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VOLUME XXXV.

The Royal Society of Western Australia (Inc.).

ANNUAL REPORT OF THE COUNCIL FOR THE YEAR ENDING 30TH JUNE, 1949.

Ladies and Gentlemen,

Your Council begs to submit the following report for the year ending 30th June, 1949.

Membership.—There has been a slight increase in membership during the year. Three Ordinary Members and four Associate Members were elected and one Associate Member was transferred to Ordinary Membership. Four Ordinary Members and one Associate Member have resigned, and it is with regret that we also record the loss by death of three members of long standing in this Society, Dr. M. Johnson, Mr. L. W. Phillips and, recently Mrs. M. R. Lukin.

There are at present two hundred and twelve members, made up as follows :—

Honorary Members	6
Corresponding Members	7
Life Members	2
Ordinary Members	135
Associate Members	27
Student Members	35

Council.—Ten meeting of Council have been held and have been well attended.

Finance.—The Government Grant has been discontinued, but Volume XXXIV of our *Journal and Proceedings* is to be printed free of cost to the Society, the volume being limited to about one hundred and fifty pages. This is by way of being an experiment and, if satisfactory to the Government, some such arrangement as this may be agreed to for future volumes.

Publications.—Volumes XXXII and XXXIII of our *Journal and Proceedings* have been completed and issued to members and distributed according to our Exchange List.

Volume XXXIV has not yet been completed. The delay has arisen from the necessity of awaiting the outcome of our negotiations with the Government regarding the printing of our *Journal and Proceedings* by the Government Printer on a new basis and, subsequently, from the serious set-back caused by power restrictions this year and the current coal strike. Considerable progress has been mado, however, and publication should not be delayed much longer.

Council wishes to express its appreciation of the efforts of our Honorary Editor who has virtually brought publication up-to-date after it had fallen so far behind because of wartime and immediate post-war conditions.

Library.—Exchange publications now arrive regularly from Australian and overseas institutions and societies.

Relations have been resumed with ex-enemy countries of Europe to which postal facilities have recently become available after nearly ten years' interruption.

During the year exchange agreements have been concluded with the Raffles Museum, Singapore, the Indo-china Institute of Oceanography, and the Geological Survey of Uganda. The Reading Public Museum and Art Gallery, Pennsylvania has ceased publication and exchange relations with that institution have been terminated at their request.

The Library of the Australian National University has been placed on our mailing list and has been furnished with a complete file of the back numbers of our *Journal and Proceedings.*

There has been an increased number of requests for the institution of exchange relations and some of these are in the course of investigation prior to further consideration.

A number of requests have been received for Volume XXVI of our *Journal and Proceedings*, many packages of which were lost at sea at the commencement of hostilities in 1939. Our stocks of this volume have long since been completely exhausted, but we have been able to send a few copies through the kindness of several members who have donated their copies of this volume for the purpose.

Our library shelves have become overcrowded for lack of space and the suitable housing of surplus stocks threatens to become a pressing problem. Even should we secure the shelves being vacated by another tenant of these premises, this will not provide much respite from this very difficult problem of housing the Society's books.

Kelvin Medal.—The Kelvin Medal of this Society to be awarded in 1948–49 in accordance with the Rules has been awarded to C. A. Gardner, Esq., for his extensive and detailed botanical work throughout the State of Western Australia.

Australian Natural History Medallion.—Mr. L. Glauert, sometimes President of this Society and continuously, for more than a quarter of a century a member of its Council, has been awarded the Australian Natural History Medallion. The presentation was made at a Joint Meeting with the Western Australian Naturalists' Club which also, independently, nominated Mr. Glauert for the award.

Delegate to A.N.Z.A.A.S. Meeting.—Dr. E. M. Watson represented this Society at the Hobart Meeting of the Australian and New Zealand Association for the Advancement of Science, held in January of this year.

J. SHEARER,
President.

S. E. TERRILL,

C. F. H. JENKINS,
Joint Hon. Secretaries.

ABSTRACT OF PROCEEDINGS, 1948-49.

13th July, 1948.

Annual General Meeting in Gledden Hall.

Presidential Address.—" The Development of our Knowledge of Western Australian Marsupials," by Mr. L. Glauert.

10th August, 1948.

Paper.—" The Fauna of Rottnest Island No. 10—The Anthuridae," by Mr. J. M. Thomson, communicated by Mr. K. Sheard.

Films.—" Abrolhos Islands Fisheries, shown by Mr. K. Sheard.

Address.—" Camden Harbour, 1864–5 " (A Victorian Attempt at Settlement on the Kimberley Coast in 1864), by Professor R. M. Crawford.

Election.—Professor H. Waring as an Ordinary Member.

14th September, 1948.

Addresses.—(1) " Genetics in Forestry," by Mr. C. B. Palmer.
(2) " Escape to Reality—A New Approach to Nature Study," by Mr. Crosbie Morrison.

12th October, 1948.

Address.—" The Utilization of Coal," by Mr. R. P. Donnelly.

Films.—(1) " Coal Mining Today."
(2) " Cotton Spinning."

By courtesy of the Shell Oil Company of Australia, Ltd.

Election.—Mr. R. Smith as an Ordinary Member.

9th November, 1948.

Excursion.—Through the courtesy of the Director of the Government Chemical Laboratories (Mr. R. P. Rowledge) the November Meeting took the form of a conducted excursion through the Government Chemical Laboratories, Adelaide Terrace.

14th December, 1948.

Exhibits.—Specially prepared exhibits accompanied by short lecturettes were shown by the following :—

(1) Mr. C. A. Gardner—" Some Rare Western Australian Plants Recently Re-discovered."
(2) Mr. L. Glauert—" Some Curiosities in Natural History."
(3) Dr. R. W. Fairbridge—" Cuttle Fish."
(4) Mr. G. H. Burvill—" Soil Erosion Photographs."
(5) Mr. C. F. H. Jenkins—" The Jarrah Leaf Miner."

8th March, 1949.

Power Restrictions.—In view of the power restrictions and their effect upon attendance, it was decided to restrict the business of the Meeting to formal matters only and to postpone the President's address on " Some Aspects of Physical Science in the United States of America " until the April Meeting.

Ballot.—Mr. E. G. King as an Associate Member.

12th April, 1949.

Address.—" Some Aspects of Physical Science in the United States of America," by Mr. J. Shearer.

25th May, 1949.

Presentation of Natural History Medallion.—The award of the Natural History Medallion presented annually by the Field Naturalist Club of Victoria for the most outstanding worker in natural history was made to Mr. L. Glauert for 1948. The Medal was presented at a combined meeting of the Royal Society and the Western Australian Naturalists' Club in the Assembly Hall, Perth.

Address.—"Museums—Past, Present and Future," by Mr. L. Glauert.

Films.—Assorted Natural History Films.

14th June, 1949.

Papers.—(1) "Eunicidae and Nereidae of South-Western Australia with some notes on the ecology of Western Australian Limestone Reefs, and particular reference to Polychaete worm fauna," by Miss Patricia Kott. (Read in title only.)

(2) "Permian Successions in Part of Irwin River Basin, Western Australia," by Professor E. de C. Clarke, Dr. J. K. Prendergast, Dr. C. Teichert and Dr. R. W. Fairbridge.

(3) "Pectens of the Gingin Chalk," by Mr. F. R. Feldtmann.

THE ROYAL SOCIETY OF WESTERN AUSTRALIA INC.

KELVIN MEDALLIST, 1949.

The Royal Society's Kelvin Medal was instituted in 1924 to be awarded at four-yearly intervals for distinguished work in science in Western Australia. The recipient chosen for 1949 was Mr. Charles Austin Gardner. Born in Lancaster, England, in 1896, Mr. Gardner became interested in botany at an early age and when in 1910 his family migrated to Western Australia he found himself in a country with a very rich and interesting flora.

His first official appointment was as a botanical collector in the Forests Department and in 1921 he was attached to the Kimberley Exploration Expedition which investigated the north-western portion of the Kimberley division of Western Australia. In 1925, he joined the staff of the Department of Agriculture of Western Australia and in 1929 was appointed to the position of Government Botanist.

In 1937 he was appointed the first Australian Liaison Officer to the Kew Herbarium in England. On returning to Western Australia he commenced the task of re-organising the Perth Herbarium on scientific lines and the preparation of a flora of Western Australia, the work estimated to take at least 20 years.

His contributions to the science of systematic botany have been outstanding. He has described no less than seven new genera and 130 new species of plants. Perhaps the most important is his recently described *Pilostyles Hamiltonii*, a record which must have had repercussions on world theories of plant distribution and phyto-geography generally.

Mr. Gardner's enthusiasm as a field collector is reflected in the great expansion which has taken place in the Herbarium collection, which now totals over 32,000 sheets of preserved and mounted specimens.

In addition to his purely technical publications Mr. Gardner has contributed numerous articles of a more popular nature to the Journal of the Department of Agriculture of Western Australia and other periodicals.

His encouragement and advice were largely responsible for the excellent botanical illustrations carried out by Mr. Edgar Dell and the book of plates prepared by Mr. Dell with descriptive notes by Mr. Gardner has aroused keen interest in the flora of Western Australia throughout the world and has done much to popularise local botany.

Mr. Gardner has had a long association with the Royal Society of Western Australia during which time he has held various offices including that of Secretary and President.

Publications for which Mr. Gardner has been responsible, either wholly or in part, include the following:—

1922: "Contributiones Florae Australiae Occidentalis I." *Journ. Roy. Soc. W. Aust.*, Vol. IX, Pt. I, p. 34 (1922–3).
"Contributiones Flor. Aust. Occ. II," *ibid.*, Pt. II, p. 37.

1923: "Contributiones Flor. Aust. Occ. III," *ibid.*, Vol. IX, Pt. II, p. 90.
"Botanical Notes: Kimberley Division of W.A." *W.A. Forests Department Bull.* 32.

1924: "Contributiones Flor. Aust. Occ. IV." *Journ. Roy. Soc. W. Aust.*, Vol. XI, p. 19.
"Key to the Eucalypts of W.A." *W.A. Forests Department Bull.* 34 (with S. L. Kessell).

1926: "Contributiones Flor. Aust. Occ. V." *Journ. Roy. Soc. W. Aust.*, Vol. XII, p. 67.
"History of Botanical Investigation in W.A." Handbook, *A.N.Z.A.A.S.*, Aug., 1926.
"Salient Features of Plant Geography of Extra-tropical W.A.," *ibid.*

1927: "Contributiones Flor. Aust. Occ VI." *Journ. Roy. Soc. W. Aust.*, Vol. XIII, p. 61.

1928: "Contributiones Flor. Aust. Occ. VII," *ibid.* Vol. XIV, p. 79.

1929: "A Taxonomic Study of the Genus *Santalum*." *W.A. Forests Department Bull.* 44.

1930 : "Enumeratio Plantarum Australiae Occidentalis." *Supp. to Journ. Dept. Agric. W. Aust.,* Vol. VII.

1931 : "The Natural Pastures of W.A.," *ibid.* Vol. VIII, p. 273.

1933 : "Contributiones Flor. Aust. Occ. VIII." *Journ. Roy. Soc. W. Aust.,* Vol. XIX (1932–33), p. 79.

1936 : "Contributiones Flor. Aust. Occ. IX," *ibid.* Vol. XXII (1935–6), p. 119.
"Trees and Shrubs, Their Place in the Agricultural Districts." *Journ. Dept. Agr. W.A.,* Vol. XIII, p. 204.

1938 : "New Species of Western Australian Grasses." Hooker's *Icones Plantarum tabulae* 3361–63 (with C. E. Hubbard).

1939 : "Contributiones Flor. Aust. Occ. X," *ibid.* tabulae 3378–84.
"Dampier's Australian Plants." *Proc. Linn. Soc. London.* Sess. 151, Pt. 2, April, 1939 (with Prof. T. G. B. Osborn).

1942 : "Contributiones Flor. Aust. Occ. XI." *Journ. Roy. Soc. W. Aust.,* Vol. XXVII (1940–41), p. 165.
"Gascoyne Stock Route Poison Plants." *Journ. Dept. Agr. W.A.,* Vol. XIX, p. 84.

1944 : "The Vegetation of W.A. with Special Reference to the Climate and Soils." *Journ. Roy. Soc. W. Aust.,* Vol. XXVIII (1941–42).

1945 : "Taxonomy and the Species Concept." *Aust. For.,* Vol. IX, p. 7.

1947 : "Vegetation of the Hill River District." *W. Aust. Nat.,* Vol. I, p. 1.
"Outlines of the Vegetation of W.A." Handbook, *A.N.Z.A.A.S.,* Aug., 1947.

1948 : "A Note on *Eucalyptus campaspe.*" *Journ. Roy. Soc. W. Aust.,* Vol. XXXI (1944–45), p. 34.
"Contributiones Flor. Aust. Occ. XII," *ibid.* p. 75.

INDEX TO AUTHORS.

RECENT DEVELOPMENTS IN IDENTIFICATION AND ANALYSIS OF CRYSTALLINE MATERIAL IN POWDER FORM.

PRESIDENTIAL ADDRESS, 1949.

J. Shearer, B.A., M.Sc., F.Inst.P.

Delivered 12th July,1949.

1. INTRODUCTION.

Solid matter in a finely divided state the particles of which are crystalline is of extremely common occurrence in nature. This arises from the fact that the conditions under which matter commonly assumes the solid state are favourable to the formation of small single crystals (which may or may not be aggregated together). Examples of such processes are solidification from a melt, condensation from a vapour, and precipitation from solution. These generalisations apply to organic compounds as well as to the chemical elements and inorganic compounds.

When the particles are less than, say, 10^{-1} mm. in linear dimensions special methods of identification and (in the case of a mixture) of analysis must be used ; a chemical analysis alone may have little significance when information is required (as is commonly the case) as to the physical (or crystalline) state of the material. This is particularly the case for mixtures of minerals chemically similar such as clays, quartz, diaspore, etc. What is required is to be able to observe a property or properties of the crystalline state as such, and then to identify the unknown material or materials from known data. The optical methods of the mineralogist come within this category but they are not readily applicable to crystalline material in a finely divided state.

The methods to be described come under two headings :

Thermal methods.

X-ray Diffraction methods.

Thermal methods make use of the energy characteristics of the structure. X-ray diffraction methods depend upon the space pattern of the structure. The former may, and the latter most certainly do require a minimum particle size. This is conceivably due, in the case of thermal methods (where a lattice change is involved as distinct from the loss of adsorbed water), to the fact that the greater the state of sub-division the less energy is available from (or required for) lattice changes. In the case of X-ray methods the limitation is due to requirements of optical resolution. A third method will be discussed in relation to recent developments in the analysis of soil colloids. This method (as distinct from thermal and X-ray methods) is of very limited application being devised for clay minerals in general and for montmorillonite in particular. It is a method very recently developed and still tentative, but its value lies in the facts firstly that it exploits a property of the montmorillonite lattice that is probably independent of particle size (for very small particles) ; secondly that montmorillonite is, on account of its properties, an extremely important clay mineral, particularly as occurring in the clay fraction of soils ; and thirdly that quantitative determination, or even identification of montmorillonite, by the thermal and X-ray methods is sometimes difficult.

