusion of granite.
3. Shearing of quartz porphyry, and continued intrusion of granite.
2. First material, rapidly cooled by contact with country rock, forming quartz porphyry.
1. Granite magma starting to rise.

The question as to what extent the Malayan granite is as a whole tin-bearing has never been investigated fully. A few analyses from ordinary granite adjacent to known tin-fields suggest that tin-ore is finely disseminated through many of the Malayan granites. Thus three analyses of Kinta granites from stone quarries and one from an apparently barren microgranite dyke gave the following percentages of SnO_2:

		Per cent SnO_2
G.S. 19841:	Biotite granite, Papan, Kledang Range	0.0025
G.S. 19842:	Biotite granite Telok Kruin, Kledang Range	0.0025
G.S. 19859:	Biotite granite, Merbau, Tronoh, Kinta	0.0038
G.S. 19856:	Tourmaline microgranite, Pulai, Main Range	0.0076

Similar determinations on some granites in the Bukit Yong area (Trengganu) are said to have given values as high as 0.02% metallic tin.

While the genesis of tin and tungsten deposits is thus invariably linked with the granite, the actual deposits occur not only in the granite, but also in the adjoining sediments that have been invaded by the granite, and, of couse, in the overlying alluvium. One of the most favourable zones of deposition is close to the 'contact' between granite and sedimentary rocks; there, in the deep alluvial channel which is commonly found at the foot of the granite hills, eluvial deposits derived from tin-bearing veins in the roof of the granite combine with alluvial material washed down from the granite or from eroded lode deposits in the adjoining schist or limestone. Such channels are generally deepest in limestone, since acid surface waters have assisted further by dissolving the carbonate rock. Another generally favourable location for the deposition of alluvial ore is the trough-and-pinnacle topography of valleys with a limestone bedrock whose irregular surface acts as a series of natural riffles to trap and concentrate the tin-ore.

Whereas primary deposits of tin-ore are commonly found in either limestone or schist, as well as in the granite, some preferential deposition takes place in the case of the tungsten-ores, as wolframite is found more frequently at granite-schist contacts, while scheelite is more common at granite-limestone contacts.

An attempt to assess the relative proportion of Sn to W in the mineralization of the Malayan granite is made difficult by the fact that most tin mining is from alluvial ore, while most tungsten mining is from lode material; also the local distribution is so irregular that a ratio worked out from a number of individual mines would be valueless. The only approximate figure that can be considered is one based on the total Malayan output of tin-ore as compared with the total Malayan output of tungsten-ore. This ratio has been given by Fermor (1939), based on the total Malayan production from 1914 to 1937, as 1.7 parts of tungsten-ores to 100 parts of tin, but the figure is open to the objection that it does not take into account their relative mining economics.

TYPES OF TIN AND TUNGSTEN DEPOSITS

The occurrences of tin-ore and tungsten-ore in Malaya may be classified into primary and secondary deposits. Primary deposits are found 'in situ' and have not been disturbed physically since their original formation in the host country rock. Such deposits are the pipes, lodes, veins, stringers, or stockworks that are intrusive into the country rock, and the less spectacular disseminations that sometimes occur in granite, aplite, or pegmatite. Secondary deposits are concentrations of ore that have been effected during weathering and erosion of the primary deposits, whether by leaching (residual deposits), gravity movement alone (eluvial deposits), or water transportation (alluvial deposits). The ore in a residual or eluvial deposit therefore lies above, or down the slope of a hill from, its parent primary ore-body. On the other hand, ore in an alluvial deposit has been transported by streams, often to localities far removed from its place of primary deposition; accumulations occur in valleys or plains or may, in some instances, even reach the sea to form beach sands or sea-bed deposits, as in the Dindings and Malacca.

Some unusual secondary tin-ore deposits are alluvial concentrations of cassiterite that have been cemented by calcium carbonate; such deposits have been mined in Perlis and in a few localities in Kinta (Perak). Another type of deposit, as found at Jasin (Malacca), consits of stanniferous laterite, residual after stanniferous schist.

In this connexion two facts were of great economic importance to Malaya. Firstly, it so happened that most of the primary deposits of tin-ore were lodged in rocks which have since been eroded away. Thus uneconomic primary deposits of tin-ore have been gradually concentrated into valuable, easily worked, secondary deposits such as the Perak and Selangor tin-fields. Secondly, it is known that at some period during the Pleistocene, the sea level stood several hundred feet lower than it does at the present day: in some instances on the West Coast as much as 450 feet, and in others, on the East Coast, nearly 200 feet. During the period when the sea level was low, the rivers near the coast cut their valleys far below the levels of their present day flows. As a result of the subsequent rise of the sea to its present position, the floors of these valleys have now been covered with alluvium to depths often exceeding 100 feet, and much valuable tin-ore, that otherwise might have been carried out to sea and lost, has been deposited in this alluvium.

Owing to the great chemical stability and degree of hardness of cassiterite, secondary deposits generally yield more valuable concentrations of tin-ore than do primary deposits, but it is different in the case of the tungsten-ores. Unlike cassiterite, wolframite and scheelite, being softer than quartz, are rapidly ground away by the constant attrition of quartz grains during mechanical transport; they are also more liable to chemical alteration. Consequently tungsten-ores are found in Malaya almost entirely as primary lode deposits and as eluvial deposits derived from them, while alluvial occurrences are rare or absent.

THE MINERAL ASSOCIATION OF THE TIN AND TUNGSTEN DEPOSITS

Alluvial deposits of tin-ore that are being concentrated commercially yield large quantities of 'amang' (heavy mineral rejects). This material is easily obtainable for examination and has often provided the first indication of the presence of a mineral hitherto not known from any particular area. A complete list of all minerals recorded from the tin-fields of Malaya is not required here, but an abbreviated list of the more important minerals is as follows: allanite, anatase, andalusite (including var. chiastolite), arizonite, arsenopyrite, beryl, brookite, cassiterite, columbite-tantalite, epidote, gahnite, garnet (almandite), gold, ilmenite, iron and manganese oxides, monazite, pyrite, pyroxene, rutile, scheelite, siderite, topaz, tourmaline, uraniferous monazite ('cheralite'), wolframite, xenotime, and zircon.

Any examination of 'amang' from the alluvial tin-fields suffers from the disadvantage that only heavy minerals sufficiently stable to survive alluvial transportation can be recorded. It is therefore necessary to supplement the above list by adding such other minerals as have been found associated with primary tin or tungsten deposits. Of these, quartz, felspar, muscovite, and biotite are almost universal, and fluorite, amphibole and chlorite are very common; less common are the occurrences of torbernite with cassiterite at Sangka Dua (Selangor); of euxenite and tanteuxenite at Jelebu (Negri Sembilan), and Bakri (Johore); of native bismuth at Klian Intan and Kinta (Perak); of galena, sphalerite, jamesonite, and related sulphides in a number of localities in Perlis, Perak, Pahang, and Selangor; of lepidolite and zinnwaldite at Sungei Lembing and Bentong (Pahang), and Sungei Bernam and Kinta (Perak); of cinnabar at Kenaboi (Negri Sembilan); of corundum at Pulai (Perak); and of molybdenite at Sintok (Kedah), and Kota Tinggi (Johore).

It can be safely said that in Malaya the ores of tin and tungsten have, in general, a common genesis, and that all are of high-temperature, hypothermal origin, although a lower temperature of formation has been suggested for the Pulai (Perak) scheelite deposit and for the stanniferous stockwork or Sungei Kakura, Gambang (Pahang). A number of typical mineral associations can also be distinguished; these are defined by the presence of certain key minerals and have been collected into a number of groups. However, these groups should not be regarded as forming a rigid or exhaustive classification, and most of the ore-deposits that are described in this paper can be attributed to more than one group. Similarly, the order of the list is not intended to indicate successive temperatures of formation, or sequences of crystallization or general genetic relationships, which are subjects that cannot be adequately discussed until more detailed studies of the Malayan tin and tungsten deposits have been made. Within these limits the groups suggest are as follows:

(a) *Pegmatite veins, with cassiterite and tourmaline as typical constituents.* Other minerals commonly found are muscovite, fluorite, topaz, zinnwaldite, and beryl. A special case of this group are the columbite-tantalite bearing deposits at Gunong Jerai (Kedah), and Bakri (Johore), with associated garnet, gahnite, and monazite.

(b) *Sulphide veins, with cassiterite and arsenopyrite as typical constituents.* Other minerals commonly found are pyrite, chalcopyrite, fluorite, and tourmaline. The 'pipes' replacing Kinta limestone are the best examples of this group.

(c) *Quartz veins with cassiterite and wolframite as typical constituents.* Tourmaline, muscovite, and the metallic sulphides are very common; scheelite and fluorite are often associated with these deposits in the vicinity of calcareous rocks. The scheelite ore-body at Pulai (Perak), is perhaps a special case of this group, caused by the extensive replacement of limestone.

(d) *Quartz veins with gold and scheelite as typical constituents.* Metallic sulphides are common with these deposits, which have been described from Raub and Tui Gold Mines (Pahang).

(e) *Iron and/or manganese oxides associated with small amounts of cassiterite.* These deposits are known from three Malayan occurrences at Bukit Besi and Machang Satahun (Trengganu), and Pelepah Kanan (Johore).

THE GEOGRAPHICAL AND GEOLOGICAL DISTRIBUTION OF THE TIN AND TUNGSTEN DEPOSITS

PERLIS

Alluvial cassiterite is recovered from cave deposits in the Ordovician-Silurian limestone of the Setul Boundary Range and from the surrounding alluvium on the western borders of Perlis near Kaki Bukit. The ore occurs in irregular pockets in many of the limestone caves and has been recorded from fissures as much as 700 feet below adit level; most of the cassiterite is alluvial, but secondary cementation gives rise in some areas to a coarse conglomerate ore consisting of pebbles of limonite, quartz, and cassiterite set in a calcareous matrix.

Small quantities of lode cassiterite and some galena have been reported from limestone adjoining Gunong China to the north, and there is no doubt that the alluvial cassiterite found in the caves is derived from the granite that forms Gunong China. Unconfirmed reports suggest that the cassiterite may be associated with small amounts of wolframite, gold, and monazite in the area north of Gunong China.

KEDAH

Deposits in Kedah are known from five distinct areas described separately below. In addition traces of scheelite have been reported from Pulau Tuba in the Langkawi Islands.

Sintok

Lode deposits of wolframite and cassiterite occur at Bukit Kachi near Sintok and at a number of other localities of lesser interest nearby. Bukit Kachi mine, owned by J.A. Russell & Co. Ltd. was a steady producer of wolframite and some tin-ore between 1916 and 1940, the ore being won by underground shafting and a little surface 'lampanning' (ground-sluicing) of eluvial material.

The country rock in the area consists of metamorphosed shale, hornfels, and schist carrying tourmaline, muscovite, biotite, and quartz, with accessory ilmenite and sulphides, and some ferruginous quartzite. An intrusion of granite occurs nearby to the east of Sintok, and isolated small outcrops of aplite, microgranite, greisen, and muscovite-tourmaline pegmatite are common near Bukit Kachi. Lodes of vein quartz cut the country rock in two systems: main fissures trend between 345° - 360° parallel to the strike of the sediments, and secondary fissures trend between 10° - 25°, both fissure systems being near-vertical. Of these the main lodes are usually entirely in tourmaline hornfels, while the secondary lodes invariably occur within dykes of granitic rock which displace the main fissures. The mineralized quartz veins range in width from about $\frac{1}{2}$ inch to 7 feet and average about 2 feet; their shape is usually lenticular. Masses weighing upward of 50 pounds of almost pure wolframite have been recovered from time to time, while pieces of 2 to 3 pounds used to be very common. The ore appears to be limited to the quartz veins, and no mineral impregnation is known in the hornfels.

The history of the mine suggests that the better ore values occurred in the upper oxidized zone of the deposit, and that with increasing depth sulphides become more prominent. Heavy minerals at Bukit Kachi, in approximate order of frequency are: wolframite, cassiterite, chalcopyrite, pyrite, arsenopyrite, molybdenite, and scheelite; muscovite and tourmaline are universal; psilomelane and fluorite, and secondary copper minerals such as chalcocite, covellite, and malachite, are rare.

Ulu Muda

Alluvial cassiterite has been found in a number of scattered localities in the Ulu Muda area of Kedah near Lubok Kemahang, Sik, and Klian Weng. These occurrences are derived from a branch of the Main Range granite that extends northward through Kedah into Thailand, and which is the parent body to a number of cassiterite and scheelite deposits that have been worked in Thailand on the other side of the watershed. None of the Malayan localities have so far proved of any economic importance.

Baling

Small lode deposits of cassiterite and wolframite are found on three hills to the north of Baling, at Bukit Ibu, Bukit Setang, and Batu Perleh. Alluvial cassiterlite derived from these hills has also been recovered.

The hills consist of schist and metamorphosed shale intersected by quartz veins; the same granite described as occurring in Ulu Muda is found a short distance to the west. Both cassiterite and wolframite are known from Bukit Ibu and Batu Perleh; cassiterite only from Bukit Setang. Accessory minerals include muscovite, tourmaline, biotite, and arsenopyrite in the veins; and epidote in the sediments.

Gunong Jerai

Alluvial and near-eluvial cassiterite occurs along the south edge of Gunong Jerai ('Kedah Peak'). The chief alluvial mines are at Semiling and Bedong, while a near-eluvial deposit known as Tungku Daud's mine was worked at a height of about 2,000 feet on the southern slopes of the mountain near Singkir. A small occurrence of alluvial cassiterite has also been recorded from the nothwest side of the mountain near Yen Kechil.

The Gunong Jerai complex consists of a dome-like structure of quartzites and occasional schists (carrying muscovite, biotite, and tourmaline) underlain by a central core of two-mica granite which emerges at the surface along parts of the southern half of the mountain. It is possible to trace in the sediments zones of regional metamorphism with distinct biotite and garnet isograds, and there is a widespread development of pegmatites and some vein quartz near the granite margins. Mineralization is found in conjunction with the granite and, especially, with the pegmatites which normally carry coarse muscovite, tourmaline, and garnet, and which are often found intrusive parallel to the bedding of the sediments.

The alluvial mines at Semiling and Bedong, located at the foot of the granite in an area of weathered quartzites which are heavily intersected with pegmatite veins and vein quartz are interesting for their subsidiary production of columbite with the cassiterite, and for their typical suite of minerals which includes cassiterite, columbite-tantalite, tourmaline, zircon, garnet, gahnite, monazite, radioactive monazite ('cheralite'), magnetite, haematite, and traces of sillimanite. It is possible to trace a gradual change in the percentage ratio cassiterite: columbite-tantalite ranging from about 95:5 near Semiling to about 80:20 near Bedong some two miles to the east.

Tungku Daud's mine near Singkir lies well within the granite area of Gunong Jerai in the valley of Sungei Jerneh, where cassiterite is found in large waterworn pebbles in the alluvium between large boulders of local granite. Although the ore is waterworn, its exceptionally coarse grade and the proximity of the valley to the watershed suggest that the deposit is near-eluvial and has been derived from a nearby lode in the granite.

Kulim

Alluvial cassiterite and small amounts of lode cassiterite and wolframite occur at a number of localities near Kulim, and are related to the Gunong Bongsu granite complex. At Bukit Betang, near Karangan, mineralized quartz veins striking 275° with a dip of 60° south, and on an average 10 to 15 inches wide, occur in granite a short distance from a sedimentary contact (shale). The veins contain irregular concentrations of arsenopyrite, wolframite, and cassiterite, with some pyrite. There are also local concentrations of muscovite and tourmaline in greisen and aplite. Heavy minerals obtained at Karangan include ilmenite, monazite, and small amounts of columbite-tantalite, pyrite, and chalcopyrite.

PENANG AND PROVINCE WELLESLEY

No deposits of tin or tungsten-ore are known in Penang or Province Wellesley.

PERAK

The State of Perak produces approximately 60% of the total Malayan output of tin-ore and about 20% of the total world production. The most important tin-producing area is the Kinta Valley, but other large tin-fields occur at Taiping (Larut), Sungei Siput (Kuala Kangsar), and Tapah and Bidor (Batang Padang). Apart from these there are less important mining areas at Klian Intan, Selama, Temengor, Bruas-Dindings, and Sungei Bernam. The occurrence of wolframite in Perak is sporadic only, but a large deposit of scheelite was mined at Pulai in Kinta before World War II and produced about 8,000 tons of scheelite between 1929 and 1939.

Klian Intan

Veins and stringers carrying cassiterite are found traversing shale, hornfels, chert, and some quartzite and limestone in a number of localities near Klian Intan and Kroh in Upper Perak. The biggest of these occurrences is found at Gunong Paku near Klian Intan where Rahman Hydraulic Tin Co. Ltd. mine the hill by opencast methods at a height of some 2,000 feet above sea level.

The sediments at Gunong Paku consist of schist, phyllite, and graphitic and calcareous shale interbedded with some limestone, and are situated about 5 miles from the nearest large body of granite; it is believed, however, that the area is underlain by granite at no great depth. The sediments range in strike from 340° to 360° and dip steeply to the east; they are cut by a stockwork of closely parallel quartz veins striking 90° and dipping south with an average width of ½ inch, rarely reaching as much as 2 feet; and also by some minor intrusions of aplite, tourmaline aplite, and quartz-tourmaline rock. The quartz veins have been proved to persist to a depth of at least 700 feet below the crest of Gunong Paku. They carry tourmaline, cassiterite, pyrite, and chlorite, and small quantities of galena, sphalerite, arsenopyrite, pyromorphite, and native bismuth; secondary iron oxides and iron staining are widespread. No wolframite or scheelite are known from the area.

Although cassiterite occurs throughout the entire hill, chiefly in the quartz veins but also to some extent in the adjacent shales, the total grade of the ore is low, averaging about 1 to 1½ katies per cubic yard. In the past richer concentrations of ore have been found in certain sections of the hill, but such enrichments were generally discontinuous and quite irregular.

Selama

Small lodes of cassiterite and alluvial cassiterite are found in several localities near Selama and to the east and southeast of Selama. All these occurrences are connected with the Main Range granite and are generally found in the vicinity of contacts with shale or quartzite formations, or with small sedimentary roof pendants overlying the granite.

Few of these occurrences are at present of economic importance, and what little mining goes on is alluvial only. At Selama the country rock is quartzite, chert, shale, pyritiferous schist, and limestone; heavy minerals found with the alluvial cassiterite are chiefly monazite, ilmenite, and zircon; iron oxides are very common. At Klian Besar a cassiterite lode found in tourmalinized shale was very rich in arsenopyrite. At Ulu Sapetang a lode known as the Blanda Mabok lode was worked a long time ago and carried coarsely crystalline cassiterite together with argentiferous galena assaying 2 pennyweights of gold to the ton; the walls of the lode were tourmalinized shale and sandstone.