2. THERMAL METHODS.

Different methods have been used by different workers. For example minerals may be identified by their dehydration curves, in which temperature is plotted against loss in weight upon heating to constant weight at higher and higher temperatures—the specimen may be weighed hot or cold.

The thermal method which is being used and studied most extensively at the present time in U.S.A. is the differential thermal method. The rest of this section will be devoted to a brief description of the method and an account of the trend of current investigations in U.S.A. of the value of the method in qualitative and quantitative analysis.

Historically the method is an old one, having been proposed by le Chatelier in 1887. The "hot" and "cold" junctions of a thermocouple are inserted one in the powder specimen under investigation and the other in a powder sample (commonly calcined alumina) which shows no thermal reaction up to say 1000°C. The two powders are mounted side by side in a nickel (or stainless steel) block and heated in a furnace at a steady rate. The temperature of the junction in the specimen will lead or lag the temperature of the other junction in the vicinity of temperatures at which exothermal or endothermal reactions, respectively, occur. The electric current flow produced by a temperature difference may operate a mirror galvanometer and be recorded on a photographic sheet wrapped around a rotating drum. In lieu of a galvanometer recorder, a high sensitivity potentiometer recorder may be used. A separate thermo-junction connected to another galvanometer (or potentiometer recorder) serves to measure the furnace temperature.

A complete description of apparatus for differential thermal analysis has been published by Berkelhamer (1), Grim and Rowland (2) and others (3). The curve obtained with such apparatus will be referred to as a *thermal curve.* This is in effect a graph of differential temperature against furnace temperature. The thermal curve of a thermally inert material will be a straight line. A dip in the curve will occur in the vicinity of temperatures at which an endothermal reaction occurs ; a hump where an exothermal reaction occurs.

Thermal reactions occur (a) with the loss of adsorbed water or of interlayer water between the lattice sheets ; (b) with the loss of so-called high temperature water, or water which is an essential part of the crystal lattice ; and (c) with any change or (in extreme cases) breaking down of the lattice, that is of the crystal structure. Following a breakdown of the lattice re-crystallisation may occur with the appearance of new crystal forms and with an accompanying thermal reaction.

Insofar as a crystalline substance gives a characteristic thermal curve, it may be identified by the curve ("identification"). Moreover, a mixture of substances gives a composite curve made up of the superposition of the component curves ("qualitative analysis"). From the relative prominence of the component curves a quantitative analysis may be made.

(a) *Identification.*

Most of the pure materials whose thermal curves have been published have been minerals. A few such substances show no appreciable thermal reactions up to 1000°C. and are therefore undetectable by differential thermal methods. Hematite, pyrophyllite (Speil (3)) and sericite (4) are oxamples. Others, of which the illite and montmorillonite clay minerals are examples, conform much less to a standard pattern than is required for certain identification.

Each worker has been obliged to obtain his own standard data, particularly because of the difficulty of accurately reproducing from equipment to equipment all the conditions that affect the final thermal curves. Among such conditions are the location of the junctions of the differential thermocouple in the specimen and the rate of rise of temperature of the furnace. As the process is a dynamic one the latter condition is particularly important. The figure usually adopted is from 10°C. to 12°C. per minute. Speil (3) has observed that changing the rate of temperature rise from 5°C. to 20°C. per minute affects both the position and shape of a thermal dip (or hump) but does not noticeably change the area associated with tho thermal effect. Variations in the curves obtained by different workers for nominally the same mineral can sometimes be attributed to impurity in one of the specimens.

A difficulty inherent in any method designed to identify minerals in the powdered state is associated with variation in chemical composition of a mineral from one specimen to another. Extensive studies are being made in U.S.A. of the effect of chemical composition upon thermal curves, but no specific conclusions have yet been reached. The only generalised statement that would summarise the common experience of different investigators is that various samples of a pure mineral (particularly of a clay mineral) may not give identical thermal graphs ; whether composition, particle size, or some other factor is responsible is not known. At high temperatures thermal effects may depend more markedly on chemical composition than at low temporatures. Slight changes in composition such as occur in the case of minerals relatively constant in composition like kaolin and the hydrous oxides of aluminium do not affect markedly the thermal analysis behaviour of these minerals.

Although the absolute amount of specimen under investigation is not commonly regarded as critical, there is some evidence (5) that, owing to the dynamic nature of the process, the thermal capacities of specimen and inert sample should be the same ; otherwise the temperature difference may not remain zero as the furnace temperature rises over a range throughout which no thermal reaction occurs. This phenomenon, if it occurs, would tend to displace peak temperatures.

There is evidence that at least in some cases the temperature at which the peak of a thermal reaction occurs diminishes with decrease in particle size (Speil (3)). This may be a secondary effect associated with an effect of particle size that will be discussed under (c) below.

An interesting feature of thermal methods of analysis is that tho presence of externally adsorbed water may be detected. It is not detectable by all methods of analysis.

(b) *Qualitative Analysis.*

Analysis is possible only if the individual constituents in a mixture are separately identifiable, that is if each constituent when pure gives a well defined characteristic thermal curve. In that case two-component mixtures may be resolved and in most favourable circumstances three-component mixtures—provided in every case that the relative proportions of the components are not very different. In the case of components with thermal reactions not widely separated in temperature, a limiting factor in the detection of small quantities of a component is the wide " temperature spread " of the average thermal reaction. Minerals most favourable for identification and analysis (both qualitative and quantitative) are the kaolin minerals, hydrous oxides and carbonates.

An effect which appears to operate for all substances and which must be recognised in qualitative analysis is a decrease in the peak temperature of a thermal reaction with decreasing proportion of the reacting substance. The effect is more marked the greater the " temperature spread " of the thermal reaction and is absent only when the temperature range of a reaction is very narrow (much less than 50°C. perhaps). In the case of the broad endothermic reaction of kaolinite centering about 600°C. and of temperature range about 150°C., the endothermic peak temperature may decrease by 50°C. as the kaolinite content decreases. from 100 per cent. to 10 per cent. The effect may be due to the relation between peak temperature and magnitude of thermal reaction discussed under (c).

(c) *Quantitative Analysis.*

Theoretical investigations of Speil (3) and of Kerr and Kulp (4) predict that the area under a peak in a thermal curve is proportional to the percentage of a component present. Experiment (with artificial mixtures) approximately verifies this prediction. Under the most favourable circumstances according to Speil, quantitative analyis may be carried out for two component mixtures of minerals with an accuracy of $\pm$ 5 per cent. Peak heights alone may suffice in many cases to give a reasonably accurate quantitative analysis and will give the same accuracy as peak areas in those cases where standard mixtures can be made up of components in the same chemical and physical state as they occur in the " unknown " mixture.

A neat device that has been suggested for determining quantitatively the amount of a constituent present in a mixture is to load the inert sample with an amount of the constituent which will eliminate the thermal graph of the constituent from the composite graph of the mixture. Such a procedure would have the advantage of making easier the identification of any other thermally active constituent or constituents that may be present. It would still involve, however, the preparation of artificial mixtures and require, for accuracy, pure material of the same chemical and physical state as the constituent in the " unknown " mixture.

The theory that predicts the proportionality of the percentage of a component present to the area under a peak takes no account of the effect of the degree of subdivision upon the total heat of the reaction. As was mentioned in the first section the smaller the particle size, the less " ordered lattice " there is to take part in lattice changes and the less the thermal reaction would be expected to be. This receives approximate confirmation from some experiments but not from others. Since the peak of a thermal reaction is the point at which the rate of heat absorption (or evolution) by the reaction is equal to the rate of gain (or loss) by conductivity (modified by the fact that the temperature of the whole system is rising steadily), one would expect that for a smaller total heat of reaction the peak would occur at a lower temperature. Some experiments show decreasing temperature of reaction with decreasing particle size ; this has already been alluded to under (a). Others (6) show constancy both of peak areas and peak temperatures with varying particle size.

The effect of particle size upon differential thermal analysis graphs is being studied extensively in U.S.A. No agreement has been reached upon the effect of particle size upon peak temperature or upon the integrated area of a thermal reaction. There appears to be agreement that the intensity of a reaction (that is, tho height of a peak) diminishos with particle size.

The effect of particle size upon thermal graphs is perhaps most important by reason of the associated effect upon thermal conductivity. This is perhaps one of the most important factors influencing the shape and reproducibility of the thermal graphs. It will vary with packing and with particle size. The theory (4) that predicts the proportionality of total heat of reaction and the area under the thermal graph assumes a constant conductivity approximately the same as that of the inert sample.

In the following section a theoretical investigation is made of the effect of particle size upon the total heat of reaction.

3. DEPENDANCE OF HEAT OF REACTION UPON DEGREE OF SUBDIVISION.

Suppose we have mass m of a substance in the form of a single cube of edge a cm. The area of the cube is $6a^2$.

If it be divided into N smaller cubes, the edge of each smaller cube will be $a/\sqrt[3]{N}$ and the aroa of all the faces will now be $6a^2 \sqrt[3]{N}$.

The area is therefore increased by $6a^2 \sqrt[3]{N}$ when N is large.

Now if E is the average energy per unit area involved in severing the lattice across any plane, then E is the energy required to increase the surface by 2 units of area. Therefore the energy required to produce N cubes from the original single cube is $3a^2 \sqrt[3]{N}\ E$.

If the cube size is further reduced by a factor n the edge of each cube will be $a/n\sqrt[3]{N}$ the number of such cubes will be Nn^3 and the energy required to produce Nn^3 cubes from the original single cube will be $3a^2\ n\sqrt[3]{N}\ E$.

If we may consider the destruction of a lattice under differential thermal analysis conditions as equivalent firstly to the reduction of the particle size to that of a unit cell and finally to the destruction of the unit cells, then if we assume the original cube to bo a single cubic crystal (unit cell edge a_0) the total energy required to destroy the lattice is $3a^2 \sqrt[3]{N_0 m}\ E + N_0 me$ where N_0 is the number of unit cells per unit mass and e is the energy required to break down a unit cell.

If the initial degree of subdivision is such that there are N particles the energy required to destroy the lattice is $3a^2 \sqrt[3]{N_0 m}\ E + N_0 me - 3a^2 \sqrt[3]{N}\ E$.

This diminishes with particle size. If the initial degree of subdivision is such that there are Nn^3 particles the energy required is

$$3a^2 \sqrt[3]{N_0 m}\ E + N_0 me - 3a^2\ n\sqrt[3]{N}\ E.$$

The ratio of the energy required in the second case to that required in the first case is

$$\frac{3a^2\sqrt[3]{N_0}mE + N_0me - 3a^2n\sqrt[3]{N}\,E}{3a^2\sqrt[3]{N_0}mE + N_0me - 3a^2\sqrt[3]{N}\,E}$$

If ρ is the density of the crystalline material $a = \sqrt[3]{m/\rho}$. Therefore the ratio may be written

$$\frac{3m\sqrt[3]{N_0\rho^2}E + N_0me - 3n\sqrt[3]{N\rho^2m^2}\,E}{3m\sqrt[3]{N_0\rho^2}E + N_0me - 3\sqrt[3]{N\rho^2m^2}E}$$

$$= \frac{m\sqrt[3]{N_0\rho} + N_0m\rho e/3E - n\sqrt[3]{N\rho m^2}}{m\sqrt[3]{N_0\rho} + N_0m\rho e/3E - \sqrt[3]{N\rho m^2}}$$

But $a_0^3N_0\rho = 1$ and $a_1^3N\rho = m$ where $a_1 = a/\sqrt[3]{N}$. Therefore the ratio becomes

$$\frac{m/a_0 - nm/a_1 + N_0m\rho e/3E}{m/a_0 - m/a_1 + N_0m\rho e/3E}$$

$$= \frac{1/a_0 - n/a_1 + N_0\rho e/3E}{1/a_0 - 1/a_1 + N_0\rho e/3E}$$

With a given value of a_1 the smallest value this expression assumes occurs when n has the value n_1 given by $a_1/n_1 = a_0$; and if at the same time $a_1 > a_0$ we may write the expression in this case

$$\frac{N_0\rho e/3E}{1/a_0 + N_0\rho e/3E}$$

$$= \frac{e/3a_0^3E}{1/a_0 + e/3a_0^3E}$$

Now if the energy required for subdivision by a large factor n_1 associated with the inequality $a_1 > a_0$ is appreciable, this ratio is very much less than unity and so to a first degree of approximation $e/3a_0^3E$ may be neglected in comparison with $1/a_0$ and the original expression for the ratio may be written

$$\frac{1/a_0 - n/a_1}{1/a_0 - 1/a_1}$$

If n is large and $a_1 > a_0$, this may be written approximately $1 - na_0/a_1$.

To get some idea of the order of magnitude of this quantity we may put $a_0 = 5$A, $a_1 = 1\mu$ and $n = 100$. The expression is then equal to 0.95. This means that the degree of subdivision within the range considered is without appreciable influence upon the total heat of reaction. This is not in accordance with some experimental evidence if the area under an endothermal peak is proportional to the energy required to break down the lattice. For example (according to Speil (3)), in the case of kaolin with $a_1 = 0.5$ to 1μ and $n = 10$ the ratio of the peak areas is about one-half. Such values could be assumed by the theoretical expression for the ratio only if $N_0\rho e/3E$ were negative and comparable to $1/a_0$. On the other hand the theoretical conclusion above is in accord with the tentative opinion expressed by Dr. S. Hendricks of the Bureau of Plant Industry, Belstville, Maryland, U.S.A., in a letter to the author outlining experience in his laboratory. It accords also with Berkelhamer (6).

Even if $e/3a_0^3$ E is of the same order of magnitude as $1/a_0$ we get, for the final approximate value of the ratio, $1 - na_0/2a_1$ a quantity still more nearly unity for the values of a_1, a_0 and n assumed above.

4. X-RAY DIFFRACTION METHODS.

Single crystal rotation and oscillation methods are available for identifying crystals of the order of a fraction of a millimetre in linear dimensions, but as only one particle can be studied at a time it is not suitable unless the material is a one component system and the amount of material is insufficient for a powder analysis. In any case the single crystal method is quite unsuitable for particles so small as to come within the category of a fine powder. The method applied in the case of such material is the one developed in 1916 in Germany and in the same year in the United States by Hull—the X-ray powder diffraction method. Slit aperture collimation or circular aperture collimation may be employed, the powder being mounted in the form of a wedge or of a cylinder or of a flat plate. In the last case the beam traverses the plate in the direction of its thickness and the diffraction pattern is limited to Bragg angles much less than 45°. Until recently a cylindrical film concentric with the irradiated portion of the sample was commonly employed for recording the diffraction pattern. In U.S.A. extensive developments have recently taken place in the use of the G.M. tube, with counter or recorder, for observing X-ray diffraction patterns. In this case the G.M. tube is mounted exactly as the ionisation chamber in an ionisation chamber spectrometer. The powder is packed into a plate and mounted as a single crystal would be mounted for Bragg reflections. At the same time the crystal powder is rotated at half the angular speed that the Geiger tube is rotated, again in the manner of Bragg spectroscopy, so that when a diffracted beam is recorded by the Geiger tube the incident and diffracted beams are symmetrical with respect to the face of the crystalline powder. This has the advantage of improving focus and simplifying effects due to absorption. In what follows diffraction patterns will be visualised as being recorded photographically on a cylindrical film, with circular aperture collimation.

Details of instrumentation and technique in diffraction analysis are referred to in a recent review by Kaufman and Fankuchen (7).

Insofar as a powder is sufficiently crystalline to give a recognisable diffraction pattern, it may be identified by the pattern. A mixture of substances gives a composite pattern made up of the superposition of the component patterns. From the relative prominence of the component patterns a quantitative analysis may be made.

(a) Identification and Qualitative Analysis.

Approximately uniform density of a diffraction line (*i.e.*, the absence of " blotchiness ") can be achieved only if the particles are sufficiently small. The " blotchiness " is not serious if the particles are as large as 10^{-1} mm. provided the specimen is cylindrical and rotated during an exposure, and disappears when the particles are as small as 10^{-2} mm. In this latter case it is found experimentally that the width of a diffraction line is governed by the geometry of the system—the smaller the irradiated sample the narrower the diffraction line. These conditions hold—sharp continuous lines—over the range 10^{-2} to 10^{-4} mm. in particle size. When the particle size is less than about 10^{-4} mm. the width of the diffraction line begins to increase over and above that fixed by the geometry—an effect explained by simple optical principles. For particles as small as 10^{-6} mm. the lines are broadened to diffuse haloes characteristic of amorphous solids. This, therefore, may be set as the extreme lower limit of size of particles in aggregates susceptible to analysis by the X-ray powder diffraction technique. The extreme range of particle size that may be handled by this method may therefore be put down as 10^{-6} mm. to 10^{-1} mm. or 1mμ to 10^5 mμ. This is a very large range and includes within it the particle size range in which colloidal properties are observed, namely, 1 mμ to 10^3mμ. For reliable analysis, as distinct from identification of a pure sample, the range of particle size permissible is perhaps 10 mμ to 10^4 mμ.

As in the case of the thermal method described, the X-ray method in general gives a true chemical analysis in that the state of chemical combination is revealed as well as the kind of chemical elements present.

The method nevertheless has definite limitations apart from the limitation in particle size. It is limited to solids sufficiently crystalline to give a recognisable diffraction pattern. Of the first 1,000 substances examined for the purpose of recording, for reference in identification and analysis, their diffraction patterns, five per cent. were " amorphous," that is, gave no recognisable pattern. Again, the weaker or more diffuse the pattern is, the greater is the minimum quantity of the substance detectable in the presence of other substances, particularly if these latter are highly crystalline. A large percentage of amorphous material may be present in this way undetected. For example, diatomaceous earth (which gives almost but not quite a typically amorphous pattern) is not detectable when mixed with crystalline material and given exposures sufficient to produce an intense diffraction pattern of the crystalline material, unless it is mixed in proportion of at least 1 : 1. Another limitation is that elements may be present in solid solution without any discernible change in the diffraction pattern. Then in the field of minerals, variation in chemical composition makes deductions as to chemical composition difficult as well as the identification of the mineral species.

(b) Quantitative Analysis.

The measurement of X-ray intensity is fundamental to quantitative analysis by X-ray powder diffration technique. The two commonest methods at present employed for recording diffraction patterns are the photographic and the Geiger tube methods. The ionisation chamber is used less extensively than it was in the early work in X-ray diffraction. The use of the photomultiplier tube, like that of the Geiger tube, is a recent development. The X-rays may be used directly to excite the photomultiplier tube. This has disadvantages which are overcome by using an X-ray phosphor to excite the tube. Maximum sensitivity is achieved when the spectral sensitivities of phosphor and tube are matched. The phosphor may be an intensifying screen (calcium tungstate) or a single crystal (calcium tungstate or fluorite).

Much work has been done on the measurement of X-ray intensities from the X-ray photographic action. Two recent investigations carried out expressly for the purpose of improving accuracy in quantitative analysis by X-ray diffraction have been that of Hellman and Jackson (8) and that of Ballard and Schrenk (9). A simplification in measuring X-ray intensities from photographic blackening is promised by a technique, now developed by Eastman Kodak, for producing from the original negative a positive whose transparency is proportional to the original X-ray intensity.

Geiger tube methods having been more recently developed, less is known about the relation of the X-ray intensities to the " count " or record obtained. With Geiger tubes developed for the purpose and with appropriately designed associated electronic circuits, there seems to be general agreement that with the requisite care and skill satisfactory intensity measurements may be made, provided the performance of the Goiger tube and associated circuits is checked from time to time against a set of standard mixtures.

Methods of quantitative analysis may be exemplified by considering four typical procedures.

(i) If an unknown mixture consists of two components say X + Y, and if pure samples X and Y are available, then a series of standard mixtures $X_n + Y_{100-n}$ may be made up (where n is percentage). From the relative intensities of suitable lines in the $X_n + Y_{100-n}$ patterns a graph may be drawn of relative intensity plotted against percentage n of the X constituent. From the measured relative intensity in the X + Y pattern, the percentage of X, and therefore also of Y, may be read off from the graph.

This method was used by Redmond (10) to determine the percentage of tungsten carbide in mixtures containing molybdenum carbide and titanium carbide respectively. The method may be exemplified as follows :—

Sample X + Y

Standard $X_n + Y_{100-n}$

(ii) Consider the case of a mixture X + Y + where X is the component to be determined quantitatively and Y+ is any number of unknown components. As before, it is necessary that a pure sample of X be available. A suitable diluent D is mixed with X in order to simulate the mixture X + Y +. A number of these standard mixtures are made up, $X_n + D_{100-n}$ (where n is the percentage). To the same quantity of each standard mixture and of the " unknown " mixture, a given quantity S of a suitable internal standard is added. From the diffraction pattern of each of the standard mixtures a graph may be drawn of the relative amounts of S and X plotted against the relative intensity of two convenient lines, one in the S pattern and one in the X pattern. From this graph and the relative intensity of the same two lines in the pattern of the " unknown " mixture the percentage of X in X + Y + may be deduced. The method may be exemplified as follows :—

Sample X + S + Y+

Standard $X_n + S + D_{100-n}$

This method has been used by Clark and Reynolds (11) to determine the amount of quartz in mine dust. Calcite was chosen for D and fluorite for S. The method applies whether components Y+ are crystalline or amorphous (that is, give no patterns by which they may be identified). From the percentage of X, the percentage of Y+ immediately follows. This may be very valuable information if Y+ is wholly or partially amorphous. If in the sample X + Y analysed by the first method, any amorphous material is also present, that method will yield the relative proportions of X and Y (which may be all that one is interested in) and not their percentages. The amount of amorphous material present would be obtained only if the second (internal standard) method were used to determine separately the percentage of X and the percentage of Y. No diluent in that case may be necessary in that Y would serve as a diluent of X and vice versa. Applied in this way, the second method may be exemplified :

Sample X + Y + Z + S

Standard $X_n + Y_{100-n} + S$

Both methods (i) and (ii) have the advantage that it is not necessary to reproduce an exposure. The lines whose intensities are compared occur in one and the same diffraction pattern. This is not the case in the following methods.

(iii) Gross and Martin (12) developed a method for determining the amount of a constituent X in a composite sample which employed no synthetic mixtures except the addition of an internal standard S to the sample to be analysed in percentage (C_s) comparable to the percentage (C_X) of X. Provided an empirical constant *k* can be determined the percentage of X is given by :

$$C_X = C_s I_X I_0 k / I_s$$

Here I_X is the intensity of an X line in the diffraction pattern of the sample (containing internal standard) ; I_s is the intensity of an S line (very close to the previous) in the diffraction pattern of the same sample ; I_0 is the intensity of the same S line in the pattern given by a sample consisting of 100 per cent. of S with an X-ray beam of the same intensity as was used in irradiating the sample with internal standard. This latter condition is difficult to fulfil. *k* is a constant involving all the factors (crystal structure, geometrical and absorption factors) upon which the absolute intensity of a line in a powder diffraction pattern depends. The authors do not make clear how *k* was determined. It is constant for any given diffraction line in a pattern of a particular crystalline material, and will vary from line to line, that is from direction to direction of diffracted beam. This is the reason why the selected line in the pattern of the internal standard must lie very close to (theoretically be superposed upon) the selected line in the X pattern.

This method may be exemplified :

Sample X + S + Y +

Standard S

Any number of constituents could be determined quantitatively in this way, and by difference the quantity of amorphous residue (if present) could be determined.

(iv) Methods of quantitative analysis have been developed which dispense entirely with synthetic mixtures or internal standards. The methods require, however, that a powdered sample can be prepared consisting of 100 per cent. of the constituent whose percentage in the "unknown" mixture is required. Arising out of the theory given by Gross and Martin (12) and deduced independently by Hellman and Jackson (8) the following simple relationship holds provided the mass irradiated in each case is the same and provided the densities and X-ray absorptions are the same :

$$C_X / C_0 = I / I_0.$$

Here C_X is the required percentage ; C_0 is the percentage in the standard sample (100 per cent. or any known concentration) ; I and I_0 are the intensities of any line in the pattern of the "unknown" and standard.

Hellman and Jackson applied this method to the analysis of clay mixtures. In the case of such material the conditions required are approximately fulfilled.

Any number of constituents could be determined quantitatively in this way and by difference the quantity of amorphous residue (if present) could be determined.

Hellman and Jackson used the photographic technique and a wedge-shaped specimen mounted so as to expose a constant mass to the X-ray beam. Wilchinsky (13) employed a similar quantitative method, using the Geiger tube technique as already described. When the flat powder sample is of thickness sufficient to absorb completely the X-ray beam traversing the powder at a grazing angle equal to the Bragg angle for the particular line under observation, the percentage concentration of X in the "unknown" sample is given by :

$$C_X = 100 I_X \mu / I_0 \mu_0 .$$

Here I_X is the intensity of the particular line under observation in the pattern of the "unknown" ; I_0 is the intensity of the same line in the pattern of the pure sample of X ; μ and μ_0 are the mass absorption coefficients of the "unknown" sample and the pure sample respectively. These absorption coefficients being coefficients for the powder require to be known (or measured). If they are substantially the same the formula reduces to the same form as in the previous case of Hellman and Jackson. In each case we have :

Sample X + Y +
Standard X

(c) *Factors Influencing Accuracy in Quantitative Analysis.*

All the methods for quantitative analysis require not too dissimilar particle size, and random particle orientation in the sample under test and the standard. If integrated peak areas, instead of peak heights, are measured (assuming microphotometer records) considerable difference in particle size may be permissible ; but (unless the same degree of preferred orientation is reproducible) preferred orientation must be absent. This is difficult (or even impossible) to achieve with platy materials like clay minerals. Perhaps it can be completely achieved only with crystals showing conchoidal fracture.

Even when preferred orientation is absent statistical factors affect the degree of randomness in the powder, arising from the fact that a finite number (as distinct from an infinite number) of crystal particles are irradiated. These statistical factors affecting the intensity of diffracted X-rays have been studied theoretically and experimentally by Alexander, Klug and Kummer (14) assuming a value for the rocking angle and neglecting extinction. From ten different samples of quartz each of the same particle-size range the percentage mean deviation was measured for the intensity of the 3·33A spacing. This was carried out for four different particle-size ranges. The observed mean intensity deviation was of the same order of magnitude as, and for the largest size range group (15 to 50 microns) in close agreement with, the calculated value assuming a reasonable figure for the rocking angle. This deviation of course diminishes with decrease in size of particles (other things being equal) and for the size of powder sample used in the work referred to was about one per cent. for particles 5μ and less.

It is interesting to examine the part played by absorption. It is apparent that in (i) absorption plays no part. That it also plays no part in (ii) may be seen by examining the analysis of Alexander and Klug (15) which shows that the proportion of X present is proportional to I_X/I_S where I_X and I_S are the intensities of convenient lines one in the pattern of X and the other in the pattern of the internal standard S. This holds for both specimens—the sample specimen and the standard specimen.

The same conclusion applies to method (iii) which is distinguished from the previous method by the fact that X is zero in the standard specimen. (This is another way of regarding the important condition that the exposure given with the standard must be the same as that given with the sample.)

The part played by absorption in method (iv) has been discussed.

5. ANALYSIS OF SOIL COLLOIDS.

About 1930, X-ray methods revealed the crystalline nature of clay. About the same time the same methods were applied to the finest constituents of soils and revealed that the fraction comprising particles less than 2μ equivalent diameter was predominating clay material. Le Chatelier's thermal method already described had been developed for the purpose of studying clays so that both the X-ray and the differential thermal analysis methods are suitable for the qualitative and quantitative analysis of soil colloids.

(a) *Preparation.*

The application of these methods to soil colloid analysis is complicated by the presence in soil colloids of organic material some of which (particularly in the case of montmorillonite clays) is interlayer material that may be considered to constitute part of the lattice. Organic material is commonly removed by treatment with dilute H_2O_2. Any treatment at all is undesirable in that it may tend to break up or modify the original material. For this reason, when it is necessary to remove organic material, it is desirable to use dilute (5 per cent. to 10 per cent.) H_2O_2 and to prolong the treatment. Organic material should be removed for two reasons :

(i) " Non-lattice " organic material by its binding action interferes with dispersion ; incomplete dispersion may mean fractionation and fractionation may mean a sample whose mineral composition is unrepresentative of the soil colloid material as a whole. For this reason removal of organic matter should precede dispersion.

(ii) In differential thermal analysis both " lattice " and " non-lattice " organic material introduces thermal effects that obscure the thermal curves of the inorganic material. (The " lattice " material is not necessarily removed by the usual treatment). In X-ray diffraction patterns the " non-lattice " organic material probably contributes to the scattered background.

In order to extract the total of (or at least a representative quantity of) the colloid content of a soil dispersion is necessary. On the principle that any treatment should be as mild as possible, in order to avoid breaking up or modifying the original material, water dispersion is desirable.

In special cases where any free iron oxides of varying degrees of hydration are present in abundance it may be desirable to remove these before dispersion for the same reason that it is desirable to remove organic matter—they act as cementing agents forming aggregates that prevent complete dispersion and so bring down clay with the silt. A technique has been developed by Jeffries (16) for the removal of free iron oxides. It involves the production of nascent hydrogen by the action of a buffer mixture of potassium oxalate and oxalic acid on magnesium ribbon at a temperature of 90° C.–95° C. The treatment affects the base exchange of some soils ; its effect on X-ray diffraction patterns has not yet been tested. The removal of iron has the advantage that copper radiation may then be used. Otherwise softer radiation (from cobalt, or softer) is desirable to reduce the background on the film produced by fluorescent iron radiation.

(*b*) *Differential Thermal Analysis.*

By reason of (ii) above and by reason of the composite nature of soil colloids thermal analysis is of doubtful value. It is of less value in the analysis of soil colloids than in the identification and analysis of pure clay minerals. It may provide evidence, however, that is useful in a difficult field of analysis, and is even being applied to soil clays containing organic matter with the object of ascertaining whether thermal curves may be used to identify the organic matter.