No tungsten ores have been recorded from this area.

Temengor

Small lodes of cassiterite genetically similar to those occurring at Selama are also found in the neighbourhood of Temengor. The best known locality is near the Sungei Klian about 3 miles southwest of Temengor. There the bedrock is granite and schist which carries, near the contact, tourmaline and andalusite (var. chiastolite), and is invaded by stanniferous quartz veins and lenticles. The granite is fine grained and locally grades into aplite. It is traversed by cassiterite-quartz-tourmaline veins varying in width from less than one inch to more than two feet; their shape is lenticular and they form an irregular stockwork in the country rock. Apart from cassiterite, arsenopyrite and pyrite are common, and rare occurrences of wolframite and scheelite have been reported.

Taiping (Larut)

Before 1889 the Larut tin-field was the biggest producer of tin-ore in Perak. All the ore mined at the present time is alluvial and is largely recovered by dredging. The tin-field lies on a level stretch of alluvial country at the foot of Gunong Hijau, part of the Main Range granite. This alluvium originally contained very rich tin-ore, in part brought down from the granite hills and in part from small lode deposits in the bedrock underlying the alluvium. Near the hills the bedrock is granitic, but farther away occur shale and sandstone, and some limestone, as exposed in the old mines or identified from bore samples.

The following minerals have been recorded from Larut: cassiterite, galena, pyrite, garnet, ilmenite, zircon, tourmaline, topaz, chalcopyrite, haematite, limonite, allanite, and epidote. There is an old unconfirmed report of an occurrence of wolframite, and the occurrence of columbite-tantalite has also been recorded.

Sungei Siput

In many ways the Sungei Siput tin-field can be regarded as a northerly continuation of the Kinta tin-field described below. Alluvium carrying good values of cassiterite lies along a main zone of mineralization near the margin of the Kledang granite range between Sungei Pari and Salak North, and on a less important belt in the vicinity of Sungei Chior and Sungei Plus. The cassiterite occurs in the alluvium and soil near the contact between granite and stratified rocks, and originates from mineralized veins in schist, crystalline limestone, and granite in the area. Sporadic occurrences of crystals of cassiterite have also been recorded in the granite itself.

Lode cassiterite is comparatively rare, but a few localities are known: a stockwork in shale and chert at Kamuning Estate, Sungei Siput; a lode in pegmatite and schist at Ayer Hangat, Salak North; quartz stringers carrying tourmaline and cassiterite in indurated shale and quartzite at Padang Balak, Salak North; an ore body in tourmaline-aplite and schist carrying cassiterite, pyroxene, biotite, and actinolite at Salak North railway station; and a quartz-cassiterite body with pyrite and arsenate of iron at Heawood Estate, Sungei Siput.

An occurrence of scheelite is recorded from Changkat Salak Estate, Bandar Bahru, where scheelite occurred in a 12-feet quartz lode traversing shale and striking about 315°, with abundant pyrite and tourmaline, a little cassiterite, and traces of arsenic and copper. No wolframite is known from the area.

Bruas and Dindings

Small quantities of alluvial cassiterite are found in a number of scattered localities in the vicinity of Bruas and the Dindings. All these occurrences are related to major granite intrusions.

The deposits at Trong and Bruas are derived from the granite mass of Gunong Bubu, and are situated on the lower slopes of the mountain and at the foot of it. The old mines at Bekor, on the western slopes of the Kledang Range, occurred at a junction of aplite and porphyritic granite with contorted shales, while at Ulu Bekor cassiterite and some wolframite were found in the granite itself.

Three localities, at Bukit Sigari, Tanjong Hantu, and Pulau Katak, are related to the separate granite intrusion at the Dindings. At Bukit Sigari cassiterite is associated with porphyritic granite and tourmaline, while at Tanjong Hantu and Pulau Katak small alluvial concentrations of cassiterite occur in beach sands and on the sea bottom.

Kinta

The Kinta tin-field possesses the greatest concentration of alluvial cassiterite at present known in the world. The source of the tin-ore is, throughout, the granite which crops out both to the east (Main Range) and to the west (Kledang Range) of the sedimentary plain. The cassiterite in the alluvial deposits has been derived from the erosion of tin-bearing veins, stockworks, and stringers cutting the granite or the sedimentary rocks in contact with it. Alluvial deposits of cassiterite have been found almost everywhere in the Kinta Valley, particularly at Chemor, Tambun, Ipoh, Menglembu, Lahat, Pusing, Tronoh, Gopeng, Kampar, and Chenderiang. They are particularly rich (a) where the underlying bedrock is limestone with pinnacles. i.e. where the irregular surface has acted as natural riffles trapping and concentrating the tin-ore, and (b) in areas of 'contacts' of granite with sedimentary rocks, where both slumped eluvial material derived from tin-bearing veins in the roof of the granite, and alluvial material washed down from eroded lode deposits in the granite or in the adjoining schist or limestone, combine to form a rich concentrate in the deep alluvial channel which is commonly found at the foot of the granite hills. The total thickness of the alluviam generally increases southwards and in some areas exceeds 120 feet.

Production of tin-ore from Kinta dates back to 1876 and has been continuous to the present day. The total production of the Kinta tin-field during the three quarters of a century from 1876 to 1950 amounted to about 1,200,000 tons of metallic tin, and present-day annual production averages approximately 28,000 tons, about 50% of which is recovered by dredges.

While from an economic point of view the occurrence of lode cassiterite is no longer of any importance, if compared with the vast amounts of alluvial tin-ore that are being recovered, considerable geological interest attaches to the type and distribution of the tin-ore deposits recorded 'in situ'. Such deposits have been found not only in the granite, but also in the sedimentary rocks, limestone and schist, which are abundant in the Kinta Valley.

The occurrence of tin-ore in granite is best developed in the Kledang Range near Menglembu, and most of these deposits consist of thin stringers of cassiterite traversing the granite, or of small lodes of quartz, cassiterite, pyrite, and arsenopyrite near the contact of granite and sedimentary rocks. Other types of deposits that have been described are in pegmatite and greisen, and in chloritized shear zones in the granite.

Tin-ore in limestone is usually found as fissure fillings or metasomatic replacements. The better known of these deposits, such as the Beatrice Mine or the Lahat Pipe, were rich ore bodies attaining depths of over 300 feet from the surface, usually of an irregular chimney-like shape; but small fissure veins with irregular bulges of ore owing to local impregnation of the wall rocks have also been recorded. In contrast to the deposits in granite, tourmaline is rare or absent in deposits in limestone; associated minerals are usually arsenopyrite, chalcopyrite, pyrite, fluorite, and tremolite.

Tin-ore in schist usually occurs as veins of cassiterite associated with pyrite or arsenopyrite and/or tourmaline that are intrusive into the schist and frequently run parallel to its strike. In most instances there is evidence that shearing has taken place in the country rock, and that subsequently intrusion occurred along the line of weakness thus created. The intrusions may be accompanied by aplite or by quartz veins.

The occurrence of tungsten-ores in Kinta is sporadic and only one locality of importance has been discovered. Both wolframite and scheelite occur: wolframite is known in small quantities from Tronoh, Chemor, Pulai, Tekka, and Gopeng; scheelite from Pulai, Selibin, Ampang, Tekka, and Temoh. Only the scheelite deposit at Pulai, mined chiefly between 1929 and 1939 by Kramat Pulai Ltd. is worthy of a detailed description. The main ore body was located underneath approximately 25 feet of alluvium at about 100 feet distance from the nearest granite outcrop of the Main Range; it occurred as an irregular body in schist that was interbedded with and faulted against limestone and was traversed by dykes and veins of aplite and pegmatite. The ore consisted almost entirely of fluorite and scheelite in a coarse intergrowth similar in structure to pegmatite; gangue material amounted to less than 1 per cent and was chiefly quartz. Contact-metamorphic minerals were found in the adjoining country rock, and included garnet, idocrase, axinite, tremolite-asbestos, and actinolite; tourmaline and cassiterite occurred in the associated pegmatites. Total production of scheelite from 1929 to 1939 amounted to about 8,000 tons.

Tapah and Bidor

The bulk of the tin-ore produced in this district is obtained from alluvial deposits, and just as the Sungei Siput tin-field can be regarded as a northerly extension of the Kinta tin-field, so the Tapah-Bidor field can be regarded as its southerly extension. As in Kinta most of the cassiterite has been derived from the erosion of stanniferous veins and stringers traversing the granite of the Main Range and the sedimentary rocks (shale, phyllite, and quartzite) in contact with it. Cassiterite lodes in situ are comparatively rare, but extensive stockworks and bands of pegmatite, aplite, and greisen in schist near Bruseh, and stanniferous quartz veins and stringers in granite near Bengkang, have been mined in the past. Tourmaline is a common accessory.

The Tapah-Bidor tin-field is remarkable for the recovery of alluvial gold as a mining by-product. It is believed that the occurrence of gold is confined to a separate phase of the Main Range and Changkat Rembian granite emplacement that is characterized by evidence of intense shearing.

Wolframite is found in considerable quantities at Changkat Rembian where it occurs associated with cassiterite in quartz veins traversing the granite, more particularly on the northern slopes of the hill. A small occurrence of wolframite is also reported from Bruseh.

Scheelite has been found in small quantities with alluvial cassiterite at Temoh near a granite-limestone contact.

Sungei Slim and Sungei Bernam

A number of scattered deposits of alluvial cassiterite occur in the valleys of the Sungei Slim and Sungei Bernam in southern Perak. The deposits are derived from the Main Range granite and adjoining mineralized sandstones and shales as exposed at Jeher near Tanjong Malim, where quartz veins carrying coarse cassiterite were mined in the past. In addition to the cassiterite the veins locally carry tourmaline, muscovite, lepidolite, kaolin, pyrite, arsenopyrite, and topaz. Local intrusions of pegmatite and aplite occur.

KELANTAN

The only deposits of tin-ore known in Kelantan occur in the valleys of Sungei Yai and Sungei Betis near the eastern margin of the Main Range granite and are associated with scheelite. Small amounts of alluvial cassiterite are also found on the Kelantan side of the Kelantan-Trengganu border near Bukit Yong.

Sungei Yai

The inaccessibility of this area has prevented exploitation until very recently. Chabai Tin Mines work alluvial cassiterite and scheelite near a contact between granite and schist showing evidence of contact metamorphism. Tourmaline is a common constituent of the heavy suite.

Trengganu

Deposits in Trengganu can be grouped into four distinct areas described separately below. These deposits, together with the occurrences at Sungei Lembing and Gambar in Pahang and most of those in Johore, make up Scrivenor's 'Eastern Tin Belt' of Malaya. There is so far little evidence from Malaya, beyond the purely geographical distribution, that the 'Eastern Tin Belt' is in any way genetically different from the 'Western Tin Belt' of Malaya. However, the question is still under discussion, and granites of two different ages have been mapped in Thailand just north of the Malayan border, with the 'Eastern Tin Belt' corresponding to the continuation of the 'Older Granite' of the Thai Geological Survey.

A point of interest is that, at two localities in Trengganu (and similarly at one locality in Johore), small amounts of tin-ore are associated with large deposits of iron-ore. Thus at Bukit Besi the iron-ore recovered from the mine has in isolated instances assayed as much as 8% metallic tin, and averages about 0.1%. Similarly at Machang Satahun the iron-ore and manganese-ore mined there often contain some metallic tin. The third locality in Johore (Pelepah Kanan) is described separately on p. 394.

Bukit Yong

Alluvial cassiterite is known from a number of localities in the basin of the Sungei Besut near Bukit Yong and to the south of it. None of these deposits are rich, and the rarity of any known lodes or stringers suggests that the greater portion of the deposits is derived from cassiterite disseminated throughout the local granite; a lesser portion of the alluvial tin-ore is known, in certain areas, to be derived from tin-bearing stringers in the granite.

Bukit Bidong Darat

Occurrences of wolframite and some cassiterite are known from the Bukit Bidong Darat and Bukit Rakit areas, where the local granite carries tourmaline and occasional irregular quartz-tourmaline veins with small amounts of cassiterite and wolframite. Bukit Bidong Darat consists of a series of indurated sandy shales striking between 295° and 315° and dipping from 70° to vertical, with an intrusion of granite known in the immediate vicinity. The shales are traversed by a stockwork of quartz veins which vary in width from a fraction of an inch to about 12 inches, and which carry some wolframite, chiefly on the east side of the hill. Traces of arsenopyrite and chalcopyrite also occur. The area was prospected recently for wolframite, but was found to be uneconomic except perhaps for a small operator.

Bukit Lentor

Deposits of wolframite and cassiterite occur at Bukit Lentor (formerly known as Bukit Runtoh) and at a number of neighbouring sites in the valleys of Sungei Dungun, Jengai, and Paka. While the alluvial deposits in the stream valleys carry both cassiterite and wolframite, the lode deposits formerly mined at Bukit Lentor predominantly contain wolframite. The bedrock there consists of quartzite, quartz schist, and slate, traversed and shattered by numerous quartz veins striking about 70°, dipping vertically, and with an average width of 12 inches, reaching as much as 3 feet width in places. The quartz veins contain wolframite together with oxides of iron and manganese, while in depth are found increasing amounts of sulphides (pyrite, arsenopyrite, and chalcopyrite). The wolframite occurs in irregular pockets, and blocks of pure wolframite weighing as much as 50 lbs have been recovered; however, in between the patches of ore the veins are barren. Mining was profitable in the upper oxidized zone, the ore becoming poorer in the lower sulphide zone.

As already mentioned, at Bukit Besi, a little distance to the northeast of these deposits, the iron-ore there contains small amounts of tin-ore.

Sungei Kemaman

Deposits of cassiterite, wolframite, and scheelite, are known from a number of localities near Sungei Kemaman and its tributaries Sungei Nipah, Tebak (north), and Cherul (South).

At Kajang and Sungei Ayam (Sungei Nipah) and at Tebak both lode and alluvial cassiterite occur. The bedrock consists of granite, schist, and quartzite, with a contact zone rich in andalusite, chiastolite, and some garnet; and lodes are found along two distinct lines of strike, one 360°, one 90°, the two intersecting frequently. Near the lodes have been developed chlorite, tourmaline, and some pyrite, while some quartz-muscovite greisen rich in cassiterite has been mined as a low grade ore at Sungei Ayam.

The wolframite-cassiterite deposits of Chendrong and Buloh Nipis lie south of the Sungei Kemaman. At Chendrong the bedrock is chiastolite-tourmaline schist and quartzite cut by numerous quartz veins as much as 3 feet wide, striking 25° and dipping steeply to east-southeast; the veins carry wolframite crystals as much as 2 inches in diameter, some pyrite, and chalcopyrite. Irregular pockets of wolframite also occur in the schist, together with occasional scheelite, cassiterite, tourmaline, muscovite, felspar, and apatite.

Lodes carrying cassiterite are well developed in the hill working at Bukit Bundi between Sungei Kemaman and Sungei Cherul. The bedrock consists of micaceous sandstone, finegrained quartzite, shale, and mica-andalusite schist, and is traversed by lodes of cassiterite striking predominantly 15° and dipping steeply or vertically. Granite is known to occur at the foot of Bukit Bundi, and there is evidence of limestone occurring in the area. Two rich cassiterite ore-bodies with associated metallic sulphides have been described from the Freda Tin Mining Co., Bundi. Alluvial cassiterite derived from Bukit Bundi has been mined a short distance to the south in the Bundi Valley by a dredging company.

As mentioned earlier, the iron and manganese ore deposits recovered at Machang Satahun, also in the Kemaman Valley, are known to contain small amounts of tin-ore.

PAHANG

Tin and tungsten deposits are found in three widely separated regions near the borders of Pahang with Trengganu, Johore, and Selangor. The most important of these deposits occur near Kuantan, and may be regarded as a southerly extension of the Trengganu mines: they comprise important cassiterite lode mines at Sungei Lembing and alluvial cassiterite in the Gambang tin field. The deposits in the Anak Sungei Endau region, near the Johore border, contain only insignificant amounts of alluvial cassiterite. The third region, bordering southern Perak, Selangor, and northern Negri Sembilan, again belongs to the 'Western Tin Belt', and lies along the eastern margin of the Main Range between Ulu Sungei Lipis, Fraser's Hill, Bentong, and Manchis; it comprises both lode and alluvial deposits of cassiterite, together with some wolframite and scheelite; south of Fraser's Hill this region merges into the Kuala Kubu tin field of Ulu Selangor.

Apart from these major regions of tin and tungsten mineralization there are a few other localities in Pahang where small quantities of tungsten-ores have been found with minerals other than cassiterite, the chief association being that of scheelite with gold. The small amount of the tungsten-ores found does not warrant a separate description of these localities, but the chief occurrences are briefly listed below for their scientific interest:

(a) *Raub:* Scheelite occurs in a system of auriferous lode channels traversing calcareous and graphitic shale in most sections of the underground mines of Raub Australian Gold Mining Co. Ltd., but it is especially abundant in the mineralized tension-fissure fillings at Raub Hole Section. It is found as an accessory with gold, pyrite, arsenopyrite, stibnite, and chalcopyrite; the gangue consists of quartz, calcite, and fragments of shale.

(b) *Kuala Lipis:* Scheelite has been found together with alluvial gold on the property of Tui Gold Ltd., Kechor. The occurrence is of interest since a chemical analysis of the concentrate gave a value for PbO, and it is likely that some stolzite ($PbWO_4$) exists together with the scheelite. Isolated occurrences of wolframite and scheelite have also been reported from the Sungei Kechau Valley.

(c) *Bukit Bongkok:* Isolated traces of wolframite have been reported from the Bukit Bongkok area of Ulu Cheka.

Sungei Lembing

The important tin lode mines of the 350 square mile concession of Pahang Consolidated Co. Ltd. at Sungei Lembing are the only large-scale underground mines for tin-ore in Malaya. The actual lode mines all lie within an area of about six square miles, with a total underground development, on levels between 820 feet above and 1,200 feet below datum, of more than 180 miles. Total production from the lode mines between 1888 and 1950 amounted to about 80,000 tons of tin concentrates, while alluvial and eluvial tin-ore from elsewhere in the concession produced during the same period an additional 3,000 tons of tin concentrates.