Grim favours the case of differential thermal analysis as a relatively quick preliminary treatment to which a large number of samples may be submitted. The collection of a large number of samples ensures representative material. The preliminary differential thermal analysis treatment permits a subdivision of the samples into two groups—normal samples and those with unusual features. One or two of the normal samples and all the samples of the second group may then be submitted to X-ray analysis.

Thermal analysis will be more valuable when the part played by particle size and chemical constitution is better understood, as well as the role of conductivity. It can be a very sensitive method of detection in particular cases where a *pronounced* thermal reaction characterises a mineral. The kaolin minerals constitute a particular example. They may, however, only with difficulty (if at all) be distinguished from one another in soil colloids. The differences (a peak shift to lower temperatures in tho 600° C. endothermic reaction) are due to decreasing stability (associated with decreasing orderliness in the superposition of the kaolin layers) from dickite through kaolinite to halloysite. A less characteristic pattern is observed for the thermal curves given by the mica clays and a still less characteristic pattern by the montmorillonites. In view of the low sensitivity of the thermal analysis method for multicomponent systems, other minerals that may be present in soil colloids such as quartz, oxides and hydroxides of aluminium, oxides and hydroxides of iron (if not removed) aro likely to be detected only if present in relatively large amounts.

(*c*) *X-ray Diffraction Analysis.*

In soil colloids from which organic material has been removed, there can still be much material that contributes to a diffuso background on the film. Tho nature of this material as distinct from the material that gives a recognisable diffraction pattern is obscure. It is loosely, but probably erroneously referred to as amorphous material. Since experiment shows that up to 50 per cent. amorphous material (relatively coarse diatomaceous earth) may be present with a highly crystalline powder before its presence is detected, the material in soil colloids producing the scattered background is perhaps crystalline and characterised by extremely small particle size. Its amount may be large and is an uncertainty in quantitative analysis. It might be assessed however by methods outlined in (b) of section 4.

In the analysis of soil colloids by X-ray diffraction mothods consideration will be given to the major constituents only—the clays. It is not practicable in this field to identify a clay mineral other than by the group to which it belongs—montmorillonite, mica and kaolin. To a first approximation these groups are identified by their basal spacing as follows :—The montmorillonite group is characterised by a basal spacing which may be of almost any magnitude from 10A and greater depending upon the moisture content or in general upon the degree and kind of solvation ; the mica group is characterised by a 10A basal spacing and the kaolinite group by a 7A basal spacing. The detection of mixtures may require special treatment. For example, in a mixture of montmorillonite and mica, hydration or solvation of the former must be ensured in order to be certain that the 10A line is correctly attributed to mica. More will be said of this later. Then again, in a suspected mixture of montmorillonite and kaolin where the former is say hydrated to give a 15A basal spacing, in order to distinguish between the kaolinite basal spacing and a second order montmorillonite heating to 600° C. will destroy kaolinite, and as this is more than sufficient to dehydrate montmorillonite its basal spacing will then be observed to be 10A (provided precautions are taken to keep it in a dehydrated state. In air it will only very slowly hydrate). Heat treatment at say 200° C. will dehydrate montmorillonite and leave the kaolin lattice intact. Mention may also be made here of a method suggested by Grim for identifying a particular montmorillonite. At high temperatures montmorillonite is destroyed and forms crystals the nature of which depends on the chemical constitution of the parent montmorillonite.

Expansible lattices, however, have been observed for clay minerals in the mica as well as in the kaolin group. Jackson (17), for example, claims that "hydrous mica" exhibits expansibility over the range 10A to 12A under solvation conditions described below and is distinguished from montmorillonite firstly by this limited expansibility (the corresponding range for montmorillonite is 10A to 18A) and secondly by a sharp line at 2.55A in its diffraction pattern compared with a diffuse line at the same position in the pattern of montmorillonite. Under similar but not identical solvation conditions Bradley (18) has observed that endellite (hydrated form of halloysite) shows an enhanced basal spacing of 10.8A (from 10.1A) and that halloysite (characterised by a line at 7.2A) shows a diffuse band extending from 7A to 11A. He observed no solvation effect upon the lattice of the mica group mineral illite.

The position with regard to recognition of the clay groups by their basal spacing is complicated by Jackson's recognition of an "intermediate" clay type which he calls "mica intermediate." Its pattern is characterised by the absence of a 10A line but otherwise fits the mica pattern. Now a crystalline particle in the form of a very thin plate would, if thin enough, give prismatic reflections only and yet its particle size in the accepted sense may not be excessively small. This may be an explanation of Jackson's "mica intermediate." A more disturbing complication is the existence of "mixed layer minerals." "Mica intermediate" may be an example of these. Bradley (18) obtained evidence of a mineral consisting of illite randomly mixed with montmorillonite in equal proportions.

The importance of montmorillonite as a constituent of soil colloids and the elusive nature of its basal spacing has led to various treatments for fixing this spacing. MacEwan (19) introduced the method of treating with glycerol. This is simple and effective and is still used extensively. Bradley studied the reaction of clay minerals to treatment by ethylene glycol and made the observations referred to above. Jackson has made an extensive study of glycerol solvation of expanding lattice minerals. His present treatment is a modification of the treatment outlined by White and Jackson (20) and overcomes the difficulty of the latter that different clays require different concentrations of glycerol for maximum intensity of pattern. This treatment consists substantially of

(i) Base exchange saturation with calcium.

(ii) Solvation with glycerol in a non-polar liquid.

It is devised to fix both the intensity and the spacings of the montmorillonite and hydrous mica basal reflections (18A and 12A respectively). The latter is necessary to improve reliability of qualitative analysis and the former to improve accuracy in quantitative analysis.

Quantitative analysis of soil colloids is difficult. Jackson claims that it is of fundamental importance, in order to achieve accuracy,

(a) to use complete solvation of expanding lattice minerals as described above and

(b) to group the clay fractions into rather narrow size ranges so that the more strongly diffracting coarse particles do not over shadow the weakly diffracting fine fractions, for diffuse lines from very fine particles tend to be missed unless the rest of the pattern is suppressed.

Unfortunately Jackson's solvation treatment for fixing intensity of basal spacing of clays can never completely achieve its objective because of the dependence of the relative intensity of any one line in a diffraction pattern upon the degree of randomness of orientation of the particles. Owing to the platy nature of clay minerals preferred orientation is always possible and therefore particle orientation is always an uncertainty in relation to accurate quantitative analysis.

Preferred (or random) orientation might be detected by either of the following procedures which take advantage of the fact that in soil colloid material particle size is small enough not to require rotation of a cylindrical sample during exposure : (a) Mount the sample in a flat container and record the pattern on a plane film. Uniform intensity throughout all the diffraction rings recorded implies random orientation about the incident beam of all the hkl reflections recorded ; (b) Use a stationary cylindrical sample mounted in the usual way and a plane film. Compare the relative intensities of lines in one exposure with those in a second exposure taken with the sample turned through 90° about the axis of the cylinder. Evidence as to the orientation may also be obtained from the intensity distribution around a diffraction ring, but this is now complicated by the cylindrical shape of the sample.

Methods commonly adopted for quantitative analysis are methods (i) and (iv) above. The constituents to be analysed are required in pure form. The best that can be done is to select in the case of each constituent a pure clay sample which has a high probability of being the same material as that occurring in the sample under investigation. The internal standard method (ii) is also used. The school at Urbana finds calcium oxalate (dehydrated to give a more convenient diffraction pattern) a suitable internal standard. It is probable that the quantitative method least likely to be affected by preferred orientation is that of synthetic mixtures (method (i)) in that the orientation assumed in the specimen is likely to be repeated in the standard mixture. Even if this occurs however, unless the orientation is random, the direction of the X-ray beam relative to the axis or axes of orientation is critical. In so far as a high degree of preferred orientation, with the X-ray beam approximately parallel to the mean plane in which the crystal planes showing preferred orientation lie, concentrates the intensity of a given reflection into a portion of a cone instead of into a complete cone, this method (employing the maximum attainable preferred orientation) has long been used to increase the sensitivity of detection of clay minerals in soil colloids.

(d) *Other Methods of Analysis.*

No attempt will be made in this review to study the application of the electron microscope or of electron diffraction to the detection and recognition of clay minerals. The former has been extensively applied and is an additional useful tool in a difficult field of analysis. For example kaolinite and halloysite which are difficult to distinguish by thermal or X-ray methods are readily distinguished under the electron microscope—the former by its hexagonal plate-like habit and the latter by its rod-shaped habit. Montmorillonite and illite too although rather formless in appearance, may with practice it is claimed, be distinguished.

Finally, a brief description will be given of a method (21) tentatively developed and still being explored in Dr. Hendrick's laboratory for the estimation of montmorillonite.

If to a given mass of a pure clay mineral (saturated with a particular cation and dried over P_2O_5) is added ethylene glycol in quantity, and if the whole is weighed at regular time intervals in vacuo over $Ca\ Cl_2$, a characteristic graph is obtained of glycol retention per gram of clay plotted against time. There are several interesting features of this graph, but only one will be referred to in this brief description. After a number of hours the glycol retention remains practically constant. This is believed to be due to the absorption of two layers of ethylene glycol upon the whole effective external surface of the clay. The figure for the ethylene glycol retention per gram of kaolinite is about 0·02 gm/gm., that for illite is rather more and that for montmorillonite is about 0·24 gm/gm. The high figure for montmorillonite is due to the fact that all possible surface, external as well as internal (that is between all silicate structural layers), is accessible to polar solvents. It will be independent of particle size provided the size is small enough for complete intrusion of glycol and provided adsorption upon a true external surface is the same as upon an inter-layer surface. The difference between kaolinite and illite may be due to the difference in behaviour of basal faces relative to side faces in each case and related to the difference in their cation exchange capacities ; or it may be due (also) to a possible limited expansibility of illite.

In any case the glycol retention may be taken as a measure of effective surface which in itself is an important property of soil colloids. In so far as the corresponding quantity for kaolinite, mica-like minerals and endellite is neglected, the glycol retention (in relation to the figure of 0·24 gm/gm. for pure montmorillonite) may be taken as an approximate measure of the quantity of montmorillonite present.

If the true external surface could be measured the inter-layer surface (or "inter-layer swelling" as Dyal calls it) could be obtained by difference and one would expect this figure to be a more accurate measure of montmorillonite (or of mixed layer minerals of the montmorillonite type). The true external surface may be measured by a lengthy and difficult method involving gas sorption at low temperatures. Dyal found that external surface and particle form of any clay mineral is not appreciably changed by heating to 600°C., whereas the property of expansibility (as well as the lattice in the case of kaoliuite) is completely destroyed. Glycol solvation following such treatment therefore provides a measure of true external surface.

Dyal found that in the case of $<2\mu$ fractions of two samples of soil colloids the montmorillonite content given by the total glycol retention was about twice that given by the inter-layer swelling. If the measurement of the external surface is not at fault, then which is the more significant quantity has yet to be established.

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1.—THE FAUNA OF ROTTNEST ISLAND X.

ANTHURIDAE.

By

J. M. THOMSON, M.Sc.

Communicated by Mr. K. Sheard.

A sequence of papers on the fauna of Rottnest Island has appeared in the Journal of this Society. The majority of the specimens were collected by Mr. Glauert, curator of Perth Museum. He kindly made available to the author his collection of Anthuridae. These were collected at different times but from one locality—Bathurst Point, Rottnest Island.

THE COLLECTION.

Sixty-nine specimens were in the collection, including representatives of five species, two of which have been recorded previously from Australian waters. The other three are described here as new species, one of which is assigned to a new genus. Only one species of Anthurid has previously been recorded from West Australian waters (Thomson 1946).

ECOLOGICAL NOTES.

As these five species of a circumscribed group were all collected in the same locality it is of interest to note that two of the species (both of the genus *Mesanthura*) had the normal type of mouth-parts; the other three had the mouth parts adapted for sucking.

A number of species of Anthurids have been recorded from the deserted tubes of worms, or in the canals of sponges; and it has been asserted by various authorities that the Anthuridae do not construct tubes. Barnard (1925) says: "So far as is known Anthurides have no means of constructing dwellings of their own, like certain amphipods, unless they hollow out galleries with their mandibles." It is of considerable interest therefore to record that Mr. Glauert has observed a tube built by one of the species recorded here. A number of Anthurids were kept alive for a period in a vessel which had some debris in the bottom. When the contents were inspected, Mr. Glauert observed that a tube much like those of some amphipoda had been constructed between a stone and the wall of the jar. Unfortunately in handling the vessel the stone was moved, thus tearing the tube and expelling the occupant. As there were several species present, it is impossible to say to which species the builder belonged.

SYSTEMATIC.

The Revision of the family by Barnard (1925) has been used as a basis for classification. Subsequent publications dealing with members of the group have been consulted.

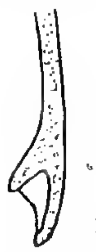
Order ISOPODA
Sub-order FLABELLIFERA
Fam. ANTHURIDAE.

1. Accalathura gigas (Whitelegge) 1901.

Calathura gigas Whitelegge 1901.
C. sladeni Stebbing 1910.
A. gigas Barnard 1925.

The specimens in the collection have only weakly pigmented eyes, and the area covered by the eye seems to be somewhat variable. Whitelegge's original specimens were described as having "eyes indistinguishable, destitute of pigment". Stebbing's *sladeni* and Barnard's South Australian specimens had pigmented eyes; also these, as with the specimens here recorded, were much smaller than the *gigas* specimens, although they included ovigerous females. Barnard, however, dismisses size of mature individuals as a specific criterion as considerable variation in this respect is shown by other species. Unfortunately Barnard was unable to view Whitelegge's types whose description was inadequate in some particulars; but basing his judgment on the published work, he was unable to find any other differences between *gigas*, *sladeni* and the South Australian specimens.

The individuals from Rottnest could not be distinguished from the three previous descriptions. However, the male stylet has not been described previously. As displayed on the Rottnest specimens it is rather similar to that figured by Barnard for *Accalathura crenulata*, except that a translucent membrane joins the lower portions of the two terminal arms, (text fig. 1).


1.

Text fig. 1—*Accalathura gigas.*

Ovigerous females had about 36 ova or young attached.

14 specimens:

♀ (with young) 1.8 cm., ♂ 2 cm. 1.2 cm. December, 1929.
♀ ovigerous 1.7 cm. 1.8 cm., ♂ 1.9 cm.; 1.3 cm., Imm. 0.9 cm. 0.8 cm. February, 1930.
♂ 1.9 cm. ? 1931.
♀ ovigerous 1.55 cm. February, 1931.
♀ ovigerous 1.8 cm., 1.7 cm., ♂ 1.2 cm. ? 1932.

2. Paranthura punctata (Stimpson) 1855.

Anthura punctata Stimpson 1855.
Paranthura costana Thomson 1882 (non Bate and Westwood).
P. nigropunctata Chilton 1906 (non Lucas).