The country rock of most of the lodes at Sungei Lembing is Lower Carboniferous shale, with subordinate siltstone and quartzite; most of these rocks dip about 30° to the east-northeast. The sedimentary rocks have generally not been greatly metamorphosed. Granite occurs underground in a number of localities at Sungei Lembing and also forms the country rock to the northwest of the mines; it is usually a porphyritic biotite granite, and chloritization is often common near quartz veins and in shear zones; some greisen also occurs. The tin-lodes are fissure veins, the fissures often containing quartz with a little cassiterite the bulk of which is an impregnation in the adjoining sediments. The chief minerals are cassiterite, pyrite, chalcopyrite, arsenopyrite, galena, sphalerite, cobaltite, and manganese minerals. Gangue minerals include chlorite, quartz, calcite, fluorite, and some lithia mica; tourmaline is rare and has not been recorded in association with cassiterite; no topaz has been found. The lodes generally strike between 270° and 300° and lie in shale mostly within about 2,000 feet of its contact with granite; they are interrupted by three major faults.

A small quantity of wolframite has been produced by the Pahang Consolidated Company from a mine at Kuala Sungei Perong, and from the granite area in Ulu Sungei Reman where it occurs in vein quartz with tourmaline and chlorite.

Gambang

Alluvial and eluvial tin-ore has been recovered from several valleys near Gambang on the junction of granite and sedimentary rocks. Most of the deposits worked have been alluvium with a maximum depth of about 40 ft. Cassiterite has also been won from a stockwork in sedimentary rocks (shale and sanstone) at Sungei Kakura, and from a shear zone in granite near Sungei Gambang. Regarding the stanniferous stockwork at Sungei Kakura Scrivenor (1928, p. 126) writes: 'An extraordinary point about this stockwork is that vegatable remains were found in shale which, I am informed, is within the limits of the stockwork. The fact that any vegetable remains should be recognizable as such in a stockwork, which one associates with an advanced degree of metamorphism and high temperature, suggests that cassiterite may be deposited at a moderate temperature in a rock which, as in the case of this shale, shows no marked metamorphism.'

Scheelite is said to have been produced at one time near Gambang, and traces of wolframite were recorded from a granite quarry at the 27th mile Kuantan-Benta road. Xenotime is an accessory constituent of the local concentrates.

Sungei Endau

Small amounts of alluvial cassiterite occur in a few localities overlying granite in the valley of Sungei Endau and Anak Sungei Endau in the Pontian district of Pahang and the Endau district of Johore. Small-scale 'lampan' mining (ground sluicing) was carried out before World War II at Sungei Ibai. Traces of wolframite have also been reported from this area.

Gunong Gapis

Occurrences of cassiterite are known from numerous small localities in the Gunong Gapis area, from Ulu Sungei Lipis, Sungei Liam, and Sungei Sampam in the north to Fraser's Hill and Gunong Ulu Semangko in the south. The tin-ore is derived from veins in the Main Range granite, and both lode deposits in the granite hills and alluvial deposits in the sedimentary valleys at the foot of the range have been worked. At Gunong Gapis the ore occurs disseminated throughout a mass of soft, weathered granitic rock, and in small irregular ore bodies distributed in it. These ore bodies measure on an average about 8 ft. x 6 ft. and consist of quartz, tourmaline, and cassiterite, or of pegmatitic material rich in cassiterite. At Ulu Kenong a system of veins in granite was once worked at a height of 3,000 feet above mean sea level; the veins were found to consist of quartz, tourmaline, cassiterite, and arsenopyrite, associated with greisen.

Bentong

Cassiterite deposits in the Bentong area include many small lode deposits in the Main Range granite and in the foothills of metamorposed sediments, and alluvial deposits in the alluvial flats below. At Gunong Bakau, on the Pahang-Selangor watershed, there occurs porphyritic granite with sill-like intrusive veins as much as 15 feet in thickness of stanniferous quartz-topaz rock and later irregular intrusive masses and veins of variable topaz-aplite carrying a small amount of cassiterite. Other minerals from the area include zinnwaldite, tourmaline, and arsenopyrite. At Murai there occurs a large stockwork of veins in tourmaline schist close to a granite and aplite contact. The veins contain quartz, cassiterite, tourmaline, iron oxide, pyrite, arsenopyrite, and traces of copper minerals, are about 18 inches apart, and dip to the south. In the Sungei Gau a cassiterite ore body with abundant pyrite, arsenopyrite, and chalcopyrite was found in altered sedimentary rocks close to an intrusion of granite and also to rocks of the Pahang Volcanic Series. Gangue minerals included wollastonite, tremolite, actinolite, and garnet, and secondary development of onyx, chalcedony, and siderite.

Apart from the lode deposits alluvial cassiterite has been mined for many years in the flat country near Bentong, and at one time a dredge was operating there. Traces of wolframite and scheelite have been reported from the Bentong tin-field.

Manchis

Alluvial cassiterite is found in a small tin-field overlying indurated shale near Manchis and at a few localities nearby, between Karak and Manchis. Although no surface outcrop of granite is known in the immediate vicinity of the mines, granite has been recorded from a number of bore holes in the area. Small veins carrying arsenopyrite, sphalerite, cassiterite, fluorite, garnet, pyroxene, quartz, and tremolite have been found traversing indurated shale at Ginting Tua.

Wolframite occurs in a number of localities to the north and west of Manchis. It has been recovered from a tributary of the Sungei Pertang known as Sungei Gaboi in the Kemasul Forest Reserve, where it is associated with some cassiterite and gold. The wolframite is carried in quartz veins and lenses cutting granite, with some shale lying close by; some secondary tungsten minerals have been reported, and arsenopyrite and other sulphides are common. The intrusions appear to be of a pegmatitic nature and do not often persist in length or depth. Other small occurrences of wolframite have been recorded from Sungei Ponson, Sungei Kachau, and Sungei Peredak, and also from the Manchis area.

SELANGOR

With the exception of the coastal belt, tin-ore is found over most of the State of Selangor. For convenience of describing these deposits they have been grouped into three areas corresponding approximately to the three Districts of Ulu Selangor, Kuala Lumpur, and Ulu Langat, but the division is an artificial one and the three areas not only merge into one another, but also continue into Pahang to the east and into Negri Sembilan to the southeast. Almost all the tin-ore produced in Selangor has come from alluvial working and has been derived from the erosion of stanniferous veins, stockworks, and stringers cutting granite and sedimentary rock near the granite contact. The occurrence of tungsten-ore is more circumscribed and is chiefly confined to the area between Ulu Yam and Ampang in the centre of the State.

Ulu Selangor

Alluvial tin-fields in Ulu Selangor centre round Tanjong Malim, Kuala Kubu, Rasa, Serendah, and Rawang, and may be seen to follow approximately the boundary of the granite forming the Main Range and to overlie the sedimentary rocks which occur directly to the west of it. The sediments in this area are predominantly quartzite, phyllite, and shale, but occasionally limestone is found interbedded with them. A few dredges operate in the area.

Lode tin-ore is known from many parts of the Main Range granite, especially Kerling, Peretak, Fraser's Hill, and Serendah. At Kerling the bulk of the lode-tin is present in quartz veins, and, to a lesser extent, in pegmatite intrusions. Most of the deposits occur in sedimentary rocks (schist and quartzite) near their contact with the granite, and although small deposits have been found no large mineralized zones rich in tin-ore have so far been located in the granite. Tourmaline, topaz, muscovite, biotite, fluorite, and wolframite, are associated with the cassiterite.

Near Peretak, in the upper reaches of Sungei Selangor, mineralization consists of an extensive permeation of the granite by small cassiterite-bearing lenticular stringers and stockworks which generally attain their best development in narrow zones where the rock is badly fractured. Although the mineralization of the granite is extensive, valuable concentrations of tin-ore are comparatively rare. The deposits of Gunong Bakau lie at the eastern end of this area and have already been described on p. 390. Another deposit in the Peretak area lies at Sangka Dua, where the cassiterite is associated with quartz, tourmaline, and mica, together with small amounts of fluorite, topaz, sulphides, and torbernite. The deposits in the Fraser's Hill area are similar to those described from Peretak: stringers of quartz-tourmaline and greisen containing cassiterite were the source of the tin-ore mined there in the past.

At Serendah, at the actual junction of granite and mica schist, veins of quartz- pegmatites carrying cassiterite have been worked in the past. The cassiterite was associated with quartz, muscovite, tourmaline, kaolin, and some wolframite.

Lodes carrying cassiterite and wolframite were worked in granite on Sungei Liam (Ulu Yam). They consist of lenticular veins of quartz, generally a few inches in width and several feet in length, of a pegmatitic nature, the minerals forming them being coarsely crystalline and occurring in irregular segregations. Wolframite as much as 6 inches long, and cassiterite as much as one inch across, occur with pyrite, arsenopyrite, tourmaline, muscovite, and felspar. The general strike of the veins is 330°, dipping 75° to the northeast.

Small amounts of alluvial scheelite have been found near the limestone-granite contact at Kaching.

Kuala Lumpur

Extensive alluvial tin-fields occur in Kuala Lumpur District near Kepong, Ulu Klang, Ampang, Sungei Besi, Serdang, and Petaling. These tin-fields are in many ways a smaller replica of those of Kinta, in that they also lie in a plain built of limestone bedrock with some interbedded shale, and quartzite, and are flanked to the east and west by granite outcrops. As in Kinta the richest alluvial deposits occur between limestone pinnacles and particularly in solution channels in limestone adjoining a granite contact: qualitatively they are of a similar richness. The deposits are frequently worked by dredges, but Malaya's deepest opencast mine, operated by Hong Fatt (Sungei Besi) Ltd. to a depth of approximately 370 feet below surface level (i.e. about 250 feet below sea level), is also found in this area and lies on a limestone-granite contact.

At Kepong alluvial cassiterite is recovered from the junction of granite with limestone and schist, and in a few localities lode deposits of cassiterite and pyrite have been found; the presence of some wolframite has also been reported. Similar alluvial deposits occur at Ulu Klang and Batu, although there limestone is predominant over shale and quartzite. Traces of scheelite are known from the Batu area.

The biggest alluvial tin-field in Selangor is centred on Kuala Lumpur and occupies the area from Ampang to Sungei Besi and Serdang, with much of the tin-ore being recovered by dredges. The bedrock is almost exclusively limestone with some shale and quartzite; the area is almost completely surrounded by granite, and there is evidence that the granite underlies the limestone at shallow depths. Small pegmatitic lode occurrences of cassiterite, with much arsenopyrite and some topaz have been reported from granite at Ampang, and quartz veins carrying cassiterite with iron oxide and pyrite from an aplite cutting limestone at Sungei Besi. Small amounts of wolframite occur with cassiterite in quartz veins at Pudu Ulu, and as a by-product of alluvial tin mining at Ulu Klang, Ampang, and Setapak. However, the famous Klang Gates quartz reef, which can be traced for over 10 miles with a maximum width of 200 yards, and which traverses part of the area, is devoid of mineralization: the only impurity found in it consisted of 0.02% of a concentrate of pyrrhotite with a trace of scheelite and cassiterite.

Rich alluvial deposits of cassiterite are mined and dredged from the Klang Valley near Petaling and Puchong; the tin-ore there is probably derived from the tongue of granite which extends southward beyond Puchong.

Ulu Langat

The alluvial cassiterite deposits of Ulu Langat are found chiefly near Kajang and Semenyih, and are generally less valuable and more scattered than those of Kuala Lumpur. Limestone and granite form the predominant bedrock and mines have been worked in both associations.

At Bukit Arang and at Bukit Payong on the Negri Sembilan border, lenticular quartz veins carrying wolframite and cassiterite have been found traversing metamorphosed sedimentary rocks in association with pegmatite and hornblende granite. Accessory minerals include pyrite, chalcopyrite, azurite, and limonite; scheelite has also been reported.

NEGRI SEMBILAN

As in Selangor deposits of tin-ore are scattered over most parts of the State, but their total value is small in comparison. The bigger concentrations of cassiterite are found in the Jelebu area and near Seremban, while lesser concentrations occur near Kuala Pilah and Port Dickson. Some wolframite is found in the Jelebu area.

Jelebu

This small tin-field lies on the eastern border of the Main Range with centres at Kuala Klawang, Titi, and Kongkoi. The cassiterite deposits in the Kongkoi and Kenaboi valleys are alluvial and occur in the vicinity of a granite-schist contact. Small quantities of gold are found with the cassiterite, and some cinnabar has been reported from

Kenaboi. The schists carry muscovite, biotite, hornblende, andalusite, and chiastolite. At Titi lode cassiterite and wolframite were found in quartz veins on a granite-schist junction; near the contact with the granite the local shales and quartzites have been metamorphosed to tourmaline and mica-schists and to micaceous quartzites. The ore is generally richer on the granite side of the contact and rarely continues far into the schist: arsenopyrite is a common constituent, and some euxenite has been reported. The strike of the ore-bearing quartz veins is 290°; these are cut by later, barren quartz veins striking 20°.

Some alluvial cassiterite continues to be found to the southeast of Jelebu as far as Kuala Pilah, and traces occur even as far as Gemencheh near the Malacca border. Geologically these deposits are similar to those found at Jelebu, but their importance is small.

Seremban

The alluvial deposits of cassiterite forming the Seremban tin-field lie on the western border of the Main Range granite, close to its contact with schist and phyllite. A few small occurrences of lode cassiterite have been reported from near Seremban and Sipiau, occurring as stringers in granite with tourmaline; and in the Ampangan-Parui area some wolframite is associated with the cassiterite.

The Seremban tin-field has minor extensions to the northwest as far as Mantin, and to the southwest to Mambau and Port Dickson.

MALACCA

Tin-ore is found in Malacca at two distinct localities: in beach sands on the coast between Kuala Linggi and Sungei Udang (and also on Pulau Besar some 20 miles further down the coast), and as alluvium derived from stockworks in the vicinity of Jasin.

Malacca Coast

Cassiterite occurs on the sea bed and in beach sands along the northern part of the coast of Malacca from the mouth of Sungei Linggi to Sungei Udang. These occurrences are related to two outcrops of granite and aplite on the Malacca coast near Kuala Linggi and near Pengkalen Balak. Apart from cassiterite the sands contain ilmenite, tourmaline, rutile, zircon, and anatase. No large-scale exploitation of these deposits has ever been attempted and their precise extent and value is not known.

A separate beach deposit is found on Pulau Besar, an island about 7 miles to the southeast of Malacca Town, where cassiterite occurs with ilmenite, monazite, and zircon. The bedrock of the island is granite.

Jasin

Only the alluvial deposits at Chin Chin are now being mined on a small scale. In the past rich stockworks of tourmaline-cassiterite veins in phyllite were worked not far from a branch of the Main Range granite; the phyllite was strongly lateritized on the surface, and such laterite was often found to be stanniferous.

Old tin-working also occur near Kesang in soft weathered country formed of phyllite with intrusions of granite.

JOHORE

Deposits of tin-ore in Johore have been found at Bakri, Jemaluang, Kota Tinggi, and Bukit Pelali at the south-eastern tip of the State. Small amounts of wolframite have been recorded only from the first three of these localities.

Bakri

The alluvial deposits at Bakri, near Muar, though of comparatively small extent, have been actively worked recently because of their association of cassiterite with columbite-tantalite. Most of the mines work alluvium overlying quartzite and shale which has been intruded by stanniferous pegmatite and quartz veins from the Bukit Mor granite complex. Other minerals occurring in the area include tourmaline, ilmenite, monazite, zircon, garnet, gahnite, tanteuxenite, arizonite, and traces of molybdenite. Although wolframite is recorded in an old report as occurring in this area it is possible that this identification was made in error for columbite.

Old alluvial and eluvial deposits of cassiterite are mentioned as occurring in the Batu Pahat area.

Jemaluang

The mines at Jemaluang work shallow alluvial and eluvial deposits of cassiterite derived from quartz veins intrusive into schists, phyllites, and quartzites, close to a granite contact. Some wolframite is associated with the cassiterite.

Kota Tinggi

There are a number of localities in the Kota Tinggi area where cassiterite is found. At the Tengkil and Linggiu mines shallow alluvial deposits of cassiterite were worked in granite country with occasional roof pendants of schist. Small quantities of molybdenite were found at Linggiu. At the Tampenis mine the country rock is micropegmatite, and some lode occurrences of cassiterite with quartz and mica have been recorded. Cassiterite and some wolframite have also been recovered from Gunong Tunjoh Laut and Gunong Muntahak where hornblende is found in the local granite. At Kambau alluvial cassiterite is associated with monazite.

An interesting occurrence of cassiterite is that at the iron-mines of Pelepah Kanan near Gunong Muntahak. There is a large deposit of iron-ore (haematite, martite, and some magnetite) is found within a mass of metamorphosed rocks (calc-silicate hornfels, magnetite-garnet-amphibole schist, and pyroxene schist) which have been invaded by granite and granite porphyry and traversed by veins of pegmatite. The veins of pegmatite and quartz traversing the sedimentary rocks contain cassiterite, with arsenopyrite and pyrite. The average iron-ore has a grade of about 64% Fe and carries approximately 0.5% Sn, although percentages of more than 1% Sn have been recorded from random samples.

Bukit Pelali

Alluvial cassiterite has been recovered in the past from Sungei Rengit in the vicinity of Bukit Pelali. Both ordinary coarse-grained granite and felsite occur in the area, the tin-deposits being associated with the ordinary granite.

SINGAPORE

No economic concentrations of tin or tungsten ores are known from Singapore Island, but traces of alluvial cassiterite have been found near Mandai railway station.

STATISTICS OF PRODUCTION

Detailed statistics on the production of tin and tungsten ores in Malaya are available for many mines and tin-fields, but are far from complete for the period up to the year 1946. For the purpose of the present paper separate production figures are given for individual States and for the whole of Malaya for tin (in ore), wolframite, and scheelite, in British long tons, for the period 1898 to 1956. The figures for 1898 to 1938 have been taken from Fermor (1939); the figures for 1939 to 1956 have been supplied by the Department of Mines, Federation of Malaya.

PRODUCTION OF TIN (IN ORE) IN LONG TONS

Year	*Perlis*	*Kedah*	*Perak*	*Kelantan*	*Trengganu*	*Pahang*	*Selangor*	*N. Sembilan*	*Malacca*	*Johore*	*F.M. Total*
1898			19,703			631	16,489	2,746			39,569
1899			18,960			803	15,180	3,410			38,353
1900			21,166			936	16,041	4,301			42,444
1901			22,921			1,330	18,012	4,479			46,742
1902			24,159			1,376	15,569	4,376			46,480
1903			25,949			1,504	17,420	5,089			49,962
1904			26,399			1,635	17,882	5,051			50,967
1905			26,594			2,076	17,254	5,067			50,991
1906			24,718			1,605	15,989	4,629			46,941
1907			25,678			1,976	16,304	4,473			48,431
1908			27,844			2,352	16,818	3,823			50,837
1909	98	536	27,480	3	261	2,568	15,834	2,861		—	49,641
1910	113	505	25,079	17	257	2,421	14,297	2,065		245	44,999
1911	77	546	26,032	20	307	2,616	13,760	1,740		198	45,296
1912	142	609	28,407	14	290	2,890	15,201	1,730		222	49,505
1913	82	608	29,403	4	238	3,433	15,406	1,884		332	51,390
1914	141	619	28,557	6	273	3,685	15,103	1,697		608	50,689
1915	173	625	27,771	4	287	3,808	13,938	1,244		2,046	49,896

Year	*Perlis*	*Kedah*	*Perak*	*Kelantan*	*Trengganu*	*Pahang*	*Selangor*	*N. Sembilan*	*Malacca*	*Johore*	*F.M. Total*
1916	158	489	27,241	—	342	3,480	12,241	907		2,453	47,311
1917	148	343	24,643	—	310	3,496	10,960	733		2,355	42,988
1918	117	?	22,983	—	437	3,017	10,744	625		1,689	39,612
1919	85	518	22,126	1.4	454	3,299	10,631	879		1,329	39,322
1920	195	372	22,134	2	348	3,252	8,852	697		1,586	37,438
1921	180	115	21,041	2.8	287	3,357	9,242	851		1,493	36,569
1922	347	276	21,848	1.7	310	3,207	9,271	959		1,490	37,710
1923	270	435	24,772	.6	341	2,953	8,852	1,072		957	39,653
1924	393	265	29,840	—	427	3,155	10,093	956		1,015	46,144
1925	253	278	30,734	.9	842	3,014	11,174	1,004		1,400	48,700
1926	301	243	30,702	.4	549	2,871	11,677	697		1,039	48,079
1927	249	289	36,319	2.5	839	2,339	12,716	806		975	54,535
1928	415	285	41,031	3	1,118	2.762	16,403	1,739		1.097	64,853
1929	421	268	42,751	1.2	952	2,910	19,499	1,883	3	672	69,360
1930	419	342	39,825	2.4	738	2,726	17,960	1,554	3	516	64,085
1931	321	148	32,506	2	493	2,332	14,281	1,535	15	426	52,059
1932	483	119	16,453	—	400	1,245	7,975	865	25	305	27,870
1933	312	113	15,034	1	252	1,069	7,133	658	41	219	24,832
1934	432	158	20,203	3	366	1,443	9,941	980	51	393	33,970
1935	323	200	25,048	6	399	1,771	12,689	1,279	44	604	42,363
1936	458	308	39,038	20	480	2,760	21,115	1,769	49	755	66,752
1937	456	341	44,874	34	429	3,158	24,576	2,510	67	814	77,259
1938	651	259	24,958	28	332	1,924	12,633	1,691	88	784	43,348
1939	638	—	26,456	—	467	1,713	15,159	1,299	174	839	46,745
1940	950	—	48,966	—	419	3,244	25,736	2,705	160	1,288	83,468
1941*	469	—	36,589	—	476	2,655	19,094	1,954	190	1,154	62,581
1942	3	7	10,726	—	1	131	4,450	425	5	—	15,748
1943	3	7	17,152	—	5	53	7,437	1,342	1	—	26,000
1944	3	7	6,072	—	56	2	2,580	560	1	28	9,309
1945	3	7	2,218	—	26	—	680	119	—	99	3,152
1946	—	14	5,225	—	40	136	2,787	163	—	67	8,432
1947	179	261	17,868	—	226	592	6,779	825	53	243	27,026
1948	254	375	29,389	—	279	1,079	11,494	1,316	154	475	44,815
1949	586	482	34,406	—	352	1,895	15,148	1,324	154	856	55,203
1950	723	392	36,500	—	305	2,226	15,145	1,566	142	768	57,767
1951	496	467	34,267	—	219	2,243	17,518	1,435	89	662	57,396
1952	446	499	35,038	—	28	2,100	16,526	1,739	113	576	57,065
1953	316	503	34,486	—	12	2,177	16,491	1,683	197	539	56,404
1954	297	536	37,596	—	46	2,236	17,862	1,549	100	711	60,933
1955	250	639	37,698	—	53	2,248	17,871	1,487	110	888	61,244
1956	371	726	38,295	1	186	2,288	17,439	1,781	80	1,129	62,296

* January-September only.

PRODUCTION OF WOLFRAMITE IN LONG TONS

Year	*Perlis*	*Kedah*	*Perak*	*Kelantan*	*Trengganu*	*Pahang*	*Selangor*	*N. Sembilan*	*Malacca*	*Johore*	*F.M. Total*
1901	—	—	—	—	—	—	—	1	—	—	1
1902	—	—	—	—	—	—	—	3	—	—	3
1903	—	—	?	—	—	—	—	—	—	—	?
1904	—	—	?	—	—	—	—	—	—	—	?

Year	*Perlis*	*Kedah*	*Perak*	*Kelantan*	*Treng-ganu*	*Pahang*	*Selangor*	*N. Sem-bilan*	*Malac-ca*	*Johore*	*F.M. Total*
1905	—	—	—	—	—	—	4	—	—	—	4
1906	—	—	—	—	—	—	15	—	—	—	15
1907	—	—	—	—	—	—	—	—	—	—	—
1908	—	—	—	—	—	—	10	—	—	—	10
1909	—	.25	55	—	—	—	31	1	—	—	87
1910	—	12	60	—	—	—	34	—	—	—	106
1911	—	16	71	—	—	2	93	2	—	—	184
1912	—	22	134	—	12	—	90	—	—	—	258
1913	—	28	53	—	83	5	114	34	—	—	317
1914	—	25	36	—	143	—	193	3	—	—	400
1915	—	13	?	—	143	—	?	?	—	2	393
1916	—	17	?	—	271	—	?	?	—	23	622
1917	—	124	—	—	201	—	?	?	—	2	748
1918	—	520	20	—	617	—	220	4	—	.65	1,382
1919	—	211	6	—	560	—	200	1	—	.3	978
1920	—	42	—	—	153	—	113	—	—	—	308
1921	—	48	—	—	1	—	55	—	—	—	104
1922	—	106	—	—	174	—	56	39	—	—	375
1923	—	62	—	—	280	—	—	38	—	—	380
1924	—	153	—	—	173	—	—	8	—	—	334
1925	—	117	8	—	77	—	106	17	—	—	325
1926	—	90	4	—	119	—	55	—	—	—	268
1927	—	70	?	—	58	—	?	?	—	—	148
1928	—	64	5	—	102	—	—	—	—	—	171
1929	—	108	2	—	71	—	12	30	—	—	223
1930	—	165	55	—	43	—	10	—	—	—	273
1931	—	167	—	—	23	—	—	—	—	—	190
1932	—	98	—	—	31	—	—	—	—	—	129
1933	—	55	25	—	24	—	8	—	—	—	112
1934	—	44	15	—	23	—	13	.49	—	—	95
1935	—	168	3	—	93	—	3	2	—	—	269
1936	—	160	—	—	112	—	2	1	—	—	275
1937	—	138	19	—	98	3	4	1	—	.13	263
1938	—	169	9	—	120	4	10	6	—	—	318
1939	—	174	—	—	140	—	—	—	—	—	314
1940	—	124	—	—	152	—	—	—	—	—	276
1941	—	—	—	—	—	—	—	—	—	—	—
1942	—	—	—	—	—	20	—	—	—	—	20
1943	—	30	—	—	34	21	—	—	—	—	85
1944	—	30	—	—	55	29	—	—	—	—	114
1945	—	—	—	—	—	—	—	—	—	—	—
1946	—	—	—	—	—	—	—	—	—	—	—
1947	—	2	—	—	27	3	1	—	—	—	33
1948	—	12	—	—	32	—	2	—	—	—	46
1949	—	5	—	—	21	—	1	1	—	—	28
1950	—	—	—	—	—	—	13	—	—	—	13
1951	—	6	—	—	—	—	15	7	—	—	28
1952	—	2	11	—	—	—	20	11	—	—	44
1953	—	3	53	—	1	—	28	14	—	—	99
1954	—	11	11	—	—	—	23	9	—	—	54
1955	—	14	9	—	—	—	23	10	—	—	56
1956	—	21	1	—	—	—	19	5	—	1	47

PRODUCTION OF SCHEELITE IN LONG TONS

Year	*Perlis*	*Kedah*	*Perak*	*Kelantan*	*Trengganu*	*Pahang*	*Selangor*	*N.Sembilan*	*Malacca*	*Johore*	*F.M. Total*
1901	—	—	—	—	—	—	—	—	—	—	—
1902	—	—	—	—	—	—	—	—	—	—	—
1903	—	—	—	—	—	—	—	—	—	—	—
1904	—	—	—	—	—	—	—	—	—	—	—
1905	—	—	—	—	—	—	—	—	—	—	—
1906	—	—	—	—	—	—	—	—	—	—	—
1907	—	—	—	—	—	—	—	—	—	—	—
1908	—	—	—	—	—	—	—	—	—	—	—
1909	—	—	1	—	—	—	—	—	—	—	1
1910	—	—	2	—	—	—	—	—	—	—	2
1911	—	—	1.5	—	—	—	—	—	—	—	1.5
1912	—	—	3	—	—	—	—	—	—	—	3
1913	—	—	18	—	—	—	—	—	—	—	18
1914	—	—	29	—	—	—	—	—	—	—	29
1915	—	—	57	—	—	—	—	—	—	—	57
1916	—	—	204	—	—	—	—	—	—	—	204
1917	—	—	340	—	—	—	—	—	—	—	340
1918	—	—	112	—	—	—	—	—	—	—	112
1919	—	—	228	—	—	—	—	—	—	—	228
1920	—	—	120	—	—	—	—	—	—	—	120
1921	—	—	—	—	—	—	—	—	—	—	—
1922	—	—	.4	—	—	—	—	—	—	—	.4
1923	—	—	—	—	—	—	—	—	—	—	—
1924	—	—	74	—	—	—	15	—	—	—	89
1925	—	—	12	—	—	—	15	—	—	—	27
1926	—	—	14	—	—	—	26	—	—	—	40
1927	—	—	—	—	—	—	—	—	—	—	—
1928	—	—	—	—	—	—	—	—	—	—	—
1929	—	—	275	—	—	—	—	—	—	—	275
1930	—	—	792	—	—	—	—	—	—	—	792
1931	—	—	368	—	—	—	—	—	—	—	368
1932	—	—	302	—	—	—	—	—	—	—	302
1933	—	—	918	—	—	—	—	—	—	—	918
1934	—	—	1,508	—	—	—	—	—	—	—	1,508
1935	—	—	1,365	—	—	—	—	—	—	—	1,365
1936	—	—	1,364	—	—	—	—	—	—	—	1,364
1937	—	—	836	—	—	—	—	—	—	—	836
1938	—	—	573	—	—	—	—	—	—	—	573
1939	—	—	174	—	—	—	—	—	—	—	174
1940	—	—	56	—	—	—	—	—	—	—	56
1941	—	—	13	—	—	—	—	—	—	—	13
1942	—	—	16	—	—	—	—	—	—	—	16
1943	—	—	52	—	—	—	—	—	—	—	52
1944	—	—	83	—	—	—	—	—	—	—	83
1945	—	—	10	—	—	—	—	—	—	—	10
1946	—	—	—	—	—	—	—	—	—	—	—
1947	—	—	11	—	—	—	—	—	—	—	11
1948	—	—	29	—	—	—	—	—	—	—	29
1949	—	—	30	—	—	—	—	—	—	—	30
1950	—	—	10	—	—	—	—	—	—	—	10
1951	—	—	15	—	—	3	—	—	—	—	18

Year	*Perlis*	*Kedah*	*Perak*	*Kelantan*	*Trengganu*	*Pahang*	*Selangor*	*N.Sembilan*	*Malacca*	*Johore*	*F.M. Total*
1952	—	—	15	—	—	9	—	—	—	—	24
1953	—	—	17	—	—	13	—	—	—	—	30
1954	—	—	28	—	—	17	—	—	—	—	45
1955	—	—	31	—	—	19	—	—	—	—	50
1956	—	—	20	8	—	16	—	—	—	—	44

REFERENCES

It has not been found practicable to supply a full bibliography, and only general regional publications have been included in the list below. For detailed regional and local bibliographies the lists of references given in the general regional publications should be consulted. Much material has been obtained from unpublished Departmental Records of the Geological Survey, Federation of Malaya.

Alexander, J.B., (in press), The Geology and Mineral Resources of the Neighbourhood of Bentong, Pahang. *Geological Survey Memoir* **8**.

Brown, G.F., Buravas, S., *et. al.*, 1951, Geologic Reconnaissance of the Mineral Deposits of Thailand. *U.S. Geol. Survey Bulletin* **984**.

Fermor, L.L., 1939, Report upon the Mining Industry of Malaya.

Fitch, F.H., 1952, The Geology and Mineral Resources of the Neighbourhood of Kuantan, Pahang. *Geological Survey Memoir* **6**.

Ingham, F.T., 1938, The Geology of the Neighbourhood of Tapah and Teluk Anson, Perak. *Geological Survey Memoir* **2**.

Ingham, F.T. and Bradford, E.F., (in press), The Geology and Mineral Resources of the Kinta Valley, Perak. *Geological Survey Memoir* **9**.

Jones, W.R., 1925, Tin Fields of the World.

Li, K.C. and Wang, C.Y., 1943, Tungsten.

Pryor, E.J. and Wrobel, S.A., 1951, Studies in Cassiterite Flotation. *Bulletin of the Institution of Mining* and *Metallurgy, Transactions*. **60** (6): 201-237.

Roe, F.W., 1951, The Geology and Mineral Resources of the Fraser's Hill Area, Selangor. *Geological Survey Memoir* **5**.

Roe, F.W., 1953, The Geology and Mineral Resources of the Neighbourhood of Kuala Selangor and Rasa, Selangor. *Geological Survey Memoir* **7**.

Savage, H.E.F., 1937, The Geology of the Neighbourhood of Sungei Siput, Perak. *Geological Survey Memoir* **1**.

Scrivenor, J.B., 1928, The Geology of Malayan Ore-Deposits.

Service, H. and Patterson, I.L., 1953, Federation of Malaya Reports. Regional Conference on Mineral Resources Development, E.C.A.F.E.

Willbourn, E.S., 1922, An account of the Geology and Mining Industries of South Selangor and Negri Sembilan.

Willbourn, E.S., 1926, The Geology and Mining Industries of Kedah and Perlis. *Journal Malayan Branch Royal Asiatic Society* **4** (3): 289-332.

SURVEY OF THE TIN-DEPOSITS OF BANGKA (Indonesia)

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(Abstract)

During many decades to come the island of Bangka will rank prominently among the tin-producers of the world, although the tin-grade of the deposits will gradually decline. Tin-mining on Bangka dates from the beginning of the 18th century (about 1710), however not until 1816 that it was done by the government.

In the past several detailed geological studies of the tin-deposits were made, and at the end of 1954 an exploration department was formed for continuation of those investigations along modern lines.

The parent rocks of the primary cassiterite deposits must have solidified at intermediate depths and are generally coarsely crystalline and porphyritic biotite-granites of post-Triassic, presumably Jurassic age. Statistical fabric analysis on several places along the southern contact-zone of the Djebus-Belinju-Sungailiat granite Batholith were carried out by V.P. Kahr.

The residual tin-ore concentration was effected during the last phase of denudation, which started after the late-Mesozoic orogeny. Weathering, chemical leaching and mechanical transport concentrated the disseminated cassiterite and its allied minerals along the slopes and on the bottom of the valleys.

The relative rise of the sea-level during the Holocene caused the submergence of the Sunda Shelf area and also covered the valley deposits of tin-ore on Bangka with sands and clays.

In the lower courses of the valleys the residual concentration of cassiterite commonly lies at somewhat greater depths below the sea-level (up to more than 30 metres) and are mined by large seagoing dredges.

TIN AND TUNGSTEN DEPOSITS OF THAILAND

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INTRODUCTION

Tin deposits have been mined in Thailand since 1827 (B.E. 2370) when placer mining was started in Changwats Phuket and Ranong. During the 25 years from 1932 to 1956 inclusive, the total recorded production of tin concentrate amounted to 238,047 long tons; an average of about 9,522 long tons per year.

Tungsten deposits were first mined in Changwat Nakhon Sithammarat in 1918 (B.E. 2461). From 1935 to 1956 inclusive, the total recorded production of tungsten concentrate was 17,367 long tons; an average of about 790 long tons per year.

Most of the tin and tungsten deposits are in southern (Peninsula), western and northwestern Thailand-regions generally characterized by sedimentary and metamorphic rocks that have been repeatedly folded, faulted and intruded by many elongated batholiths of granitic rocks. Northeastern Thailand, the Khorat Plateau, which composes of relatively undisturbed Mesozoic sedimentary rocks, has only one reported occurrence of tin in Changwat Surin and two reported occurrences of tungsten in Changwats Surin and Buriram.

The most important and productive areas for tin and tungsten are in the Peninsula region of Thailand. The most important tin deposits are placer deposits, whereas the most important tungsten deposits are eluvial and primary deposits.

Most of the tin and tungsten mined in Thailand is exported. The annual domestic consumption of tin metal is less than 200 tons and there is no domestic consumption of tungsten.