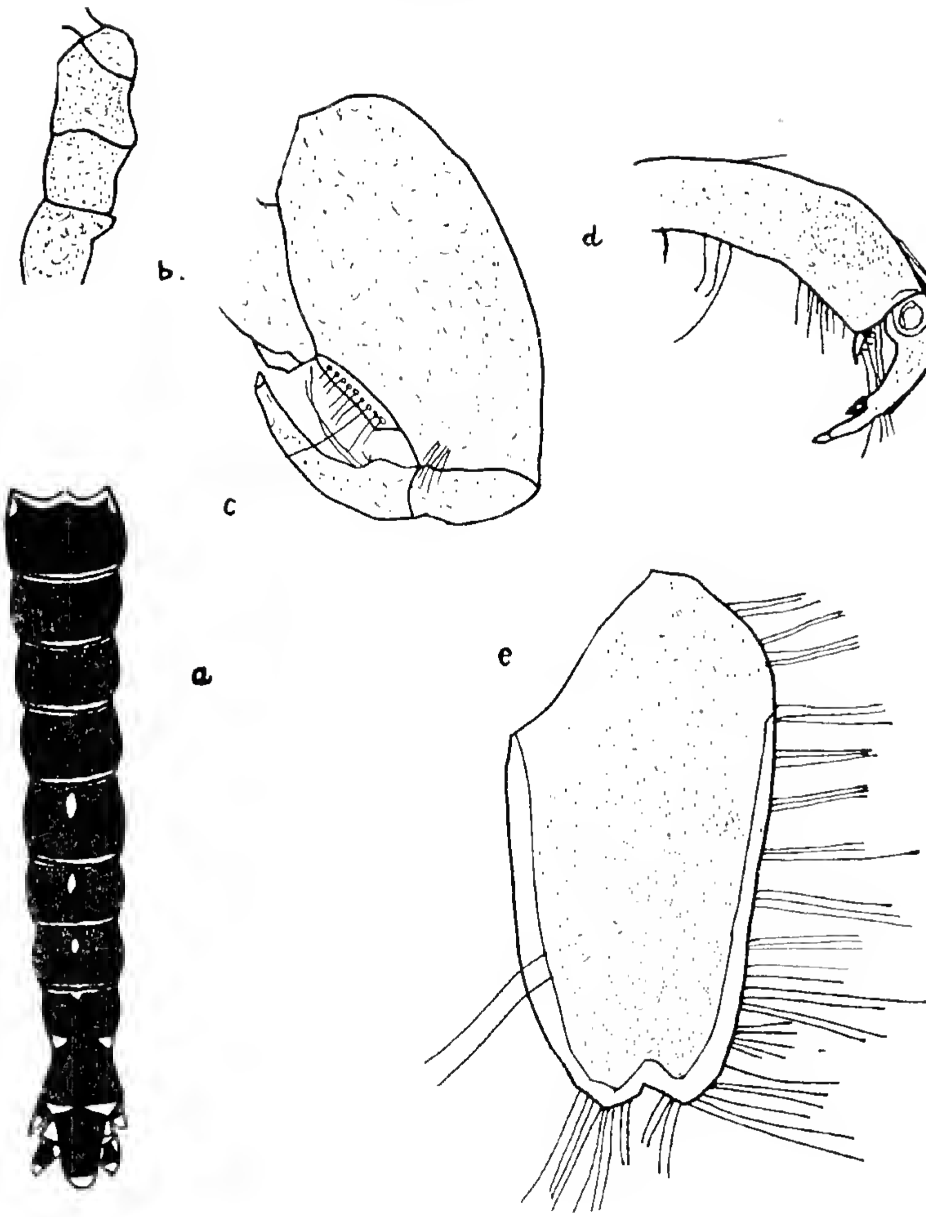
This species has already been described from specimens taken in New Zealand, New South Wales, Tasmania, South Australia and South Africa.

10 specimens:

♀ ovigerous 1·95 cm. ♀ 1·85 cm. ♂ 1·45 cm., 1·1 cm.
Imm. 0·9 cm. ? 1931.
Imm. 1·2 cm., 1·2 cm., 1·15 cm. 1·0 cm.
(10982/86)
from Cymodoce Cottesloe.

3. **Mesanthura albinotata** n. sp.

(Text fig. 2a–e)



Text fig. 2—*Mesanthura albinotata.*

The principal characteristic used as a specific criterion in this genus is the pigment pattern. Indeed descriptions of some of the species are lacking in details of the anatomy.

M. albinotata has a pattern which differs only a little from that of *M. maculata* (Haswell) in the extent of the tergum that it covers. But it differs in having small oval pigment-free patches anteriorly on segments, 4, 5 and 6 of the peraeon, and on segment 7 is an unpigmented notch medianly at the anterior end of the pigment patch (text fig. 2a).

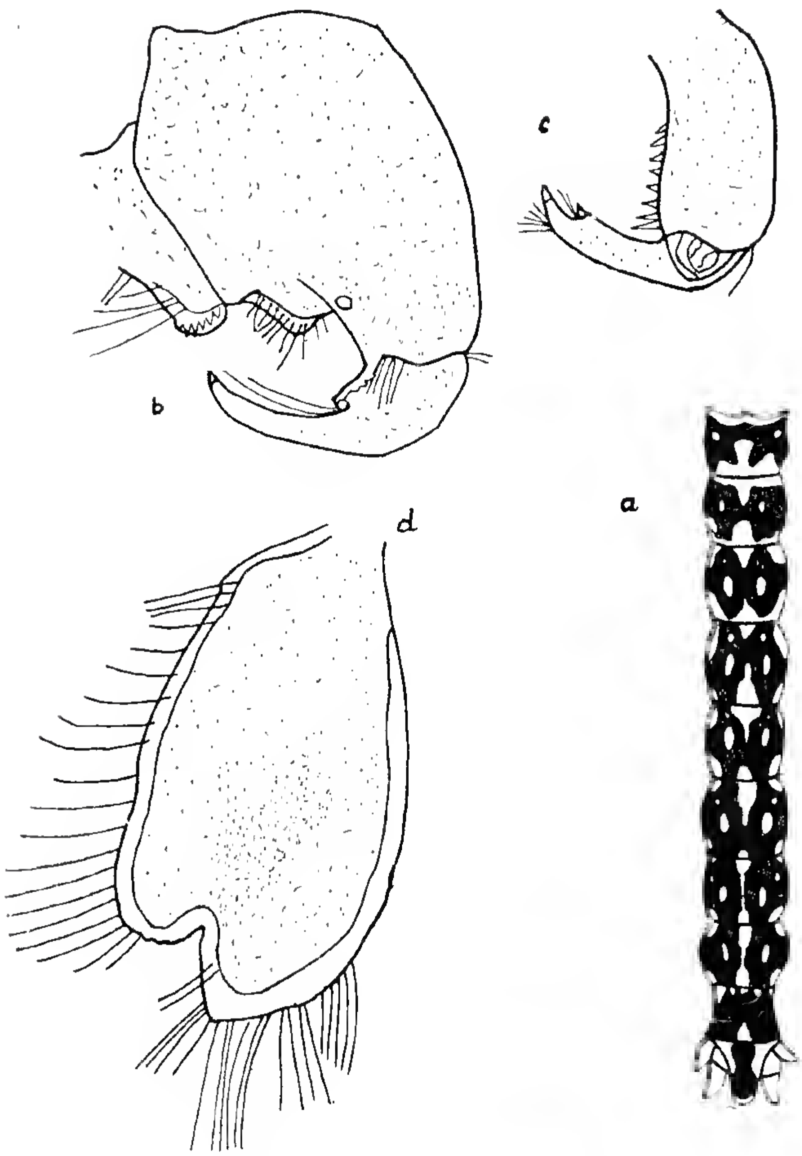
The mandibular palp is not markedly strong in proportion to the trunk; in which point the species differs from *M. catenula* (Stimpson) but agrees with the other species of the genus whose palp has been described. The maxilliped is 5-segmented but the third joint is only feebly indented to form a "waist" (text fig. 2b) whereas this indentation is marked in other species of *Mesanthura*. The propodus of pereiopod 1 is ovate, the palm being excavate distally, whereas the proximal portion is straight and bears a row of nine setae (text fig. 2c). Pereiopod 2 has a spine, which bears a comb of four or five teeth, on the distal end of the propodus (text fig. 2d). The male stylet is simple and rod-shaped. The telson is not sinuate laterally ; exopod of the uropod tapers more or less evenly from near the base but is notched apically (text fig. 2e). Females with five large eggs each.

4 specimens :

♂ 1.45 cm., 1.0 cm. ; ♀ ovigerous 1.6 cm., 0.6 cm.

4. **Mesanthura bipunctata** n. sp.

(Text fig. 3a–d)



Text fig. 3—*Mesanthura bipunctata.*

The pigment pattern of this species is quite distinctive (text fig. 3a). On each peraeon segment there is formed a pair of oval patches free from pigment. Besides these there are two smaller antero-lateral circles. The pigment area is almost separated medianly by a central unpigmented channel, but a bar of pigment prevents complete partition. This connecting pigmented area is further back in position on succeeding peraeon segments except on segment 7, where it is somewhat further forward as compared with segment 6.

A ring of pigment runs down from the tergum under the insertions of pereiopods 2 and 3. In the hinder peraeon segments this ring is broken into a tongue of pigment in front of and below the pereiopods. The anterior edge of the basipodite of pereiopod 1 bears a pigmented patch.

The mandibles and maxillipeds are much as in *M. albinotata* except that the "waist" on the third joint of the maxilliped is more marked. The propodus of pereiopod I is ovate with a proximo-dorsal knob (text fig. 3b). The palm is distally excavate, and proximally it is somewhat bulbous, and bears a curving row of 11 setae. The distal spine on this propodus is smooth. (text fig. 3c).

The exopod of the uropod is somewhat expanded and broad compared with that of *M. albinotata* (text fig. 3d.) It is notched apically.

8 specimens.

♂ 1.05 cm., 1.05 cm. December, 1929.
♂ 0.9 cm., 0.4 cm., 0.65 cm.
♀ ? imm. 1.5 cm. February, 1931.
♂ 1.6 cm. January, 1937.

5. **Aenigmathura lactanea,** n. gen. n. sp.

(Text fig. 4a–k)

Eyes poorly developed, weakly pigmented, though usually discernible. As other species in the same tubes have heavy pigment in the eyes, the poor pigmentation is presumably representative of the living condition and not an effect of storage in spirit.

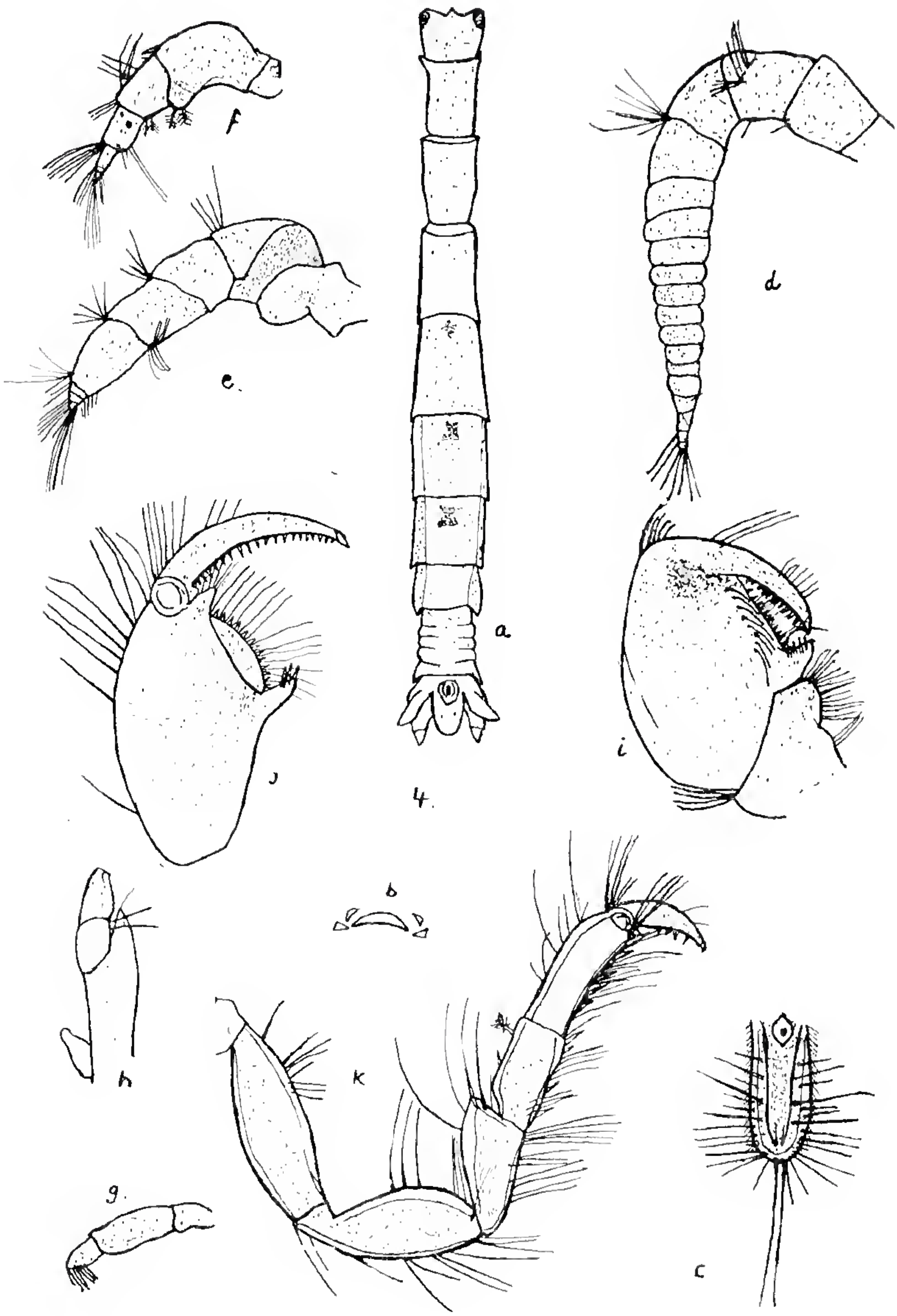
The peraeon segments bear scattered setae marginally on either side. Segments 4 to 7 have dorso-lateral keels and these are slight. Shallow dorsal pits occur anteriorally on segments 4, 5 and 6. Segment 7 is shorter than the other peraeon segments but not so markedly as in *Accalathura*. The pleon is relatively short—about the same length as segment 6. The pleon sutures distinct laterally but variably so dorsally, where they are never discernible in the mid-dorsal line (text fig. 4a).

The telson is broadly rounded and slightly less than the pleon in length. Dorsally it is convex, ventrally slightly concave (text fig. 4b). The margin is smooth and clothed in dense fine setae. Two rows of longer setae originate dorso-laterally inside the margin. Apically there are four pairs of long setae originating on the margin except for the central pair, which originate a little way forward on the dorsal surface. There is a single large median statocyst proximally (text fig. 4c).