TYPES OF DEPOSITS

The tin and tungsten deposits of Thailand may be classified in two types:

1. Placer deposits
2. Primary deposits
    - a) Hydrothermal origin
        - 1) Hydrothermal veins
        - 2) Contact Metamorphic deposits (tin only)
    - b) Magmatic Segregation origin
        - 1) Disseminated and Aplitic deposits
        - 2) Veins
            - a) Pegmatite and Aplite veins
            - b) Pegmatitic and Hypothermal Quartz veins

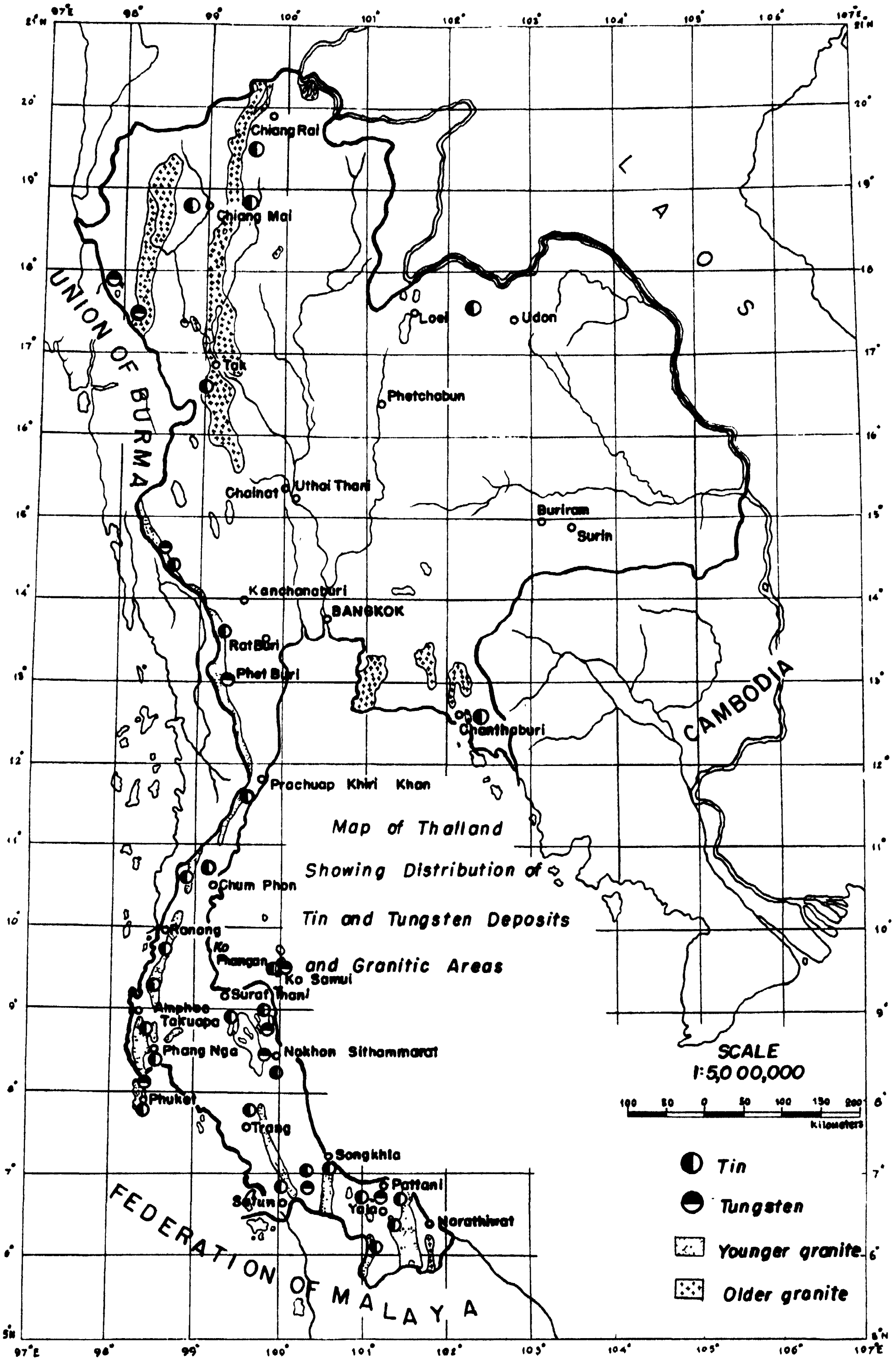
PLACER DEPOSITS

Although the richest and most easily mined tin placer deposits are rapidly being depleted, still more than 95 percent of the tin-concentrate now being produced in Thailand comes from placer deposits. Only a very small amount of tungsten is derived from the placer mines, most of it by magnetic seperation in tin mines at Takua Pa in Changwat Phang-nga and in Tambons Ratsada and Ko Kaeo in Changwat Phuket.

Important tin placer deposits occur in nearly all changwats in the Peninsula region of Thailand south of Latitude 11°N. Most placer deposits have been derived mainly from pegmatites, pegmatitic and hypothermal quartz veins. These deposits range in thickness from a few feet to more than 100 feet and vary in nature from muds to coarse boulder beds. Carbonaceous matter occurs in the clay and silt that are found as constituents of placer deposits from near Takua Pa southward to Phuket. Plant debris have been tightly pressed to form laminal and thin layers of peat in the placer deposits at some localities. Most of the material, however, consists of silt and fine to coarse sand with some gravel. Some tin-bearing gravel and boulder beds in the Khuan Krot and Liwong areas of Changwat Songkhla have been locally cemented by iron oxide and silica. Similar cementation of tin-bearing alluvium occurs at Na Prasert in Phuket and in Changwat Phang-nga.

The bed rock for the tin placer deposits varies greatly from place to place. Granite is common as also are phyllitic slates of the early Paleozoic Phuket Series. Limestone occurs in the Phang-nga, and sandstone and quartz are common in the Songkhla region.

Poorly cemented eluvial materials or regoliths with enough tin to provide profitable mining occur



Map of Thailand Showing Distribution of Tin and Tungsten Deposits and Granitic Areas in the weathered zone above some primary deposits. In some cases the bedrock deposit was sufficiently rich in tin to be economically mined. In other cases the primary deposit may be too low-grade for economical mining, but surficial weathering and erosion may selectively remove enough barren material to produce a residual detrital deposit of profitable grade. Such is the case at Chong Chang Mine in Amphur Nasan, Changwat Surat.

Tin is found associated with gold in many placer deposits at Phang-nga and in the Pracham-mai Valley of Changwat Kanchanaburi. It occurs with gold and platinum in Amphur Phue, Changwat Udon; with rare diamonds in Phang-nga; with radioactive columbite-tantalite at Takua Pa, Phuket, Ranong, Phang-nga and Trang and west of Songkhla, Phuket, with Eluxenite and Samarskite at Phang-nga, Phuket, Kanchanaburi, Takua Pa and Yala; with cinnabar at Lampam, Takua Pa; with stibnite at Nai Uan's mine, Changwat Tak; and with bismuthite at Amphur Thepha in Changwat Songkhla.

All tin ore is cassiterite. The cassiterite in the New Chiang Phra placer deposit at Tambon Thung Toa, Changwat Surat has an exceptionally wide range of colour and contains the highest tin content (76.6%) known in Thailand.

Many quite a lot of tin placers were lost because it is too fine to be recovered by the present method of gravity separation. Enormous amounts of very fine tin remain in tailing dumps. Even larger amounts probably have been carried from mine tailings and from eroded outcrops to be deposited with the slimes and muds in the estuarie and the off-shore areas of Southern Thailand.

Rich tin placer deposits containing both coarse and fine cassiterite are widespread off the coasts of Southern Thailand. Most of them cannot now be mined because the sea is too deep or too rough, but those in the half sheltered water east of Phuket and in the gulf of Phang-nga are being successfully mined by dredges.

The placer deposits of Thailand range in age from Pleistocene to Recent, and some are forming even now.

PRIMARY DEPOSITS

Tin and tungsten occur individually or together in various proportions in many of the primary deposits of Thailand. These deposits are generally associated with granitic igneous intrusions that are of at least two ages, tentatively assigned a Permo-Triassic and a Late Cretaceous Age. The granitic magmas were believed to have yielded the tin and tungsten and intruded phyllitic slate and quartzite of the Cambrian Phuket Series in the western part of Peninsular Thailand, the Permian Ratburi limestone in Surat and Yala regions, and the Carboniferous Kanchanaburi Series and Mesozoic sandstone and shale in Songkla region.

HYDROTHERMAL VEINS

Many hydrothermal tin and tungsten deposits occur in southern and western Thailand. Some of the most important ones are:—

(1) A tungsten- bearing system of quartz veins in Amphur Mae Sariang of Changwat Mae Hongson in north western Thailand is closely related to granitic intrusions. Here the veins traverse phyllitic slate sandstone and shaly limestone. The veins are richest where they cut the phyllitic slaty sandstone or sandy phyllite. Scheelite and Wolframite are the predominant ore minerals, and fluorite is an unusual associated gangue mineral.

(2) The tin lode deposits at Labu, Changwat Yala occur in a system of sulphide-bearing veins that strike about east-west and traverse dark gray intergrading phyllitic and psammitic partly metamorphosed rock. The veins are richest where they cut the psammitic rocks. The principal vein minerals are cassiterite, sphalerite, galena, chalcopyrite, pyrite, arsenopyrite, quartz, calcite and dolomite. The veins have been followed to depths of 800 to 1,000 feet. A diamond drill hole in this general vicinity is reported to have found the upper part of granite at about 600 feet.

(3) The tin-bearing veins at Ko Saba mine in Changwat Songkhla strike nearly north-south and traverse quartzite and quartzitic slaty shale. The veins are believed to follow generally a fault between quartzite and slaty shale, cutting sometime into the quartzite of the foot wall and sometime into the slate of the hanging wall. Granite is exposed about 2.5 kms. west of the mine. The veins contain cassiterite, wolframite, pyrite, arsenopyrite, and galena.

(4) A small wolframite-bearing vein traverses coarse grained granite at Chenkit Mine, Changwat Surat. The vein contains wolframite, sphalerite, pyrite, chalcopyrite, galena, rhodochrocite, fluorite and quartzite.

(5) The tin-bearing sulphide veins also occur at about sea level in Ko Pha-ngan, Changwat Surat. The deposit is on the west coast at Chaloklam village.

CONTACT METAMORPHIC DEPOSITS

A contact metamorphic tin deposit occurs in the Pinyok mine in Amphur Bannangstar, Changwat Yala where sedimentary rocks have been intruded by granite. Metamorphosed Permian limestone occurs on one side of the deposit with granite on the other side flanking a zone of tin-bearing altered and mineralized rock of about 100 feet in width. Tin content was found in low amounts in the granite but never in the limestone. The principal ore and gangue minerals in the mineralized zone are cassiterite, galena, pyrite, arsenopyrite, chalcopyrite, magnetite, secondary limonite, grossularite, andradite, quartz and diopside.

Smaller similar deposits occur at Tham Thalu not far to the north of Pinyok and Dida mine in the westerly adjoining area. The deposit at Tham Thalu contains a considerable tonnage of ore with a high content of cerussite and galena.

DISSEMINATED DEPOSITS

Tin and tungsten occur disseminated in granitic rock at many places in Thailand. The deposits at Hat Som Paen and at Bang Phra in Changwat Ranong are good examples.

I. At Hat Som Paen tin and tungsten occur mainly in a zone of aplitic rocks that lies between a large granitic massif and the phyllitic slate of the Phuket series into which it intruded. The mass of mineralized aplitic rocks average about 2 kilometers long and 500 meters wide and 75 meters thick. The mineralized zone trends north-south parallel to the intrusive contact.

The tin and tungsten occur in scattered pockets throughout the aplitic rock. Individual pocket yields from a fraction of a kilogram to as much as 60 tons. Small veins of pegmatite containing tin and tungsten are also numerous. Veins of aplitic rock that penetrate the phyllitic slate country rock yield tin and tungsten and trends N-S, but there are also quartz veings that cut the slates with a general strike of N 50° - 70°W, dipping S 45° - 80°.

Concentrates won from the disseminated ore contain from 15 to 98 percent wolframite and from 2 to 85 percent cassiterite. The tungsten content is highest in the upper part of the zone; decreasing gradually with elevation.

The order of intrusions at this particular place is as follows:-

1) Porphyritic biotite granite containing small amount of original tin and tungsten.

2) Medium grained tourmaline aplite containing small amount of tin and tungsten.

3) Aplite containing disseminated grains and pockets of tin and tungsten constituting the main occurrence of ore bodies.

4) Pegmatite veins containing tin and tungsten.

5) Quartz veins usually barren of minerals.

II. Deposits of tin at Thung Khamin and Na Mom in Changwat Songkhla are of this type. The tin occurs disseminated in fine-grained muscovite granite intruding sandstone country rock. Torbernite was rarely found in cracks in the granite here.

III. At Nam Noi in Changwat Songkhla a large mass of light coloured muscovite granite contains disseminated tin (0.05% Sn.), some of it not visible to the naked eye. Tin also occurs in thin veinlets, and constitutes 70% of the mass.

IV. At Bua Lan mine near the Tham Thalu area of Changwat Yala, tin occurs in pockets closely associated with aplitic derivative of a biotite granite intrusion into limestone. Similar disseminated deposits occur elsewhere in the Tham Thalu area.

V. A disseminated tin deposit in granite was found in the Chenkit mine in Changwat Surat.

PEGMATITE DEPOSITS

Pegmatites that contain majority tin and minor tungsten are common throughout western and southwestern Thailand. In many areas, such as Changwat Ratburi they are the primary rocks from which placer deposits were originated.

Tin-bearing pegmatites occur in the Chon mine in Changwat Surat; in many mines in the Takua Pa district; at various places in Changwat Phuket especially in Kathu Village. Pegmatites that contain both tin and tungsten occur in the Hat Som Paen deposits of Changwat Ranong, and tungsten-bearing pegmatite is found at Ko Pha-ngan, Changwat Surat.

Most of the tin and tungsten bearing pegmatites occur in veins that cut the intrusive granite and the slaty shale, phyllite and schist country rocks.

PEGMATITIC QUARTZ AND HYPOTHERMAL QUARTZ VEINS

Tin and tungsten deposits occur in pegmatitic quartz veins in the Pilok area where ordinary barren veins of quartz are also numerous. The Pilok mineralized zone is about 20 kilometers long, trending generally north-south along the outer part of a granitic batholith that intrudes phyllitic slate and quartzite of the Phuket series in the northwestern part of Changwat Kanchanaburi very close to the Thailand - Burma border.

Mineralization is limited to the granitic rocks, except at Khao Chang Phuak in the northern part of the area where mineralized quartz veins intrude the phyllitic country rock, and at Pha Pae III where wolframite bearing quartz veins cut the quartzite country rock. The main production in the area is tungsten, but Pha Pae V produces tin mainly. The southernmost known deposit is in Sattamit mine where tin is produced from granite that intrudes limestone and shale. The amount of tungsten decreases noticeably from north to south in the Pilok district and also with reduction of elevation.

Minerals found in the deposits of this particular area are wolframite, cassiterite, sphalerite, pyrite, chalcopyrite, arsenopyrite, molybdenite, bismuthite, quartz, beryl and muscovite.

MISCELLANEOUS

Hypothermal quartz veins that carry tin and tungsten are present in many different types of deposits. At Mae Moei, Changwat Tak for instance, tin bearing quartz veins cut granite, and at Lam Phaya, Changwat Yala, similar veins occur in aplitic granite, a uniform mineralized quartz veins stretches north-south and dips west 50° to 70° in the Wang Pha deposit of Changwat Songkhla.

Many tin and tungsten deposits that have not been fully investigated are also believed to be associated with granitic rocks. Some of these deposits are:- Wiang Pa Pao in Changwat Chiang Rai; Chae Hom and Mae Samoeng in Changwat Chiang Mai; Amphur Ban Phue in Changwat Udon and in Changwat Petchabun. Changwats from which the tin or tungsten deposits have been recently reported, but not investigated, are Loei, Buriram, Surin, Uthai and Chainat.

An unexplored small deposit occurs in Changwat Chanthaburi.

REFERENCES

Memorandum on the Mining Operation in Siam—Royal Department of Mines and Geology B. E. 2468 (1925) (in Thai).

The Mineral Wealth of Thailand—Department of Land and Mines B.E. 2482 (1939) (in Thai).

William R. Jones, 1925, Tinfields of the World. Mining Publications Limited.

Glen F. Brown, Saman Buravas, Jumchet Charaljavanaphet, Nitipat Jalichandra, William D. Johnston Jr., Vija Sethaput, and George C. Taylor Jr., Geologic Reconnaissance of the Mineral Deposits of Thailand. *U.S. Geological Survey Bulletin* **984**.

Li K.C. and Wang, C. Y. Tungsten. *American Chemical Society Monograph Series* **130**.

Chhibber H.L., 1934, The Mineral Resources of Burma. Macmillan and Co., Limited, St. Martin's Street, London.

Scrivenor J.B., 1931, The Geology of Malaya. Macmillan and Co., Limited, St. Martin's Street, London.

Sydney Fawns, 1907, Tin Deposits of the World. *The Mining Journal*, 46 Queen Victoria Street, E.C.

SIGNIFICANT MINERALIZATION OF THE COPPER-TIN-TUNGSTEN DEPOSITS AT THE AKENOBE MINE,JAPAN

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INTRODUCTION

Some geologic features of the copper-tin deposits of the Akenobe Mine were described about thirty years ago by Dr. T. Kato (1917, 1920, 1926), it is, however, due to recent investigations that the more detailed nature of the deposits has been clarified. It is noteworthy that the deposits show some characteristic relations between tin-tungsten mineralization and base metal sulphide ores. Accordingly, it may be considerable significance that some characteristic features of the mineralization are metioned here.

For many years the mine has been the foremost producer of tin ore in Japan and also the productive mine of copper, zinc, lead and tungsten ores. The mine has been worked for copper since as early as about 806 A.D., but it was since the 18th century that the development of the deposits has been profoundly carried. The total crude ore mined up to 1956 is summed up to about 10 million metric tons. Present status of production of crude ores is that the Cu-Sn-W ore is 6,500 metric tons (Cu 0.9%, Sn 0.8%, WO3-0.1%, Zn 1.0%), Cu-Zn ore is 14,200 metric tons (Cu 1.2%, Sn 0.1%, Zn 2.5%), Pb-Zn ore is 5,000 metric tons (Cu 0.4%, Pb 1.2%, Zn 3.5%), cupriferous pyrite ore is 300 metric tons (Cu 2.5%, S 28%), and some amounts of Au-Ag ore, totalizing about 26,000 metric tons per month[1]. With milling recovery of Cu 82%, Sn 44%, Pb, 83%, and Zn 54%, the total concentrates are 2,000 metric tons per month[2].

OUTLINE OF GEOLOGY AND ORE DEPOSITS

GEOLOGIC FEATURES

The Akenobe mining district is mainly composed of Paleozoic formations, hornblende gabbroic rocks, granophyre, and dike rocks. General features of the geology are summarized as follows.

Paleozoic

The Paleozoic is represented, in descending order, of black clayslate, sandstone, conglomerate, limestone lenses, green tuffaceous and gray phyllitic slate, chert, and green rocks of basic extrusive origin, including pyroclastic 'schalstein' and variolitic bassalt flows. The general trend of the sedimentary rocks is N40°-70°E, and dips are mainly 30°-80° NW. The mining district is divided into two areas by the Akenobe fault striking nearly north-south, and the active movement of the fault may be pre-ore deposition. In the eastern area, phyllitic slate, chert and green rocks are widely exposed, while in the western half black clayslate and sandstone are predominantly covering the green rocks. The sedimentary formation may belong to the Chichibu Paleozoic Group of Permo-Carboniferous age.

Hornblende Gabbroic Rocks

Gabbroic rocks, intruding into the Paleozoic sedimentary rocks mentioned above, are exposed in three large elongated masses striking generally northeast. The rocks are highly heterogeneous in rock facies and textures, and vary from a coarse-grained hornblende-rich gabbro to find-grained hornblende-poor dioritic rock facies. In many cases, schlierens and pockets of fine-grained quartz-diorite aplite, and acidic differentiate of the gabbroic rocks are found in the masses. Intense mineralization of epidote and prehnite as a deuteric alteration of gabbro intrusion is recognized in the masses and surrounding rocks, especially in green rocks. The age of intrusion is not clear, but may be Jurassic.

Granophyre

Having proto-mylonitic and granophyric textures, granophyre or partly granite-porphyry

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[1] The maximum annual production of crude ore was attained about 550,000 metric tons during 1940-1943.

[2] The kinds of concentrates recovered are Cu-, Pb, Zn-, Zn-, Sn-W, pyrite-, arsenopyrite-, and magnerite-concentrates. The grade of WO3 in Sn-W-concentrates is 1.5-5.4%, and tungsten is extracted as CaWO4 from slag of the Sn smelting at the Ikuno smelter.

occurs in the westernmost portion of the mining district. The rock intrudes into black clayslate, sandstone, and phyllitic slate. The age of intrusion seems to be late Cretaceous or early Tertiary.

Dike Rocks

Dikes of various kinds are abundantly distributed throughout the district. They are felsite, hornblende porphyrite, garnet-bearing felsitic rock, rhyolite, hornblende andesite, and basalt. Many of them, except the former two, cut the ore deposits and is clearly later than the metallization. These dike rocks are thought to be of Miocene age.

ORE DEPOSITS

The productive vein deposits of the Akenobe mine have some interesting features in the mineral assemblage, paragenesis and succession of mineralization. The veins are fissure-filling in type. The symetrical crustified banded structure, brecciated structure, and cockade ore structure are clearly recognized.

Ore Minerals

The major hypogene ore minerals are chalcopyrite, sphalerite, cassiterite, hornite, wolframite, scheelite, galena, arsenopyrite and magnetite in order of economic importance. Other subordinate minerals are pyrrhotite, pyrite, native bismuth, bismuthinite, molybdenite, hematite and a trace of stannite. Chalcocite, covellite and other supergene minerals are also found in the upper parts of the veins.

Gangue Minerals

The gangue minerals are quartz, chalcedony, siderite, calcite, manganiferous calcite, fluorite, apatite, chlorite and kaolin minerals.

Magnitude of the Veins and their Distribution

More than thirty major veins are arranged regularly, and are grouped as follows: (1) Parallel veins striking northwest and dipping steeply northeast are the most prominent and champion veins; (2) Veins striking nearly east-west and dipping steeply north are also important; (3) Veins striking northeast and dipping gently northwest are also productive; and (4) A few veins have north-south strike and a steep dip. Furthermore there are abundant minor veins and branches throughout the district. The major veins are generally about 300-1500 meter in strike length and with an average width of 0.3-1.5 meters. They extend about 300-500 meters in depth.

Wall Rock Alteration

The walls of the veins are composed of the rocks mentioned above in the section on geology. Alteration of those wall rocks is not conspicuous, but chloritization is widespread especially in the green rocks, and silicification, argillization and carbonatization, mainly sideritization, are intense in some veins. No pneumatolytic alteration of wall rocks is recognized.

MINERALIZATION

Kind of Ores and Zoning

The relative amounts of various ore-forming metals specify the classification of the veins as those of Cu-Sn-W ore, Cu-Zn ore, and Pb-Zn ore. The horizontal zoning of the minerals is not strictly clear, because the stages of mineralization of various metals are remarkably complicated with regard to each vein. Generally speaking, however, the veins of Cu-Sn-W ore are located near the center of the district, while those of Pb-Zn ore are found in the peripheral parts.[1] Owing to the same reason, hypogene mineral zoning due to depth zone is also indistinct, furthermore it is not regularly arranged, but with the general tendency that the tin and tungsten contents increases toward the depth with a decrease of lead and zinc.

Succession of Mineralization

The mineralization of the deposits is significantly complicated. As a whole, the following four stages of mineralization are recognized: Stage 1, Pb-Zn stage—sphalerite and galena are major minerals and associated with chalcopyrite, arsenopyrite, pyrite, magnetite, siderite and a trace of hematite. Stage 2, Cu-Zn-Fe stage—chalcopyrite, sphalerite, bornite and magnetite are major minerals and associated with galena, pyrrhotite, pyrite, and siderite. Stage 3, Sn-W stage—cassiterite, wolframite, and scheelite are associated with fluorite and apatite. Stage 4, Cu-Zn-Fe stage—chalcopyrite, bornite and magnetite are the major minerals. The stages of molyb-

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[1] The zone of lead and zinc is furthermore surrounded by the zone of the Au-Ag veins distributed remotely.

denite, native bismuth, and bismuthinite are not properly proved. It is a remarkable fact that the magnetite, forming euhedral, blade like, and shrinkage crack textures, occurs invariably in close association with sulphide stages. Between stage 1 and 2, and stage 2 and 3, fracturing and reopening of the vein-filled fissures are recognized in many cases. The features are shown by the facts that the breccias of stage 1 ore are fringed by ores of stage 2, and veins or crustified bands of stage 3 cut and displace those of the earlier stages, etc. The complete series of the four stages are not always found in all veins, but the relative succession is always applicable to most veins.

The succession of the mineralization indicated by four stages mentioned above is incompatible with conventional views of the ordinary succession of many other deposits, namely with regard to the mineralization of Akenobe deposits, the rather high temperature tin and tungsten minerals were deposited later than the low temperature base metal sulphides. The evidences are somewhat similar to the tin deposits of Monserrat and Carguaicollo, Bolivia (Turneaure and Gibson 1945, 1950), although no complex sulphosalt minerals of tin are found in the deposits under consideration.

The mineral assemblage and paragenesis of the deposits may be the best example of the highly telescoped ore, and to such deposits the term "xenothermal" may be applicable. The geologic age of the ore deposition is not directly evidenced, but the geological facts of the surrounding area[2] may prove the age of the ore deposition to be of Miocene age. Therefore, the conditions and circumstances of the ore deposition may be "subvolcanic" as proposed by H. Schneiderhohn (1955). The deposit is one of the best examples of the several similar tin- and tungsten- bearing base metal veins of Japan, and in turn the geologic conditions mentioned here may be the characteristics of the Tertiary tin-tungsten mineralization of the Circum-Pacific orogenic belt.

REFERENCES

Gibson, R. and Turneaure, F.S., 1950, Tin deposits of the Monserrat Mine, Bolivia. *Mining Engineering*, Tr. AIME. **187**: 1071-1078.

Kato, Takeo, 1910, The ring-ore from the Akenobe Mine, Province of Tajima. *Jour. Geol. Soc. Tokyo*. **24**: 35-41.

———, 1920, A contribution to the knowledge of the cassiterite veins of pneumato-hydatogenetic or hydrothermal origin. A study of the copper-tin veins of the Akenobe district in the province of Tajima, Japan. *Jour. Fac. Sci., Imp. Univ. Tokyo*, **43** : 1-60.

———, 1926, The Ikuno-Akenobe metallogenic province. *Jap. Jour. Geol. Geogr.* **5** (3) : 121-133.

Schneiderhohn, H., 1955, Erzlagerstätten. Kurzvorlesungen zur Einführung und zur Wiederholung. 3te Auflage. S. 160.

Turneaure, F.S. and Gibson, R., 1945, Tin deposits of Carguaicollo, Bolivia. *Amer. Jour. Sci.* **243-A** (Daly Volume) : 523-541.

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[2] At the Ikuno mine, about 18 km southeast of the Akenobe mine, the vein deposits resembling the Akenobe deposits are found in Miocene volcanic and sedimentary rocks.

TIN AND TUNGSTEN DEPOSITS OF JAPAN

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INTRODUCTION

The occurrence of tin and tungsten has been known in many places in Japan, especially in Honshu and Kyushu islands. They occur usually in close association with acid igneous rocks of the plutonic to hypabyssal type. Some complex polymetallic deposits of tin, tungsten, copper, lead and zinc are found in the Tertiary volcanic areas. Most of tin and tungsten deposits are not large in scale. The production of tin and tungsten in Japan has been insufficient to meet her domestic demand, though the history of mining of both metals is rather old. In recent years, domestic mines produce annually about 800 tons of tin metal and 900 tons of tungsten concentrate on an average.

TYPES OF DEPOSITS

Tin and tungsten deposits of Japan may be classified into the following types:

(I) deposits of plutonic type—
  (a) contactmetasomatic or pyrometasomatic deposits and
  (b) veins;
(II) deposits of subvolcanic type—xenothermal veins; and
(III) placer deposits.

(I) Deposits of Plutonic Type

(a) *Contactmetasomatic (or pyrometasomatic) deposits.*

Tin: The contactmetasomatic or pyrometasomatic tin deposits of workable scale are found in such a confined area as in east-central Kyushu, where the Permo-Carboniferous limestones of Chinchibu system have been intruded by younger granites of probable Tertiary age. The Obira, Hoei, Mitate, Toroku and Kiura mines are major tin producers in this area. The ore bodies of these deposits are irregular in shape and sometimes tabular or in pipe-form. Cassiterite and stannite are the principal tin minerals, and accompanied by such skarn minerals as hedenbergite, and radite, wollastonite, epidote and ilvaite with boron and fluorine minerals such as tourmaline, axinite, danburite, datolite and fluorite. In close association with these skarn minerals the sulphide and arsenide minerals such as pyrrhotite, arsenopyrite, loellingite, sphalerite, galena and chalcopyrite occur also in or near the skarn masses. A small amount of scheelite is also present. Some pneumatolytic to hydrothermal veins containing cassiterite and stannite with various kinds of sulphide minerals occur also in the Obira mining district, as mentioned below.

Tungsten: The occurrence of contactmetasomatic tungsten deposits is rather uncommon in Japan. However, several tungsten-bearing skarn masses, consisting mainly of garnet, hedenbergite, diopside, actinolite, chlorite, calcite and quartz with scheelite as the chief ore mineral, are found in the upper Palaeozoic limestones or calcareous hornfelses intruded by the late mesozoic granitic rocks, especially in the Kiwada-Kuga district in Yamaguchi Prefecture. The sulphide minerals such as pyrrhotite and chalcopyrite occur commonly in association with pyrite, arsenopyrite, sphalerite, galena, bismuthinite and a little cassiterite in the skarn ores.

A small amount of scheelite has often been discovered in many contactmetasomatic deposits of iron, copper, lead and zinc, as an accessory mineral.

(b) *Veins*

Tin and tungsten veins of the pegmatitic to hypo- or meso-thermal type are very common in Japan.

Tin: Some cassiterite quartz veins occur in the Mesozoic sediments or the granitic rocks of Tertiary age, in Kagoshima Prefecture, southern Kyushu. The vein deposits of the Suzuyama district are characterized by the occurrence of the earlier pneumatolytic minerals such as axinite and apatite. Some cassiterite-bearing sulphide veins, containing pyrrhotite, pyrite, arsenopyrite, chalcopyrite, sphalerite and a little stannite, are frequently observed. Small amounts of tetrahedrite, stibnite, argentite and weissite were also discovered in some veins. Though the skarn ores are scarcely recognized, mineralogic features of this district resemble closely those of the Obira-Mitate district described above.

Excellent examples of tourmaline-cassiterite-quartz veins are found in the Obira district, as mentioned already. They occur mainly in the fractured zones formed along the contact between the Palaeozoic sediments or lithoidite and the later granite-porphyry. The cassiterite is earlier than sulphide minerals and frequently altered to stannite by the later solution. Stannite-dots of exolution product are common in sphalerite in these veins.

Tungsten: A large number of tungsten deposits of this type have been discovered in Japan, and are of economic importance.

The cassiterite-bearing scheelite quartz veins at the Otani mine in Kyoto Prefecture are the most productive ones in Japan. The veins occur in a granitic stock of late Cretaceous age, which is surrounded by Upper Palaeozoic formations, composed of clayslate, sandstone and chert. Scheelite and a small amount of cassiterite are associated with some sulphides such as pyrrhotite, pyrite, arsenopyrite, chalcopyrite, sphalerite, stannite and galena. Quartz and muscovite are the chief gangue minerals. The wall rock alterations of granitic rocks into quartz-muscovite rocks are commonly observed.

The cassiterite-bearing wolframite veins occur also in the weakly metamorphosed sandstone, clayslate or chert of Palaeozoic age in the Takatori mining district, Ibaragi Prefecture. Wolframite occurs as the chief tungsten mineral and is usually rich in manganese, while scheelite has not been found in this mine. Sulphide minerals found in the veins, are arsenopyrite, pyrite and chalcopyrite with small amounts of pyrrhotite, sphalerite, stannite and galena. Topaz, fluorite, Li-bearing mica and tourmaline are frequently found in both, veins and altered walls.

Wolframite and scheelite occur together abundantly in the veins of the Kaneuchi and Wachi mines in Kyoto Prefecture. The country rocks are composed of the weakly metamorphosed slate, chert and sandstone of upper Palaeozoic age, forming the roof-pendant of unexposed granitic intrusive masses. Simple or composite veins are mainly filled with quartz, muscovite, adularia, calcite, wolframite, scheelite, arsenopyrite, pyrrhotite, chalcopyrite, pyrite, sphalerite and cassiterite. Small amounts of molybdenite, stannite, galena, bismuthinite, native-bismuth, apatite, tourmaline and chlorite are also found.

In the southern Kitakami district, gold-silver-bearing scheelite quartz veins, genetically related with the early Cretaceous granitic or monzonitic rocks, are found in the Mesozoic or Palaeozoic rocks. Veins at the Higashiiwai and Setamai mines, Iwate Prefecture, were worked for gold and tungsten. Tungsten deposits of network type occur in the gabbroic rocks intruded by later granitic rocks at the Koganesubo mine, Iwate Prefecture. Scheelite-bearing sulphide ores composed mainly of pyrrhotite, chalcopyrite and arsenopyrite, sometimes associated with nickel-cobalt minerals or uranium minerals, have been discovered in this district.

In the Ebisu-Togane district, Gifu Prefecture, wolframite-quartz veins, sometimes carrying workable amounts of bismuth minerals, occur in granitic rocks and Palaeozoic hornfelses. The veins of the Ebisu mine contain wolframite, rich in iron and a little scheelite with native bismuth, bismuthinite, emplectite, cassiterite, molybdenite, arsenopyrite and loellingite. Greisenization of the granitic rocks along veins is very conpsicuous Monazite, topaz, proto-lithionite, muscovite, fluorite and quartz occur in the greisen.

(II) POLYMETALLIC TIN-TUNGSTEN VEINS OF SUB-VOLCANIC TYPE (XENOTHERMAL VEINS)

In contrast with the tin or tungsten veins of plutonic type, which occur in or near granitic masses, tin-tungsten veins of the Tertiary volcanic areas are mineralogically very complex.

Polymetallic tin-tungsten veins of the Akenobe-Ikuno district have been worked for tin, tungsten, copper, lead, zinc, bismuth, etc. and are of economic importance. These veins are characterized by so-called "telescopic" association of various kinds of metals. The veins of the Akenobe mine occur in the Palaeozoic and Mesozoic formations and its associated basic intrusive masses, which comprise the basement foundation of the district. Many and exotic dykes cutting the older rocks are found in close association with the veins. More than fifty veins have been discovered in this mining area. The ore minerals of the veins include chalcopyrite, cassiterite, wolframite, scheelite, bornite, sphalerite, galena, magnetite and arsenopyrite with small amounts of pyrite, pyrrhotite, hematite, bismuth, bismuthinite and molybdenite. Quartz, chalcedony or chalcedonic quartz are the chief gangue minerals. Fluorite, siderite, calcite, apatite, chlorite and other clay-minerals are also found in these veins. According to recent studies by the geologists of the mine, major mineralization of tin and tungsten took place after the formation of most of the copper, zinc and lead minerals. However, tin-tungsten minerals increase in the deeper part of the veins, while the base metal minerals decrease. South-east of the Akenobe mining area, lies the Ikuno mining area. Here many polymetallic veins occur in the Tertiary sediments and volcanic rocks, which overlie the Palaeozoic and Mesozoic rocks. These veins contain lesser amounts of tin or tungsten minerals in comparison with the Akenobe mine, while the occurrence of cassiterite and stannite is their characteristic feature.

Similarly, the Tertiary gold-silver, copper or lead-zinc veins in Japan sometimes show the xenothermal telescoped ores. From the copper veins of the Ashio mine, Tochigi Prefecture the association of wolframite, scheelite, cassiterite, stannite, bismuthinite, wittichenite and others have been known. Wolframite - scheelite - cassiterite-bismuthinite - matildite association in some gold-silver ores from the Nishizawa mine in Tochigi Prefecture, wolframite - cassiterite - bearing copper ores from the Kishu mine in Mie Prefecture, and cassiterite-stannite-bismuthinite-tetradymite-bearing ores from the Suttsu lead-zinc mine in Hokkaido, are other examples.

Generally, as the tin and tungsten minerals in these Tertiary subvolcanic veins are very fine-grained compared with those from the veins of the plutonic type, it is usually very difficult to recover these metals from the complex ores.

(III) Placer Deposits

Tin or tungsten deposits of placer type in Japan are not of economic importance. Some cassiterite placers of the Quaternary age were formerly worked in the Naegi district, Gifu Prefecture, where granites and pegmatites, containing cassiterite, wolframite, monazite, topaz, beryl, fergusonite, sapphire and other minerals occur on a large scale. The cassiterite placer derives from the tungsten veins and was once mined at Suzugoya in the Takatori district, Ibaragi Prefecture.

METALLOGENETIC PROVINCES AND EPOCHS

The South Kitakami tungsten province is characterized by the occurrence of scheelite in the gold quartz veins of plutonic type. In the Takatori-Itaga, Otome, Ebisu-Togane, Setouchi and Yakushima provinces, many wolframite quartz veins are found in or near the granitic rocks. The association of scheelite and wolframite and abundant occurrence of scheelite are characteristic features of the veins of the Kaneuchi - Otani province. This province is economically important. The Kuga-Kiwada province comprises several contactmetasomatic scheelite deposits of skarn type. The Obira-Mitate and Suzuyama provinces are two important tin provinces of plutonic type, and the former is rather characterized by contactmetasomatic deposits, the latter by cassiterite quartz veins. More or less telescopic characters are noticeable in some ores from these provinces. In the Akenobe-Ikuno province, xenothermal telescoped ores of tin, tungsten, copper, lead and zinc have been exploited extensively. The Ashio-Nishizawa province belongs also to this group.