Antenna I swollen in the male (text fig. 4d.) and of about 18 joints. In the female it is normal and the flagellum is four to five jointed (text fig. 4e). Antenna II has a flagellum of three or four joints in both sexes (text fig. 4f). There is a groove overhung by an expansion in the basal segment in which antenna 1 normally lies.

The mandibular palp (text fig. 4g) has the first and third joints subequal and the third joint bears a comb of setae. The second joint is markedly larger than the others.

The maxilliped (text fig. 4h) is 4-jointed ; the second joint is prolonged distally reaching barely beyond the base of the fourth joint.



Text fig. 4—*Aenigmathura lactanea.*

Pereiopods 1-3 are sub-chelate with a basal tooth to each palm. Pereiopod 1 has a convexly arched palm in the female and young males, but almost straight in the adult male (text fig. 4i). There is a row of spinules along the unguis, the palm and the basal tooth, and on either side a row of long setae laterally to the palm, and a long seta at the distal base of the basal tooth.

Pereiopods 2 and 3 have convex palms strongly arched in the female—less so or almost straight in the male. The female has a small distal tooth on the palm of pereiopods 2 and 3 (text fig. 4j) but this structure is represented in the male only by a very slight swelling. The spines on the basal tooth of pereiopods 2 and 3 are much stouter in the female than in the male.

Pereiopods 4 to 7 have rather short and stout joints, the fifth of which very slightly under-rides the 6th (text fig. 4k).

Pleopod 1 is somewhat indurated but not strongly operculiform. Pleopods broad and squat. The inner ramus of pleopod 1 only half as broad as the outer—in the remaining pleopods the inner ramus is at least three-quarters as broad as the outer. The male stylet is a simple rod.

There is no marked inner projection on the base of the uropod which is lined with long ciliate setae on the outer side and the distal half of the inner margin. The exopod is very slightly arched over the telson and both it and the endopod with the base of the uropod are somewhat splayed—forming an open cu-shaped tail fan. The endopod of the uropod is less than half the length of the base, and projects slightly beyond the end of the telson. Its margin is lined with non-ciliate setae—those on the inner margin being only half as long as those on the outer. The female has four pairs of oostegites—which enclose about 36 ova. No pigment could be discerned apart from the faint darkening of the eyes. The preserved specimens are creamy in colour.

In many respects, the genus is intermediate between *Accalathura* Barnard and *Leptanthura* Sass.

As in the *Accalathura*, the maxilliped is 4-jointed. The prolongation of the second joint reaches nearly to the distal end of the fourth in *Accalathura*, whereas in *Aenignathura* it projects scarcely beyond the base of segment four. In these two genera also the third joint of the mandibular palp is subequal to the first. But the second joint is not much larger than the others in the case of *Accalathura* whereas this joint is markedly elongated in *Aenigmathura*. Although *Accalathura* has the basal tooth or lobe at the base of the palm of pereiopod 1 it lacks the similar teeth which *Aenigmathura* has on pereiopods 2 and 3.

The swollen first antenna of the male is common to *Aenigmathura* and *Leptanthura* but not to *Accalathura*; but in *Leptanthura* it is densely clothed in short setae; whereas the specimens of *Aenigmathura* have the swollen flagellar portion almost bare. The flagellum of the female first antenna is not so rudimentary in *Aenigmathura* as in *Leptanthura* as at least three and sometimes four joints can definitely be made out.

The flagellum of the second antenna, the feeble eyes, the large statocyst, the elongate second joint of the mandibular palp and the under-riding of segment 6 by segment 5 in pereiopods 4-7 and the relative sizes of the telson to the pleon are common to *Aenigmathura* and *Leptanthura*. But another difference occurs in the third joint of the mandibular palp which has a comb of setae in *Aenigmathura* but none in *Leptanthura*. A most important difference is the presence of a 3-jointed maxilliped in *Leptanthura*. It is 4-jointed in *Aenigmathura*.

33 specimens.

♂ 2.0 cm., 1.8 cm., 1.8 cm., 1.7 cm., 1.7 cm., 0.9 cm. ♀ ovigerous 1.8 cm., 1.4 cm., 1.2 cm. ♀ 1.1 cm., 0.9 cm. December, 1929.
♀ 1.6 cm., 1.45 cm., 1.45 cm., 1.4 cm. January, 1930.
♂ 1.3 cm., 0.5 cm. ♀ 0.7 cm. February, 1930.
♂ 1.3 cm., 1.1 cm. ♀ ovigerous 2.0 cm., 1.5 cm.
♀ 1.7 cm. Imm. 1.3 cm., 1.1 cm., 1.1 cm., 0.55 cm., 0.3 cm. February, 1931.
♀ 1.8 cm.—16062/05.
♂ 1.2 cm. ♀ ovigerous 1.6 cm. ♀ 1.5 cm., 1.3 cm. January, 1937.

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2—PECTENS OF THE GINGIN CHALK.

By

F. R. FELDTMANN.

Read 14th June, 1949.

INTRODUCTION.

Although it is nearly 90 years since fossils were first found in the Gingin Chalk, the only comprehensive paper on the larger forms that has appeared so far is that by Etheridge (**6**)* published in 1913. Of subsequent papers, those by Withers on the stalkless crinoids *Uintacrinus* (**17**) and *Marsupites* (**18**) were of particular importance as the discovery of these forms definitely established the age of the Gingin Chalk as Santonian (Middle Senonian).

A detailed survey, by the writer, of McIntyre Gully, two miles north of Gingin railway station, during 1939, followed by systematic collecting by student parties from the University of Western Australia under Professor E. de C. Clarke in 1940 and 1941, showed that of a total thickness of 67 feet of chalk at that locality, the lower 20 feet 3 inches corresponds to the European zone of *Marsupites testudinarius* and like it is separable into a lower *Uintacrinus* subzone and an upper *Marsupites* subzone ; the *Uintacrinus* subzone extends from the base of the Chalk to 13 feet 3 inches above and the *Marsupites* subzone from 13 feet 3 inches to 20 feet 3 inches.

Since Withers' papers were published much material has been collected and many new forms await description. Of these, only one small group, the pectens, is dealt with in the present paper.

Only one pecten, *Camptonectes ellipticus*, was described in Etheridge's paper (**6**, pp. 19, 20, Pl. 1, figs. 16, 16a). Glauert's list of Upper Cretaceous fossils included, in addition to this species, species of *Pecten*, *Chlamys*, and *Amussium* (**9**, p. 58), but no descriptions of these have been published.

Most of the pectens described in the present paper are from the *Marsupites* subzone at McIntyre Gully and at Molecap Hill, half a mile south-east of the railway station. At the last-named locality the evidence supplied by the occurrence of the more restricted forms indicates that the lower 11 feet of the *Uintacrinus* subzone is missing from the Chalk, and there is an overlap of the two crinoids between 2 feet 6 inches and 3 feet 2 inches above the base of the Chalk. A very few specimens of pectens have been found in the *Uintacrinus* subzone, but, with the exception of one species, *Chlamys subtilis*, insufficient material has been collected for accurate description. Two specimens representing species different from those of the Chalk have been found in the underlying Lower Greensand and are described at the end of this paper.

The *Syncyclonemas* represent an interesting development of a new group in Western Australian waters.

The Gingin pectens are all more or less fragile and most of the material available for examination was in a poor state of preservation, much being very fragmentary. Several of the better preserved specimens still retain

* The numbers in heavy type shown in parenthesis correspond to those of the papers mentioned in the Bibliography.

some colour, this being noticeable in the three species of *Syncyclonema*, particularly in *S. subserratus* and *S. subreticulatus*. Descriptions are from specimens in the collection of the Geology Department of the University of Western Australia and from those in my own collection. Type specimens are in the possession of the Geology Department.

I wish particularly to express my gratitude to Professor E. de C. Clarke for his encouragement and for permitting me to make full use of the Geology Department's collection and library; to Dr. Curt Teichart and Dr. R. W. Fairbridge for their generous assistance in many ways; and to Mr. H. W. Smith for the excellent photographs which accompany this paper.

DESCRIPTION OF SPECIES.

Superfamily **PECTINACEA.**

Family **PECTINIDAE** Lamarck.

Genus **PECTEN** Müller.

Subgenus **SYNCYCLONEMA** Meek, 1864.

Section **CTENIOPLEURIUM** nov.

Distinguished from *Syncyclonema* s.s. by the presence of fine, usually spinous, radial threads or riblets. Type: *Syncyclonema subreticulatus*. Shell nearly equilateral, inequivalve, the right valve slightly convex, the left valve moderately so, suborbicular to ovate, apical angle wide; ears usually ascending slightly above the umbo, subequal, anterior ear of right valve slightly the larger, byssal sinus absent or very shallow; ctenolium absent; hinge with two pairs of well-developed crura; margin entire. Radial ornament of low narrow threads or riblets which may be spread over the surface of the valve or confined to the submargins; closely set spines may be present on all the riblets or confined to those of the submargins. Concentric laminae and fine concentric striae as in *Syncyclonema* s.s., but fine concentric threading may also be present. Surface of shell glossy or waxy. Interior smooth.

Syncyclonema (Cteniopleurium) subserratus sp. nov.

Pl. I., Figs. 1–3.

The material available for examination consisted of three nearly perfect specimens, including a fairly large right valve and two rather smaller left valves, and the ventral half of a still larger right valve, all from Molecap.

Dimensions:—

	Syntype. Right valve. mm.	Paratype. Left valve. mm.	Syntype. Left valve. mm.
Height	26.8	23.7	22.6
Length	26.6	23.2	21.0

The valve represented by the ventral fragment was probably fully 30 mm. in length.

Diagnosis.—Shell fairly thin, suborbicular to subovate, height equal to or slightly greater than length, nearly equilateral, inequivalve. Dorsal margins straight, the anterior usually slightly longer than the posterior, both being rather longer than half the height of the shell. Umbones fairly sharp, apical angle about 107°. Hinge line straight, about equal in length to one-third the length of the shell. Ears rather small, nearly equal, the anterior slightly the larger, both ascending slightly above the umbo and bent very slightly backwards from their junctions with the disk; byssal sinus absent. Surface of shell smooth and glossy when well-preserved. Interior of shell smooth. Margin entire. Ventral arc includes an angle of nearly 240°.

Right valve nearly flat. Concentric ornament consists of about five well-marked and fairly evenly spaced growth rings, averaging about 3 mm. apart on the syntype ; a few less prominent rings are also present ; the growth laminae are ornamented with very numerous fine concentric striae, hardly visible to the naked eye. Submargins decorated with, usually, five or six radial riblets, the two, sometimes three, nearest the dorsal margins being the longer and better defined ; each riblet furnished with a row of short thin tooth-like spines, sharply inclined towards the dorsal margins and up to ten in number on the longer riblets. Incipient radial ribbing of the median portion of the disk is suggested by barely discernible low narrow undulations on the ventral portion of the valve. Distal margin of anterior ear convexly curved ; surface of ear shows fairly well defined growth lamellae from which a row of small, low, tooth-like spines, directed dorsally, serrate the dorsal margin of the ear ; finer concentric striae are also present. Posterior ear slightly oblique, distal margin straighter than that of anterior ear ; ornament similar to that of anterior ear.

Left valve moderately convex, slightly compressed near the dorsal margins. Concentric ornament of very numerous fine striae, visible under a lens, and more prominent growth rings fewer, less evenly spaced, and less marked than those of the right valve, the left syntype showing three fairly distinct, irregularly spaced rings. Radial ornament of the disk similar to that of right valve. Distal margin of anterior ear less curved than that of right valve. Posterior ear slightly more oblique than the anterior. Ornament of ears similar to that of right valve, but the more prominent concentric lamellae of the anterior ear are less evenly spaced. The hinge, exposed on the paratype, consists of two pairs of strongly supported narrow crura, the lower pair, which are less clearly defined, diverging at very acute angles from the upper and separated from them by narrow rounded furrows. The dorsal surface of the hinge is formed by the dorsal margins of the ears being bent inwards at an acute angle to form very narrow triangular shelves approximately normal to the commissure and widest distally, the straight inner edges of the shelves forming the upper crura ; on the shelves, the growth lamellae, particularly the outer two, rise as strong curved ridges slightly inclined towards the umbo, their inner ends crenulating the upper crura. The distal ends of the hinge are clearly defined, projecting inwards well beyond the interior surface of the ears.

Remarks.—Except for the radial riblets on the submargins, this species shows a fairly close resemblance to *Syncyclonema orbicularis* Sowerby and *S. membranaceus* Nilsson. Prominent concentric laminae are apparently fewer on right valves of the Gingin species than on those of *S. orbicularis* as figured by Woods (**20**, Pl. XXVII.), the dorsal margins are slightly longer in proportion to the height of the valves, and the angle between them and the ventral margin is more marked.

This species is the most strongly coloured of the Gingin pectens, the two left valves being of a noticeable creamy yellowish brown colour. The more weathered right valves are of a rather patchily distributed pale reddish colour.

The species, so far as I know, has been found only at Molecap, where it occurs near the junction of the *Uintacrinus* and *Marsupites* subzones.

Syncyclonema (Ctenioplеurium) subreticulatus sp. nov.

Pl. I., figs. 4, 5.

The material examined consisted of a nearly complete but partly decorticated valve (the holotype) and another nearly complete valve, recovered in a fragmentary condition, from McIntyre Gully, two, in a similar condition, from Moleeap, a few other fragments from both localities, and a fragment from Hosking's Chalk, a mile north-west of McIntyre Gully. All are right valves.

Dimensions :—

	Holotype. McIntyre Gully. mm.	Paratype. McIntyre Gully. mm.	Paratype. Moleeap. mm.	Paratype. Moleeap. mm.
Height	29.5	32.0	27.6	24.8
Length	26.5	30.0 ?	26.2	23.3

Diagnosis :—Shell thin in the middle and umbonal portions but thickening near the margins, suborbicular to ovate, height greater than length, nearly equilateral. Dorsal margins straight, but merging almost imperceptibly into the ventral margin ; postero-dorsal margin slightly longer than the antero-dorsal and about equal to half the height of the shell. Umbo fairly sharp, apical angle 105° or 106°. Hinge-line straight, length of hinge rather more than one-third the length of the shell. Ears of moderate size, the anterior slightly larger than the posterior, both ascending slightly ; byssal sinus very small. Interior of shell smooth ; pallial line obscure, remote. Ventral margin entire ; ventral arc includes an angle averaging about 230°.

Right valve slightly convex ; surface of disk nearly smooth except at and immediately below the submargins. Concentric ornament of, usually, five or six fairly evenly spaced more prominent growth lines and innumerable fine incremental striae ; in addition, an exceedingly fine and barely discernible concentric threading, fairly regularly and closely spaced, is present. The radial ornament consists of exceedingly numerous, closely spaced low threads, which start at a distance from the umbo about equal to a quarter of the height of the valve ; on the median three-fifths of the disk, the radial threads are varely visible to the naked eye, except close to the ventral margin where they form a minute network with the concentric threads which are widened and thickened where they pass over the radials. At a distance from the lateral margins approximately equal to a fifth of the length of the valve, the radial threads become more prominent and clearly defined and their junctions with the concentric threads are marked by closely spaced nodes, which become larger and farther apart near the dorsal margins, developing into short tooth-like spines on the three or four threads nearest the margins. Where the outer layer of shell is missing from the middle portion of the holotype only the concentric ornament is present.