As to the metallogenetic epochs, the following three major epochs are recognized: (1) early Cretaceous; (2) late Cretaceous to early Tertiary and (3) late Tertiary (Miocene). Most of the workable tin deposits in Kyushu are considered to be genetically connected with the late Tertiary acid igneous rocks. The important tungsten deposits were probably formed in late Cretaceous to early Tertiary except for some veins in the South Kitakami province, which were formed in early Cretaceous time. All of the polymetallic tin-tungsten deposits of subvolcanic type may be genetically related to the late Tertiary activity.

PRODUCTION AND GRADES OF ORES

In Japan, tin mining began in the 16th or 17th century in the Obira-Mitate or Suzuyama district in Kyushu. The discovery of tin ores at the Akenobe mine in Kyogo Prefecture, in 1908, gave an important supplement to Japanese tin resources. About 50 percent of domestic tin has been produced from this mine. Average annual domestic production in recent five years (1952-1956) is about 800 tons of tin, that is just about 15 percent of Japan's total requirement.

Though the first exploitation of tungsten ore was reported in 1902 at the Otome mine in Yamanashi Prefecture, the domestic output previous to World War I was negligible. About 730 tons of concentrate in 1917 and 1200 tons in

1942 were the two peaks in the past, corresponding to the time of World War I and II, respectively. After World War II, production declined considerably, as after World War I, and the annual production in 1948 was only 7 tons. Since then, however, production has increased gradually, and reached 1050 tons (65 % WO_3) in 1954. The average annual domestic production in recent five years (1952-1956) is about 900 tons (60% WO_3).

In general, the workable tin or tungsten ore contains 0.8-1.0 percent Sn or 0.4-0.6 percent WO_3, respectively, and the former is beneficiated to a concentrate containing 30-50 percent of Sn, and the latter to 40-60 percent or more of WO_3. In the case of the polymetallic ores of the Akenobe mine, even 0.2 percent of tin in ores is profitable.

ORE RESERVES

The total reserves of tin and tungsten ores in the active Japanese mines are roughly estimated at 2,500,000 tons with an average grade of 0.86 percent Sn, and at 3,300,000 tons with 0.69 percent WO_3, respectively.

REFERENCES

Geological Survey of Japan, 1954, *Mineral resources of Japan*, **B-I c**—Iron, Ferro-alloy and Light Metals—(in Japanese). Tokyo.

Geological Survey of Japan 1955, *Mineral resources of Japan*, **B-I a**—Gold, Silver and Minor Metals—(in capanese). Tokyo.

Geological Survey of Japan, 1956, Geology and Mineral Resources of Japan. Tokyo.

Kato, T., 1914, The pyrrhotite tin-vein of the Mitate Mine, Prove. Hyuga, Japan. *Jour. Geol. Soc. Tokyo*. **21**: 9-31.

Kato, T., 1916, On the pneumato-hydatogenetic or hydrothermal formation of some cassiterite veins. A microscopic study of the tin veins at the Suzuyama Mine Prov. of Stsuma, Japan. *Jour. Geol. Soc. Tokyo*, **23**: 145-164.

Kato, T. 1920, A contribution of the knowledge of the cassiterite veins of pneumatohydatogenetic or hydrothermal origin. A study of the copper-tin veins of the Akenobe district in the Prov. of Tajima, Japan. *Jour. Fac. Sci., Imp. Univ. Tokyo*, Art. 5: 1-60.

Kato, T., 1937, New Geology of Ore Deposits (in Japanese). Fuzanbo Co., Tokyo.

Kinosaki, Y., 1953, On the granitic rocks in Chugoku, and the molybdenite and wolframite deposits in them (in Japanese). *Rep. Earth Sci. Univ. Hiroshima*, **3**: 62-75.

Miyahisa, M., 1955, On the Obira metallogenetic province (in Japanese). *Earth Science* (Chikyu Kagaku), **23**: 15-24.

Miyahisa, M., 1953-1954, Sulphide Ore Deposits of Dohi Vein, Obira Mine, Kyushu (I-III) (in Japanese). *Jour. Mining Inst. Kyushu*, **21-22**.

Nakamura, T., 1951, High temperature mineral association in a certain quartz vein at the Ashio Mine. *Jour. Fac. Sci. Univ. Tokyo*, Ser. II, **8**: 89-98.

Nakamura, T., 1954, Tin mineralization at the Ashio copper mine. *Jour. Polytech. Osaka City Univ.*, Ser. G. **2**: 35-52.

Sekine, Y., 1956, Some notes on the metallogenetic epochs and provinces of Japan (1-2) (in Japanese). *Earth Science* (Chikyu Kagaku), **26-27** and **29**.

Shibata, H., 1939, Granites and Pegmatites in Naegi district (I-IV), (in Japanese). *Jour. Geol. Soc. Japan*, **46**.

Takimoto, K., 1939, Geology and ore deposits of the Kiwada Mine, Yamaguchi Prefecture (in Japanese). *Jour. Geol. Soc. Japan*, **46**: 47-57.

Takimoto, K., 1944, Studies on the tin deposits of Japan. *Jap. Jour. Geol. Geogr.*, **19**: 195-242.

Watanabe, M., 1942, Gold tungsten deposits of the Higashi-Iwai mine, (in Japanese). *Jour. Jap. Assoc. Min. Petr. & Econ. Geologists*, **27**: 204-213.

Watanabe, M. and Ko, S., 1942, Geology and ore deposits in the vicinity of Ide, with a special reference to the gold-tungsten breccia-pipe of the Koganetsubo mine (I-II), (in Japanese). *Jour. Jap. Assoc. Min. Petr. & Econ. Geologists*. **28**.

Watanabe, T.et al., 1956, Progress in Economic Geology (in Japanese). Fuzanbo Co., Tokyo.

TUNGSTEN MINERALIZATION IN HONG KONG AND THE NEW TERRITORIES

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GENERAL GEOLOGY

1. The area of Hong Kong and the New Territories forms one small part of the great batholith of acidic rocks which stretch from Hangchow Bay on the East China Coast southwest to Cambodia and Thailand. This batholith is not only complex in age but also in the composition of its igneous rocks. The oldest rocks would appear to be associated with the mountain building of the Jurassic (Yen Shan No. 1). The later Laramide (Yen Shan No. 2) and Alpine revolutions also produced both extrusive and intrusive formations.

2. The rock however that everywhere dominates the topographical scene is a pinkish white granite. In Hong Kong this granite occurs in three main belts which trend in a S.W. to N.E. direction (Fig. 1). The most westerly belt comprises the barren rugged country which flanks both sides of Castle Peak Bay. The middle belt to the east starts in the Soko Islands and stretches northeast outcropping on many islands and reaching the mainland at Shan Shui Po and the area around Tide Cove. The third belt runs from Lamma Island in the South to Stanley Peninsula, Cape D'Aguilar and the Pu Toi Islands in the northeast.

3. The country rocks that the granite intrudes are with the minor exception of schists, predominantly older igneous rock; volcanics, porphyries and granodiorites.

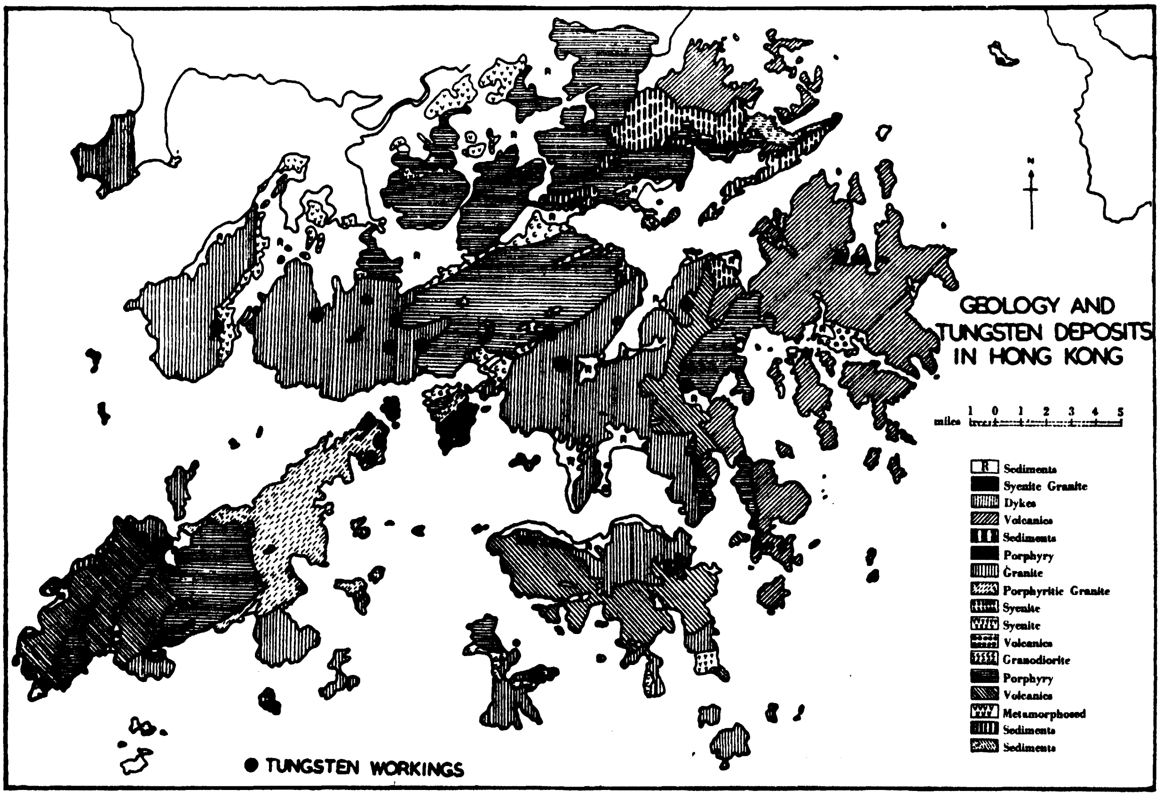

Fig. 1.

DISTRIBUTION OF DEPOSITS

4. The discovery of tungsten in South China dates back only to 1915. It was the armament requirements of World War I that encouraged mining and very quickly China became the world's largest producer. The Colony of Hong Kong was also not slow in taking advantage of its deposits and began active exploitation in 1917.

5. The largest production of wolfram ore comes from underground mining but many stream beds and paddy fields have alluvial and placer deposits. Altogether there are 17 workings that can be classified as mines: 2 as major workings (Needle Hill and Lin Fa Shan) using some mechanical equipment and 15 as minor workings. These minor workings are worked in primitive fashion employing the traditional Chinese style of shallow surface cuts and adits which are limited in length and depth to the amount of fresh air available. Slow hand methods and poor dressing operations have resulted in low recovery.

6. Estimates of ore reserves have been hazarded from time to time but they vary so widely that they are not worth quoting. The whimsical occurrence of the mineral makes it impossible to be reliable. What is certain in Hong Kong is that the demand for wolfram is always satisfied and that the reserves are greater than were ever thought possible 40 years ago. In 1953, the most recent year of high production, approximately 50 tons of tungsten ore concentrate (mainly wolframite) were mined each month. The final ore concentrate usually contains about 65% WO_3.

MINERALIZATION

7. The main tungsten mineral of economic importance is wolframite. In one area however scheelite also occurs. The wolframite occurs in both pegmatite dykes and in fissure veins. Associated minerals are molybdenite, cassiterite, pyrite, quartz, orthoclase, fluorite, beryl, zircon, sphene, garnet, muscovite and biotite. In two areas the pegmatite granite has been altered to greisen. A characteristic of this greisen is the

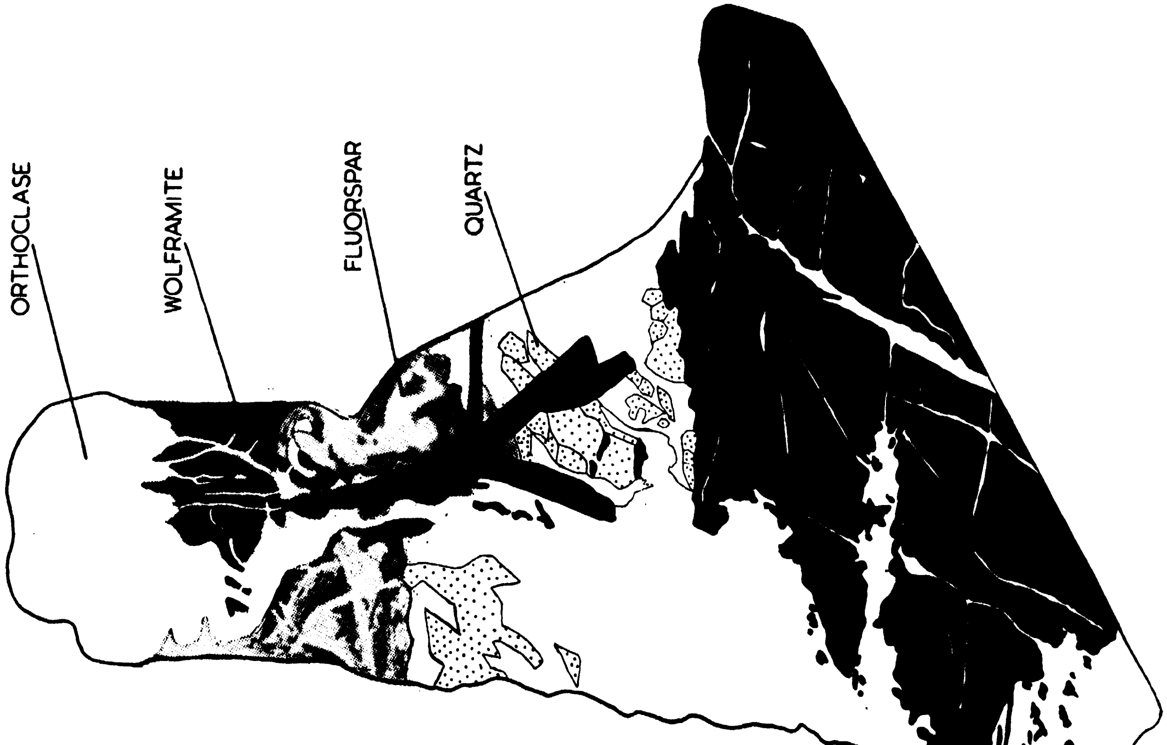

Fig. 2.—Needle Hill Mine. Hand Specimen. Enlarged 11/2 times.

box-network of quartz veins representing infillings and replacements along the same fractures that gave access to the solutions causing the greisenization.

SEQUENCE OF MINERALIZATION

8. The wolframite ores of Hong Kong occur in three main deposits: pegmatite, quartz vein and replacement.

9. A typical wolfram bearing pegmatite is illustrated in Figure 2. The principal minerals present are wolframite, orthoclase and fluorite. At Devils Peak and Sheko (below Dragon's Back) large beryl crystals also occur in the pegmatite. The paragenesis is fluorite, which exhibits definite cubic form, followed by the orthoclase felspar which has itself been injected by the irregular shaped wolframite. The fluorite acted as the principal flux in the primary magma. As a consequence differentiation probably took place at lower temperatures than have normally been associated with wolframite.

10. A typical wolfram-bearing quartz vein deposit is illustrated in Figure 3. There are two main minerals only: wolframite and quartz. This represents the transition stage in which the pegmatites have graded into quartz veins and the felspars have completely disappeared. A regular feature of the quartz veins is that the further they are away from the main body of the intrusion the narrower become the veinlets bearing the wolfram while the wolfram becomes coarser. Costly proof, typical everywhere in Hong Kong that thick quartz veins and dykes (over 12 inches) are not likely to carry economic amounts of wolfram has been furnished in the Needle Hill Mine. Here two long adits were cut to follow what were first thought to be promising wide veins. They proved a failure as the cost of extraction was far too expensive in relation to the yield. The paragenesis is: first the formation of the wolframite followed at a much later stage by the quartz. At Lin Fa Shan these quartz veins contain not only wolframite but cassiterite and small amounts of scheelite as well.

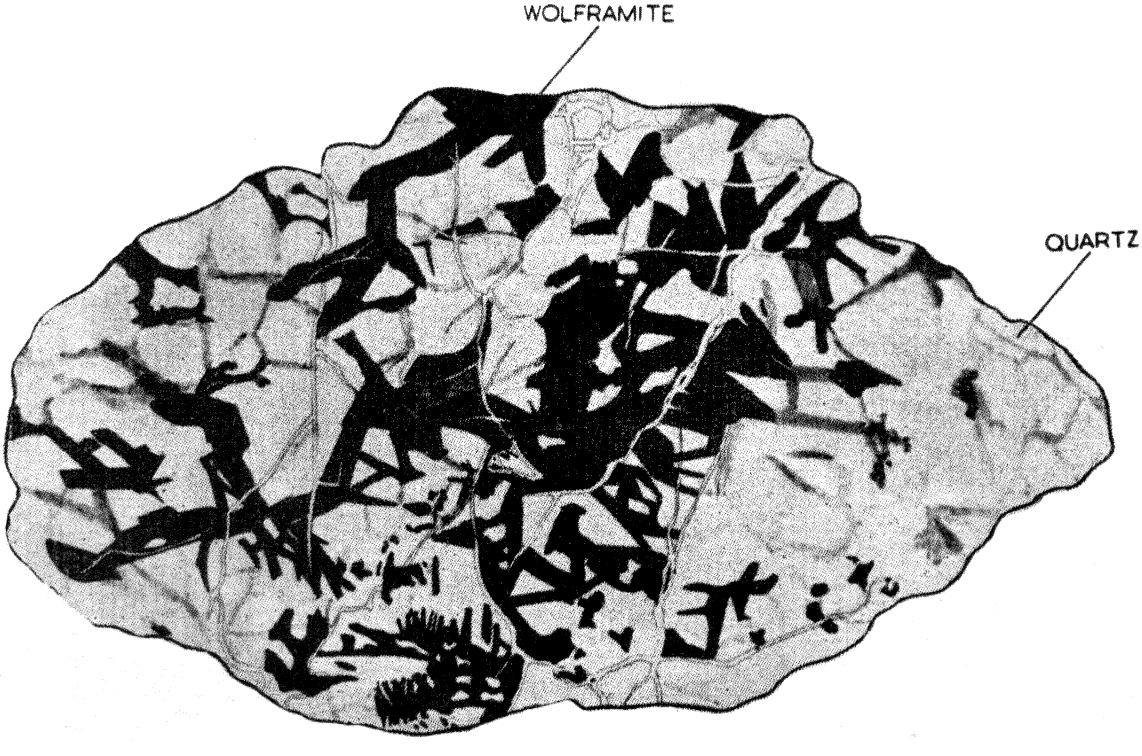

Fig. 3.—Lin Fa Shan Mine. Hand Specimen. Enlarged 1 1/2 times.

11. A typical fissure vein deposit is shown in Figure 4. It differs from the pegmatite because there is a much higher percentage of fluorite present with the wolframite and quartz. The paragenesis is clearly fluorspar first and then not so clearly wolfram and quartz: possibly in this order. This type of fissure vein is farthest from the main body of the intrusion and is pyrometasomatic or contact-metamorphic. The invaded rock giving this specimen is a rhyolite from Sha Lo Wan, Lantau Island. In a similar geological occurrence at Ma On Shan besides wolframite there is garnet and fluorspar. The felspars have been largely altered to chlorite. The presence of garnet and fluorspar indicates conditions of high temperatures and pressures aided by suitable fluxes. At Ma On Shan a large lenticular mass of magnetite (prove reserve of 10 million tons) is located close to the wolfram-bearing rocks. This points also to hypothermal conditions. There is also evidence of grading from the quartz veins to the pyrosomatic deposits. In the contact-metamorphic zones the effects on the invaded rocks vary quite widely. In some places the alteration consists chiefly of re-crystallization due to heat and supersaturated solutions.

12. In Hong Kong erosion of great thicknesses of the upper country rocks has revealed the present outcrops of pegmatites and contact-metamorphic deposits. If the widely supported theory that pyrometasomatic deposits form at from 400°C to 800°C at high pressures and at depths of from 1 to 2 miles it will be readily seen that mountain building in Hong Kong and South China was originally above 7,000 feet. Practically everywhere the zone of metallization is at 500 to 1,000 feet above sea level. At Castle Peak, northern Lantau, Wong Nai Tung, Ho Chung and Sokku Wan (Lamma Island) wolfram deposits occur at lower levels due to lateral contacts. While there is evidence that some of the wolframite deposits in Hong Kong have been formed under hypothermal conditions and high pressures there is also evidence to indicate that other wolframite

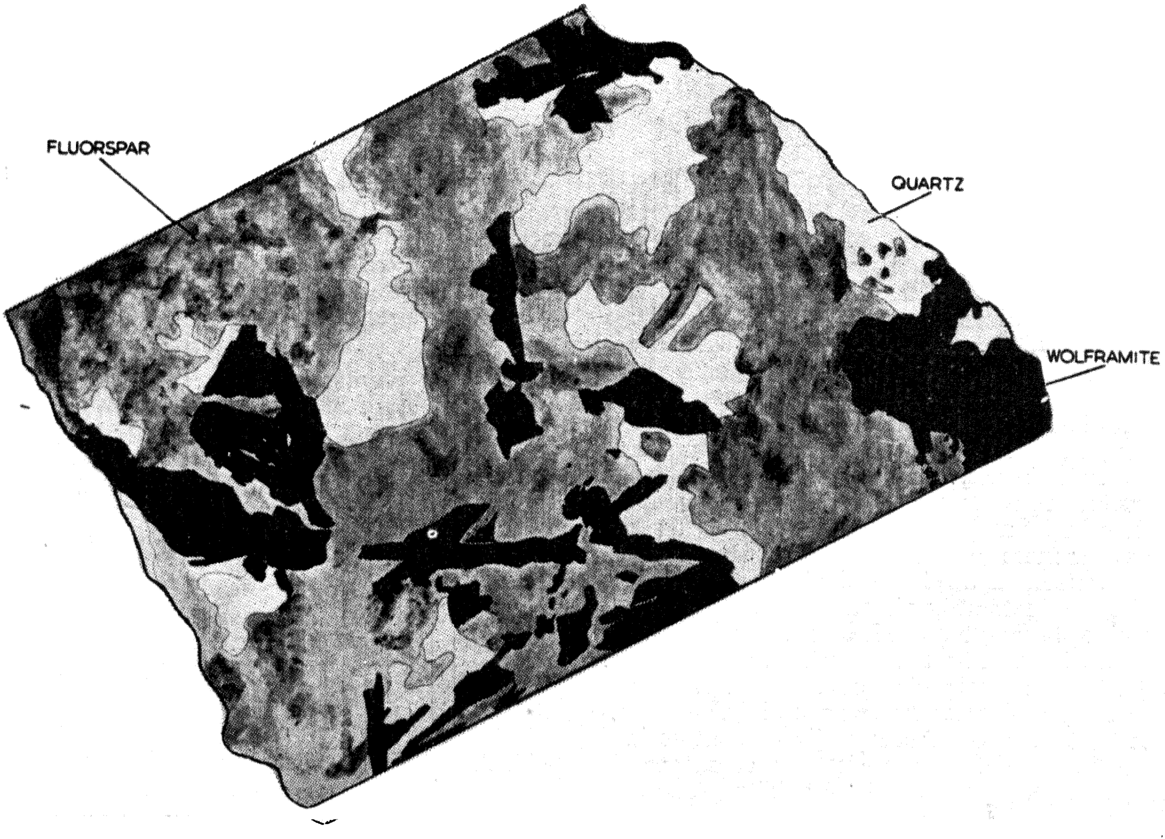

Fig. 4.—Sha Lo Wan Mine. Hand Specimen. Enlarged 1 1/2 times.

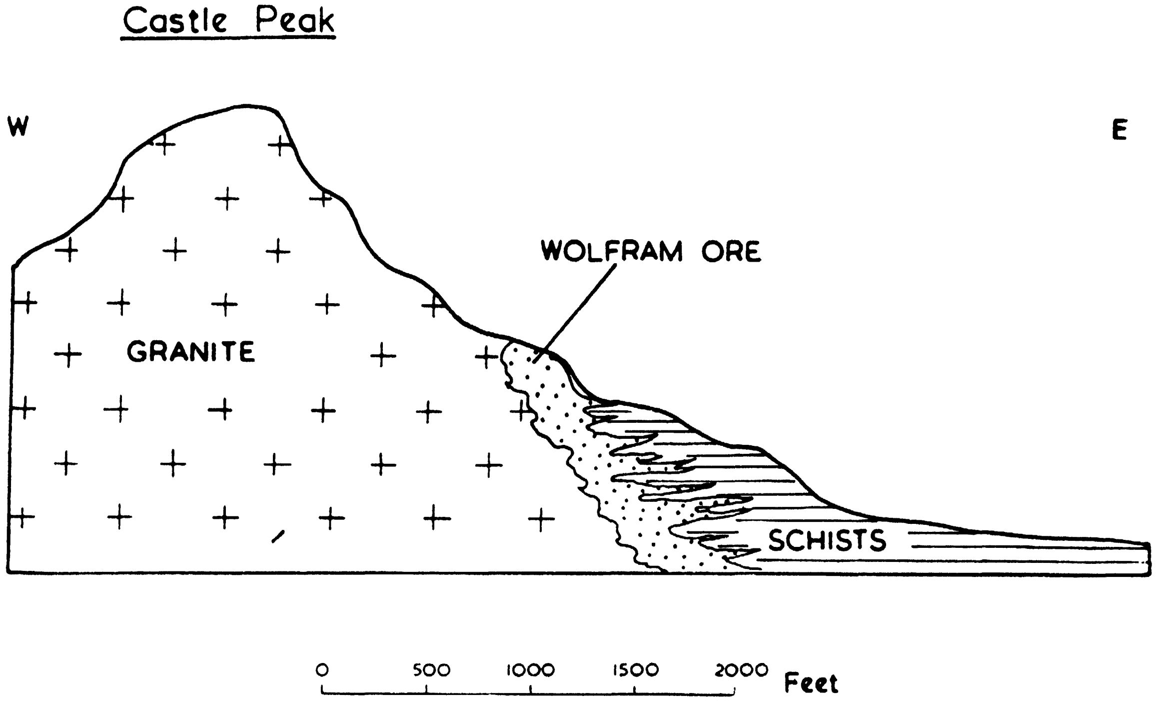

Fig. 5.—Cross Section Contact Metamorphic Deposit At Castle Peak (Generalized).

deposits formed under mesothermal conditions. The depositing agents seem to have been largely liquid and therefore with lower pressures. A. Holmes[1] throws important light on this crystallization problem while discussing the rate of cooling of magma. He says, "Crystals can grow only if the atomic groups of which they are built have time to move towards the points where crystallization is beginning. In a viscous magma diffusion takes place more slowly than in a mobile magma, and consequently a second controlling factor is viscosity. It is well known that rhyolite magmas form glassy rocks much more commonly than basalt magmas despite the fact that basalts are far more abundant as rocks than rhyolites. The reason for this is that liquid silica and orthoclase are extremely viscous near their crystallization temperatures whereas the minerals of basalt form melts that are much more mobile. Thus given equal periods of cooling the molecules in a basalt magma move more rapidly, and therefore build crystals more easily than those in a rhyolite magma. The viscosity of magma is reduced, and its period of fluidity prolonged, by the presence within of dissolved gases or volatile fluxes. It is for this reason that thin dykes of granitic composition rarely have glassy margins, whereas those of dacite or basaltic composition are more frequently bordered with a glassy selvage."

13. In Hong Kong there is consistent evidence of wolfram bearing quartz veins and stringers penetrating up to 300 feet into the country rocks and showing no signs of having produced the slightest contact metamorphism. This phenomenon can only be explained by assuming that the temperature of the liquid magma was much lower than that required in experimental laboratory tests to produce crystallization of wolfram and quartz. It seems certain from the evidence of minerals found in the pyrosomatic zones at Lin Fa Shan, Devils Peak and Sha Lo Wan that hydrothermal conditions together with carbon dioxide, hydrochloric acid and fluoric acid were favourable aids in the crystallization of the melts.

14. A basic factor, which is possibly responsible for the dissolving of normally difficult fusible

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[1] A. Holmes, "Petrographic Methods and Calculations". p. 335.

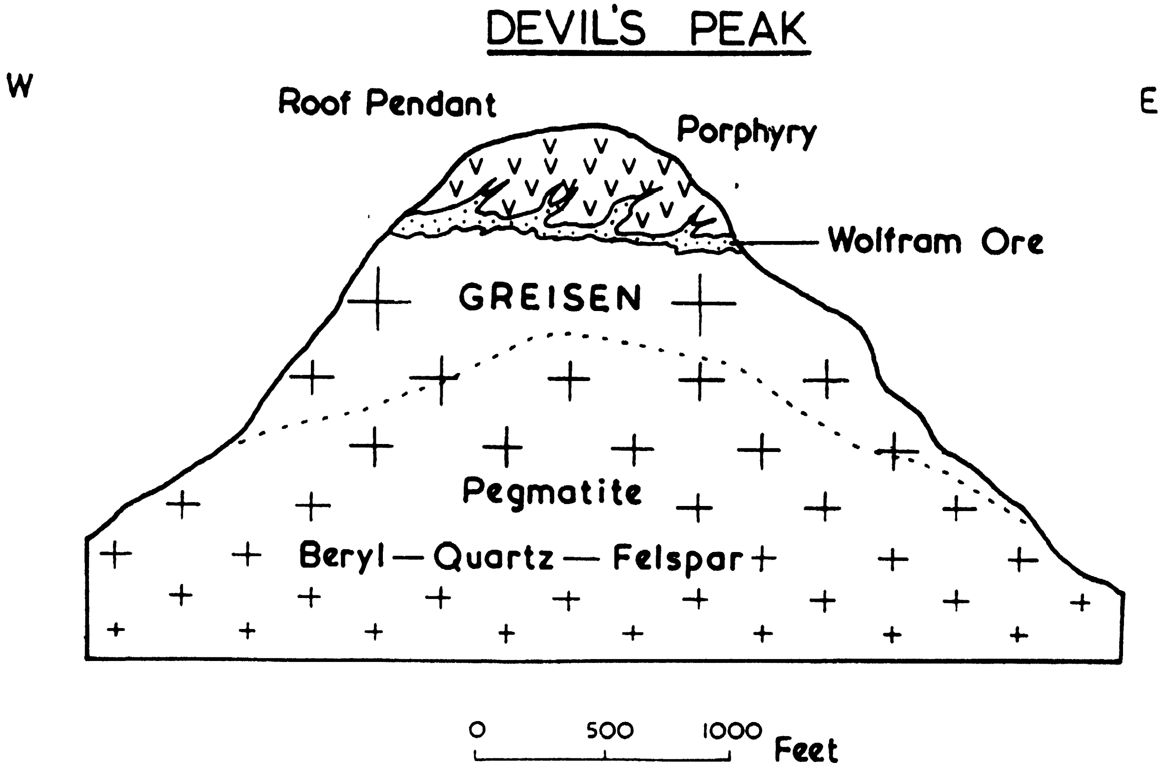

Fig. 6.—Cross Section Contact Metamorphic Deposit At Devil's Peak (Generalized).

material is concerned with the original eutectic mixture. Teall[1] and Vogt[2] long ago suggested that intergrowths of orthoclase and quartz that form last in many igneous rocks and fissures are eutectic mixtures. Teall gave a mixture of 63.05% orthoclase 37.95% quartz as a mixture having maximum solubility. Vogt suggested 74.25% orthoclase and 25.75% quartz.

15. It is quite obvious that the crystallization of minerals takes place in complex solutions of many constituents. Minerals precipitate when the melt reaches a point at which the substance cannot be kept in solution because of lower temperatures. It is now almost certain that minerals do not form at the temperature of their melting point. The presence of other constituents act as catalysts and allow crystallization at much lower temperatures. Again there seems to be no well established sequence or order of crystallization or indeed mineralization. The monumental research work of N.L. Bowen on eutectic mixtures has demonstrated how involved and complex are the relationship of temperature, solubility and mixtures. Field evidence in Hong Kong certainly points to the possibility that the temperatures at which mineralization took place were lower than laboratory evidence demonstrates.

16. The author in 1955, while on a United Nation Study tour of Senior Geologists in the U.S.S.R., visited the Department of Mineralogy, in the Institute of Geology, Academy of Science of Georgia, Tiflis. Here Professor G.V. Gvacharia showed him a mineral specimen that was predominantly stibnite enclosed in wolframite. Most antimony deposits are formed by hydrothermal solutions at low temperatures and shallow depth, giving rise to filled fissures, joints and rock pores and to irregular displacement deposits. The evidence of this specimen is of great importance because it indicates that later impregnated tungstate was at a sufficiently low temperature to crystallize itself without completely dissolving the stibnite, or even causing partial resorption of the mineral.

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[1] Teall. J.J.L. "British Petrography" page. 395, 1888.
[2] Vogt. J.H.L. "Die Silikatschmelzlosungen" Pt. 2, page 113, 1904.

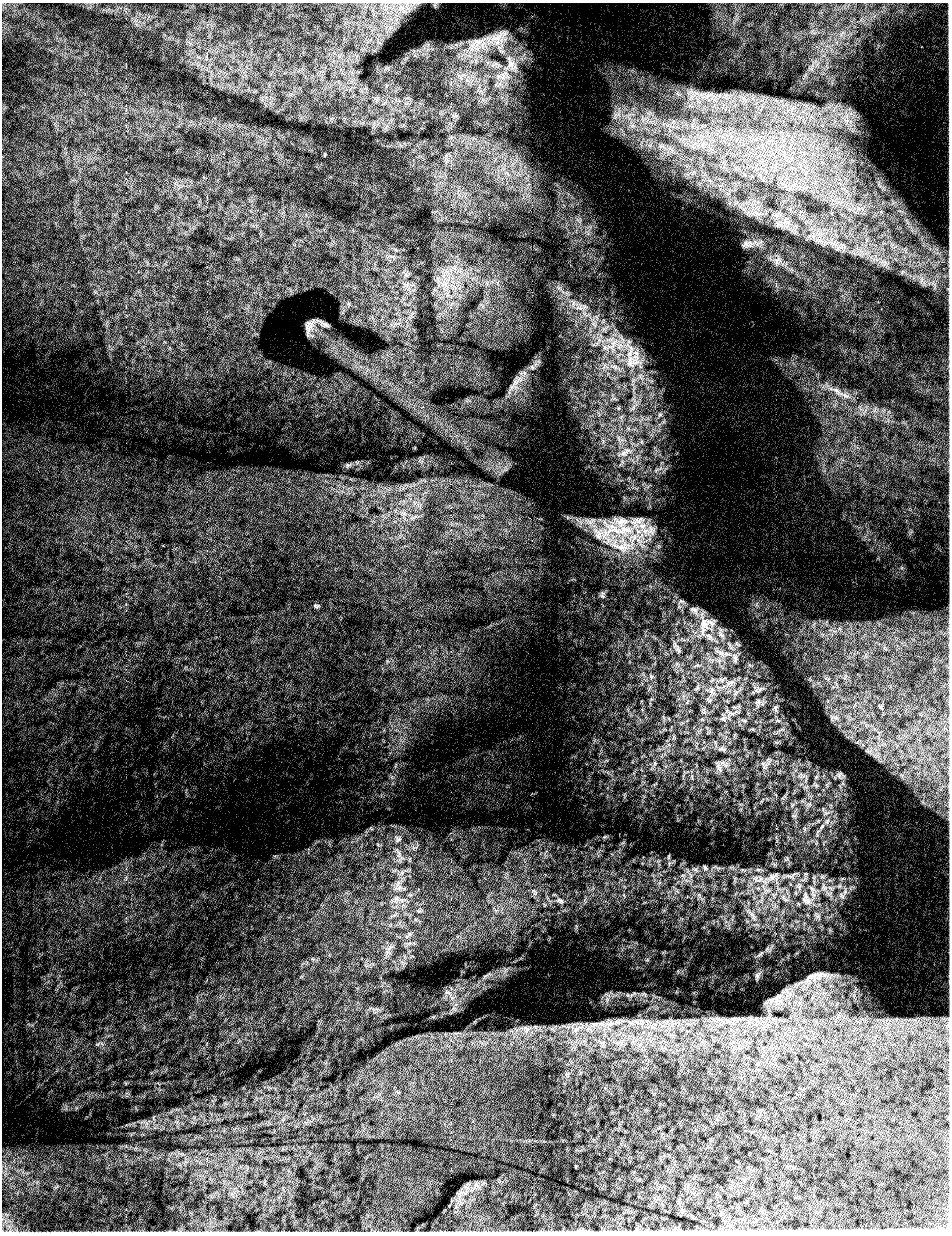

Fig. 7.— Aplite traversing country rocks showing marked pyrometasomatism and therefore low temperature origin of wolframite.