Outer margins of anterior ear rounded, the distal margin descending in a slightly sinuous curve to a very shallow byssal sinus. Concentric ornament of fine striae and a few stronger ridges, some bearing a short tooth-like spine at the dorsal end. Radial ornament of four or five, usually faint, threads with low nodes at their junctions with the more prominent concentric ridges. Posterior ear smaller and more oblique than the anterior, outer margins rounded on the holotype, but on the paratypes the posterior ears are more nearly triangular in shape ; concentric ornament similar to that of anterior ear ; radial ornament of posterior ear obscure on the holotype, but on the smallest valve it consists of three rather indistinct threads with fairly closely spaced, short imbricating spines ; three stronger spines also rise above the dorsal margins. The junction of the anterior ear with the disk is marked by a very narrow beading of cross ridges, which starts about half-way down the junction, divaricating below the ear to follow the major growth lines for a short distance.

Hinge generally similar to that of *S. subserratus*, but the lower crura are much wider than the upper and are stronger and wider and their ventral margins are more clearly defined than on the paratype of *S. subserratus* ; this, however, may merely represent the difference between the hinges of right and left valves ; the lower limb on the posterior ear is rather wider than that on the anterior ear and its ventral margin is more convexly curved. Very fine closely spaced cross ridges are visible on the crura of the better preserved valves. The upper crura are crenulated by the ends of the curved ridges which represent the growth lamellae on the dorsal surface of the hinge ; as in *S. subserratus* the two outer ridges are more prominent than the rest, and end as short tooth-like spines.

Left valve not seen.

Remarks :—Individuals of this species vary in degree of convexity and in the strength of their radial ornament, which is more marked on the holotype than on the other specimens. The largest specimen is nearly flat and its surface, which, like that of the other paratypes, is better preserved than that of the holotype, is nearly smooth, except for the growth ridges and the radial threads near the lateral margins, the radial ornament of the median portion appearing to the naked eye as fine striae, even near the ventral margin. The two Molecap specimens are rather more convex ; on the larger of these only the lateral radial ornament is visible, the remainder of the disk appearing smooth except for two growth rings near the ventral margin. On the smallest valve the radial threads are rather more prominent. The radial threads of this species are more closely spaced than those of *S. Subserratus*. The surface of the better preserved valves is pale buff in colour and has a waxy lustre.

In its shallow byssal sinus *Syncyclonema subreticulatus* resembles the Southern Indian species *S. sivaicus* Stoliczka (**14**, p. 435, Pl. XLII, fig. 5), but the ears of the Gingin species are more rounded than those of *S. sivaicus*. The reticulated appearance of the median portion of the disk recalls to some extent that of *Chlamys intertextus* Roemer, which Arkell (**2**, pp. 102, 103, Pl. VIII, figs. 1, 2) has taken as the type of his subgenus *Camptochlamys*, but the concentric ornament of the Gingin shell is fine, instead of coarse as in *Camptochlamys*, and in other respects there is no resemblance.

The species is one of the least scarce of the Gingin pectens. The McIntyre Gully specimens were found at about two feet or less below the top of the *Marsupites* subzone, whereas the Molecap specimens were found nearer the middle of that subzone. The shells are very brittle and almost impossible to recover intact.

Syncyclonema (Ctenioplеurium) perspinosus sp. nov.

Pl. I, figs. 6–8.

The available material consisted of four fairly well preserved specimens, all apparently left valves, and portions of six other valves. All except one are from the lower half of the *Marsupites* subzone at Molecap, the remaining specimen, a ventral fragment, being from the middle of the same subzone at McIntyre Gully. The McIntyre Gully specimen is flatter than the others and its growth rings are more regularly spaced; it may represent a right valve.

Dimensions :—

	Holotype.	Paratype.	Paratype.	
	mm.	mm.	mm.	mm.
Height	25.9	26.8	22.3	19.8
Length	25.0	25.4	20.4	18.3

An incomplete valve (U.W.A. 17198a) from which most of the anterior half is missing has a height of 31 mm.

Diagnosis :—Shell thin and translucent in the middle and umbonal portions, thicker and opaque near the lateral and ventral margins, suborbicular to ovate, height rather greater than length, almost equilateral; dorsal margins straight, approximately equal in length and usually a trifle longer than half the length of the shell. Ears rather small, subequal; hinge fairly strong, hinge-line straight or descending very slightly from the umbo, length equal to about two-fifths the length of the shell. Umbones sharp, apical angle ranging from about 103° to 108°, usually about 107°. Surface of shell waxy or glossy when well-preserved. Ventral margin entire; ventral arc includes an angle of about 230°. Interior of shell smooth; pallial line remote.

Right valve not seen.

Left valve moderately convex. Concentric ornament of disk consists usually of four or five more prominent growth-rings, irregularly spaced, and innumerable fine striae discernible only under a lens. Radial ornament of, usually, 25 low narrow main ribs starting near the umbo, as well as eight others interpolated on the ventral half of the valve; of these last, usually five start about half-way down the valve, the remaining three near the ventral margin. The interspaces between the main ribs are fully twice as wide as the ribs. The smallest nearly complete valve has only 21 main ribs, and eight others interpolated near the ventral margin, the interspaces being wider than usual. The ribs are decorated with closely set high spines, normal to the surface of the shell; near the umbo, the spines start as a faint beading of low nodes. The number of spines on each rib usually ranges from 15 on the ribs nearest the dorsal margins to 30 on the median ribs, but on the second smallest specimen the range is from 9 to 20. In cross section the thickness of the spines is greatest parallel to the concentric striae; the dorsal sides are convex and the ventral straight or slightly concave; distally the spines end in a convexly curved edge extended in a direction parallel to the concentric striae. Both ears obliquely triangular in shape, with the outer angles slightly rounded; the dorsal and distal margins usually straight, but the distal margin of the anterior ear may be slightly curved convexly. Ears separated from the disk by a very narrow beading of fine ridges normal to the line of junction. Anterior ear ornamented with concentric lamellae and two radial rows of small spines with a third row along the dorsal margin; posterior ear with similar concentric lamellae and three rows of still smaller spines with a fourth row along the dorsal margin. Hinge similar in type to those of *S. subserratus* and *S. subreticulatus*; as in the paratype of *S. subserratus*, the upper crura are the stronger and more sharply defined; they, and particularly the posterior limb, appear to be wider distally than the upper crura of the other two species; the intercrural groove is usually deeper and wider on the posterior half of the hinge, and the lower limb descends at a slightly greater angle ; thin curved ridges terminating the grooves distally and linking the lower and upper crura are more distinct than in the other species ; fine cross ridging of the grooves and lower crura is visible on the better preserved specimens.

The difference between the thickness of the umbonal and middle portions of the disk and that of the marginal portions is very marked in the larger valves ; the thicker portion forms a concentric band about equal in width to a quarter the height of the valve : the thickening starts just within the ventral margin, the margin itself being thin.

The exterior surface of the valves is pale creamy or yellowish brown in colour, paler and, in some specimens, yellower than that of *S. subserratus*.

Remarks :—In its radial ornament this species shows a certain resemblance to the North American Miocene species *Chlamys coccymelus* Dall (**3**, p. 741, Pl. XXXIV, fig. 1), but in the Gingin species the ribs and the spines are more numerous, and the spines are apparently more erect, and irregularly distributed secondary ribs with spines similar to those of the main ribs are present in the interspaces instead of the beaded radial threads of the American species. In other respects the shells are markedly different.

The three species described above form an interesting group, the members of which differ from the more typical *Syncyclonemas* in the presence of radial ornament, but resemble them in the principal characters of the shell. *S. subserratus* forms a link between the more strongly ornamented members of the group and the normal *Syncyclonemas*. The difference in thickness between the umbonal and middle portions of the disk and the lateral and ventral portions so marked in *S. perspinosus* is less noticeable in *S. subreticulatus* and very slight in *S. subserratus*.

Subgenus **CHLAMYS** Bolton, 1798.

Chlamys subtilis sp. nov.

Pl. II., figs. 1–3.

The material examined consisted of seven specimens from Molecap, all more or less imperfect and including three left valves, two right valves and two indeterminable. The horizon of six of these is uncertain, but is probably the upper portion of the *Uintacrinus* subzone, from the appearance of the enclosing chalk ; the seventh, a small right valve, is from about 2 ft. 6 in. above the base of the Chalk.

Dimensions : —

	Right Valve.	Right Valve.	Left Valve.	Left Valve.	Probable left valve with ears missing.
	Holotype.		Anterior half.		
	mm.	mm.	mm.	mm.	mm.
Height	17 .5	14 .7	19 .2	17 .5	16 .3
Length	15 .3	12 .8	?	15 .5 ?	13 .8

Diagnosis.—Shell small, thin, ovate, higher than long, nearly equilateral ; dorsal margins nearly straight and equal in length, antero-dorsal very slightly the longer and usually slightly concave, postero-dorsal slightly convex. Ears of moderate size, unequal, byssal sinus well-defined, hinge-line straight or descending slightly from the umbo and slightly longer than half the length of the disk. Umbones sharp, apical angle 86° or 87°. Margin entire. Interior of shell smooth, pallial line obscure.

Right valve very slightly convex, ornamented with between 60 and 70 low narrow radial threads or riblets, mostly arranged in pairs, a few single threads being interpolated in the ventral portion of the valve ; the riblets on the posterior submargin are rather stronger than those elsewhere. Apart from two clearly defined growth laminae, the concentric ornament of the holotype is obscure, being represented only by faint minute raised threads on the radial riblets, but closely spaced fine concentric threading is visible over the greater part of the disk of the smaller right valve. The radial and concentric threading gives a lattice-like appearance under a lens, but to the naked eye only the radial ornament is visible. On the ventral, particularly the postero-ventral, portion of the disk the shape of the radial and concentric threads is modified by a fine, closely spaced diagonal striation, discernible both on the radial threads and in the interspaces. Anterior ear rather small, produced, alar in shape, distal margin rounded, lower margin descending slightly in a sinuous curve towards the disk : radial ornament consisting of 7 (?) low threads modified by faint concentric threading near the dorsal margin, which is serrated slightly, both by the concentric threading and by the raised margins of the growth lamellae ; fasciole shallow, with concentric ridges not very strongly marked ; the ctenolium appears to consist of four minute denticles. Posterior ear small, triangular, oblique, the distal margin slightly concave dorsally ; radial ornament of three narrow threads on the lower half of the ear, diagonal striae being visible in the interspaces ; concentric ornament of fairly closely spaced faint lamellae, which inbricate slightly at the dorsal margin.

Left valve rather more convex than right valve. Radial ornament of low threads similar to those of right valve. The threads appear to range from about 40 to 80 in number, the total number probably depending largely on the number of interpolated threads. Concentric ornament of very fine threads, more prominent where they pass over the radial threads. Diagonal striation, modifying the shape of the radial and concentric threads, was noticeable only on the better preserved antero-ventral portions of two of the left valves examined. Anterior ear moderately large with convex distal margin ; radial ornament of closely set threads with, on one specimen, a trace of diagonal striation in the interspaces ; visible concentric ornament consists of a few growth laminae. Posterior ear not seen.

Remarks.—*Chlamys subtilis* appears to be confined to the upper portion of the *Uintacrinus* subzone. The rock enclosing six of the specimens examined has the characteristic appearance of the lowest foot of the Molecap Chalk, which contains noticeably more and coarser glauconite than the rest of the exposure, and I have found fragments belonging to this species at about six inches above the base of the Chalk. The small right valve is from the approximate top of the subzone.

In its ornament and proportion of length to height, this species would appear to resemble *Camptonectes ellipticus* Eth. fil. (**6**, pp. 19, 20, Pl. I., fig. 16), although the difference in the shape of the anterior ears of the right valves, the greater size of *C. ellipticus*, in which, also, the junctions of the dorsal and ventral portions of the disks are less marked, show them to be separate species. I have not been able to trace the type of Etheridge's species, nor have I come across any other specimens, although, according to Glauert's list (**8**, p. 11), it is moderately common at One Tree Hill. The markedly ovate shape of Etheridge's species and the presence of radial riblets in addition to divaricating striae suggest that it should be assigned rather to *Chlamys* than to *Camptonectes*. As Dall (**3**, pp. 695, 696) and others have shown, the *Camp-*

tonectes striation is not confined to the shells of that subgenus but occurs also in *Chlamys* and *Aequipecten*. There also appears to be a close resemblance in ornament and proportion between *Chlamys subtilis* and *Pecten greenoughiensis* Moore (**13**, p. 248, Pl. XI., fig. 10), and it is possible that the species are identical, although Moore's figure shows the ears of his species to be set much lower than those of *C. subtilis*, the antero-dorsal margin as convex instead of straight or slightly concave, and he does not mention the presence of diagonal striae. Unfortunately nothing is known of the circumstances of occurrence of Moore's specimen or of the exact locality from which it was obtained.

Chlamys ginginensis sp. nov.

Pl. II., figs, 4–6.

Although this is the commonest species of *Chlamys* in the Gingin area, so far as I know, no really well preserved specimen has been found. The material examined consisted of the remains of a dozen individual valves, most in a very fragmentary condition. The disks of only two right valves and one left valve were nearly complete, the anterior ears being missing, and the anterior ears were present only on two left valves and one right valve, all very imperfect. Details of the surface ornament were particularly well preserved on the ventral fragments of a right valve and a left valve, both larger than the specimens of which it was possible to obtain measurements.

Dimensions :—

	Cotype. Right Valve. Molecap.	UWA17290a Right Valve. Molecap.	Left Valve. McIntyre Gully.	UWA17290c Left Valve. Molecap.	UWA12790b Cotype. Right Valve. Molecap.	Left Valve. McIntyre Gully.
	mm.	mm.	mm.	mm.	mm.	mm.
Height....	16.9	21.7	18.6	17.1	15.8	15.7
Length	15.2	18.4	17.5	15.1	14.1	13.7

Diagnosis.—Shell small, thin, subovate to ovate, higher than long, inequivalve, inequilateral, usually slightly oblique. Antero-dorsal margin straight or slightly concave and longer than postero-dorsal, which is short and slightly convex ; submargins narrow but fairly well defined. Ears of moderate size, unequal ; byssal sinus well-marked. Hinge-line not straight, descending slightly from the umbo ; length of hinge about equal to half the height of the shell. Umbones sharp, rising slightly above the hinge-line, apical angle about 89°. Ventral margin entire. Pallial line obscure.

Right valve flat, the disk ornamented with fairly strong low rounded main radial ribs, ranging from 13 to 20, but usually 14 to 16 in number ; on the submargins the ribs are obsolete. Near the umbo the ribs become less distinct and pass into groups of two or three threads, with additional threads in the interspaces. The interspaces are usually slightly narrower than the ribs. Occasionally the place of one of the main ribs is taken by a pair of narrower ribs. The number of ribs is increased by interpolation of secondary ribs or, more rarely, by bifurcation ; both types of increase may occur on the one valve. The number of ribs interpolated ranges from 1 to 12, and on some valves interpolation takes place only below the first growth ring ; the interpolated ribs are usually narrow but those interpolated below the first growth ring may be nearly equal in width to the main ribs. Concentric ornament consists of evenly spaced fine, low threading, more prominent where it crosses the ribs, but visible only on the better preserved specimens. The larger valves show one or two prominent growth laminae, which thicken at their margins to rise abruptly above the next ventrally situated lamina ; on the ventral fragment of a large right valve, the difference in elevation is one millimeter. Very numerous closely and evenly spaced fine diagonal striae, directed downwards in the median portion of the valve at an angle approaching 45° from a median line but nearly horizontal at the junction of the dorsal and ventral margins, are present in the interspaces of the better preserved valves. Anterior ear rather small, produced, distal margin rectangularly truncated or slightly rounded, distal portion of lower margin approximately parallel to dorsal margin ; radial ornament of three fine slightly waved threads set closely together just above the middle of the ear ; fasciole wide, with closely set strong curved, concentric ridges inclined towards the umbo and passing, on the ear, into finer, less distinct growth lamellae, which pass threadlike over the radial threads ; at the dorsal margin of the ear, three evenly spaced growth lamellae imbricate as small tooth-like projections ; ctenolium with three short, relatively stout spines ; smaller spines of earlier stages of ctenolium, diminishing in size towards the umbo, are visible at the junction of the disk and the fasciole. Posterior ear small, triangular, oblique, distal margin convexly curved ; ornamentation of three low radial riblets rather more prominent and more widely spaced than those of the anterior ear ; the riblets crossed by growth lamellae decorated with small nodes, or tooth-like spines, at the junctions, the lamellae projecting as short teeth above the dorsal margin of the ear. Interior of valve smooth except a small area above the first growth ring where it is faintly fluted in harmony with the exterior ribbing. Two pairs of long cardinal crura start at a short distance from the resilial pit, the upper pair extending to the distal margins of the ears, the lower to within a short distance from the margins ; the lower pair, which are slightly the thicker, diverge radially from the upper at an exceedingly acute angle, the intervening furrows starting at about one-third the distance from the resilial pit to the distal margins of the ears.

Left valve moderately convex ; ornamentation of disk similar to that of right valve. Anterior ear relatively large, outer angle obtuse, distal margin convex, radial ornament of four well-marked rounded riblets as well as a pair of narrower riblets close to the junction with the disk ; concentric ornament of three more prominent growth lamellae as well as barely perceptible, fine incremental lines. Posterior ear small, triangular, oblique, distal margin straight or slightly convex ; radial ornament of two main riblets and a narrower pair close to the disk ; concentric ornament of three or four growth lamellae with short thick spines at their junctions with the riblets. Interior of disk usually wholly shallowly fluted, but that of the large better-preserved ventral fragment is smooth near the ventral margin. Cardinal crura similar to those of right valve, except that the upper pair are slightly the thicker, especially at the distal ends.

Remarks.—The largest right valve measured (U.W.A.17290a), of which two anterior, three median, and one posterior ribs are bifurcated, is probably merely an unusual example of bifurcation within this variable species rather than a representative of a separate species, as bifurcation of single ribs occurs in other specimens and other features of the valve, including the number of spines in the ctenolium are similar.

This species closely resembles *Chlamys britannicus* Woods (**20**, p. 167, Pl. XXXI, figs. 1, 2) in shape, apical angle, and radial ornament. Woods states that the ribs of his species do not bifurcate and that only rarely is a new rib introduced between two others. On the other hand, the large number of relatively narrow ribs present on the ventral fragment figured by him (fig. 1a) suggests bifurcation or interpolation as in the Gingin species. The anterior ear of the left valve is relatively larger in the Gingin species. The concentric ornament of *C. ginginensis* more nearly resembles that of *Aequipecten arlesiensis* Woods (**20**, Pl. XXXVII, fig. 11) than that of *C. britannicus*, from which, also, diagonal striae are apparently absent.

The Molecap specimens obtained *in situ* are from the lower half of the *Marsupites* subzone ; the McIntyre Gully specimens are from the upper half of the same subzone. A fairly well preserved left valve from One Tree Hill is in the Western Australian Museum collection. In colour the shells are pale cream, very pale pink, or pale grey.

Chlamys clarkei sp. nov.

Pl. II, figs. 7, 8.

The available material consisted of a single fairly well preserved right valve and a specimen showing the interior of a much smaller right valve partly superimposed on the interior of the apparently corresponding left valve. Both specimens are from the lower portion of the *Marsupites* subzone at Molecap.

Dimensions :—

	Holotype. Right Valve. mm.	Small. Right Valve. mm.	Small. Left Valve. mm.
Height	16.6	9.6	9.8 ?
Length	15.2	9.2 ?	9.3 ?

Diagnosis :—Shell small, thin, somewhat obliquely ovate with the anterior portion produced, height rather greater than length, inequivalve, inequilateral ; antero-dorsal margin concave and longer than postero-dorsal, which is slightly convex and passes insensibly into the ventral margin ; submargins narrow. Ears unequal and rather large; byssal sinus well-marked but rather narrow. Hinge-line straight, longer than half the height of the shell. Umbones fairly sharp, apical angle of holotype about 90°, those of smaller valves rather greater. Ventral margin entire. Ventral arc includes an angle of about 220°. Pallial line obscure.

Right valve flat ; the disk smooth for a short distance below the umbo, thence the radial ornament consists of exceedingly fine threads arranged in groups of two or three, the threads of each group uniting at a distance from the umbo equal to about two-fifths of the height of the valve, to form low rounded ribs. The main ribs, from 20 to 22 in number, are separated by shallow rounded furrows only slightly wider than half the width of the ribs ; rarely a pair of narrower ribs takes the place of a normal rib. The last two ribs on each side are slightly obsolete. Single secondary riblets, usually threadlike, but varying in width and length, are present in some of the furrows, being more common on the anterior half of the holotype. One growth-ring, about half-way between the umbo and the ventral margin, is present on the holotype ; though well-marked, it is not raised abruptly above the next lamina as in larger specimens of *Chlamys ginginensis*. Concentric ornament consists of very faint, low, rather widely spaced threading, perceptible only on the median ribs. Diagonal striae similar to those of *C. subtilis* and *C. ginginensis* are noticeable in the radial furrows, the change of direction of these occurring some distance anteriorly of the median line in the holotype. Anterior ear large, deep, produced, distal margin convex and curving downward and inwards to a well-marked, but shallow, byssal sinus ; ear decorated with about six narrow radial riblets, on which there is a trace of concentric threading. Fasciole broad and well-marked and ornamented with about 16 closely-set strong concentric ridges inclined towards the umbo. Ctenolium with about seven minute spines. Posterior ear small, triangular, oblique, decorated with two more prominent beaded riblets as well as a pair of narrower riblets near the junction with the disk. Dorsal portion of interior of disk smooth, ventral half faintly corrugated in harmony with the exterior ribbing. Colour of valve very pale pink.

Left valve moderately convex ; exterior not seen, but the main radial ornament appears to be similar to that of the right valve ; traces of fine diagonal striae in the furrows are visible through the shell. Anterior ear not seen. Posterior ear small, triangular, oblique. Interior of valve more strongly corrugated than that of the corresponding small right valve, the corrugation extending much nearer to the umbo, suggesting a corresponding extension of the main exterior ribbing. Lirae absent.

Remarks :—This species resembles *Chlamys ginginensis* fairly closely in its proportions and ornament, but differs from it in the shape and larger size of the anterior ear of the right valve, the greater obliquity of the disk, and the number and smaller size of the spines of the ctenolium. The number of ribs is slightly greater and the ribs do not appear to bifurcate as in some specimens of *C. ginginensis*. Moreover, the hinge-line is straight, whereas that of *C. ginginensis* usually descends slightly from the umbo. The fine radial threading which represents the ribs near the umbo in both these species suggests their descent from a finely ribbed species such as *C. subtilis*, a close relationship to which is also indicated by the similarity of the concentric ornament and diagonal striation of the three species. *Camptonectes ? ellipticus* may possibly also be a member of the same group.

Although covered by Meek's definition (**12**, p. 39), the diagonal striation of the three species of *Chlamys* just described differs from the true *Camptonectes* striation, as found in the species of that subgenus and in some species of *Chlamys* and *Aequipecten*, in the direction of the striae on the median portion of the shell and in the lesser degree of curvature of the striae. In the *Camptonectes* striation, the striae on the median portion are more nearly radial and, in species of *Chlamys* and *Aequipecten*, approach parallelism to the median ribs, whereas in the three Gingin species the striae in the median portion of the shell are directed downwards and outwards at an angle usually of about 45°, but occasionally as much as 50°, from the median line or, more correctly, from the radial line of origin, as the change of direction does not always occur at the median rib, but may occur at some distance from it ; the striae on the opposite sides of the line of change, therefore, diverge from each other at an angle of 90° or more. As the direction of the striae close to the junction of the ventral and dorsal margins is approximately normal to the median line, the curvature of the striae is much less than in the *Camptonectes* striation. The change of direction is not always constant ; in the holotype of *Chlamys clarkei* a change of direction occurs at a radial thread in a furrow situated anteriorly of the median line, but the striae in the next anterior furrow revert to the posterior direction, finally returning to the anterior direction in the third anterior furrow, thus producing a local herring-bone pattern. In a specimen of *Chlamys ginginensis* a partial change occurs in the furrow immediately anterior to the median rib, the striae below the main growth-ring being directed anteriorly, whereas those above the growth-ring are directed posteriorly, the change being completed in the next anterior furrow.

Among the European Cretaceous species, *Pecten dutemplei* D'Orb. (11 p. 59, fig. 27) appears to be striated similarly to the Gingin shells.

Chlamys curvicosta sp. nov.

Pl. II, figs. 9, 10.

A very imperfect specimen (U.W.A. 17199), showing the mould and portions of the interior of a right valve represents a species of *Chlamys* which differs from those already described in the curvature of its ribs, though broadly resembling them in type of sculpture. A postero-ventral fragment, showing the exterior, of another right valve appears also to belong to this species. The more complete specimen consists only of the exterior mould and part of the ventral portion and the postero-dorsal portion of the valve, but the mould is so clearly marked that details of the external sculpture and the shape of the anterior ear can be readily determined. Height of shell 17.4 mm.; length 16.2 mm.; length of hinge 8.8 mm. Locality of specimen not stated, but probably Molecap; the smaller fragment is from Molecap.

Diagnosis :—Shell small, thin, suborbicular, height rather greater than length, inequilateral; antero-dorsal margin concave and longer than postero-dorsal which is short and passes imperceptibly into the ventral margin; submargins narrow. Hinge-line straight, hinge consisting of two pairs of narrow crura separated by very narrow furrows; ears small and unequal, byssal sinus well-marked; umbo sharp, apical angle about 86°. Ventral margin delicately scalloped; ventral arc includes an angle of about 230°. Interior of shell nearly smooth, ventral half faintly fluted in harmony with major exterior ribbing.

Right valve very slightly convex, the more complete specimen ornamented with about 34 narrow riblets, beginning almost at the tip of the umbo; the riblets may have been rather fewer in number on the shell represented by the postero-ventral fragment; the riblets near the lateral margins are simple, those near the posterior margin being apparently wider than those near the anterior, but the median riblets are composed of groups of, usually, three fine threads; one or two threads are interpolated in some of the interspaces which are shallow and rounded and about equal in width to the riblets. The riblets on the anterior third of the disk are fairly strongly curved in harmony with the antero-dorsal margin, with the concave sides facing anteriorly, the curvature increasing towards the margin; the curvature of the median and posterior riblets is relatively slight. On the small postero-ventral fragment the seven posterior riblets are simple; of these the remnants of the two nearest the dorsal margin are flat and obsolete, the next two low and rounded and about equal in width to the interspaces, becoming wider, flatter, and obsolete near the ventral margin; the remaining three are narrow above, but widen rapidly ventrally, the interspaces remaining constant in width; single radial threads are present in the interspaces between these last three riblets; the eighth riblet consists of two threads, but the ninth, though consisting of two threads above, becomes simple towards the ventral margin; the remaining three riblets visible are each composed of three low threads. The concentric ornament consists of exceedingly numerous and fine threads best seen where they cross the radial threads. Diagonal striae similar to those already described are clearly defined in the radial furrows, the change of direction of the striae occurring, in the more complete specimen, posteriorly of the median line. Anterior ear produced, distal margin convex, byssal margin straight ; the impression shows traces of at least three radial threads. Posterior ear small, triangular, oblique, ornament not seen.

Left valve not seen.

Remarks.—This species differs from those of the *Chlamys subtilis* - *C. ginginensis* group in the curvature of its ribs and the scalloping of its ventral margin, but a relationship to that group is suggested by the similarity in type of sculpture, the radial ornament being about midway between that of *C. subtilis* on the one hand and *C. ginginensis* and *C. clarkei* on the other ; the concentric threading is very similar to that of *C. subtilis* and the diagonal striation is similar to that of all three species of the group ; the shape of the anterior ear is something between that of *C. subtilis* and that of *C. clarkei.*

Chlamys teicherti sp. nov.

Pl. II, fig. 11.

A single imperfect specimen from Molecap differs markedly from the species of *Chlamys* already described. It consists of the internal cast, the posterior half of the disk, and both ears of a left valve. Height 9.5 mm ; length 9.3mm ; length of hinge 3.8 mm.

Diagnosis.—Shell small, thin, suborbicular, length almost equal to height, nearly equilateral ; dorsal margins about equal in length, the postero-dorsal straight, antero-dorsal slightly concave. Hinge-line straight, ears of moderate size, unequal. Umbo not very sharp, apical angle obtuse, about 96°. Ventral margin apparently scalloped. Ventral arc includes an angle of more than 200°. Interior of shell smooth.

Left valve moderately convex, the dorsal third of the disk smooth, the remaining two-thirds ornamented with, probably, 21 narrow ribs, high, angular, simple and well defined on the middle of the valve, but becoming obsolete towards the lateral margins; the four lateral ribs are adorned with, usually, three short, closely-set, relatively large spines. Interspaces about twice as wide as the ribs and smooth. No other ornament visible on the disk except a very faint, fine, concentric striation. Anterior ear triangular, with oblique, very slightly convex, distal margin. Posterior ear rather smaller, triangular, oblique, marked off from the disk rather more sharply than the anterior ear. Both ears ornamented with two rather faint growth lines and exceedingly faint concentric striae. Exterior surface of valve has a waxy lustre and a pale creamy brown colour. Interior surface smooth, except for a curious narrow, wire-like concentric flange which starts at the junction of the dorsal and ventral margins and continues downwards just within the ventral margin. Two pairs of cardinal crura appear to be present, the lower pair being short, but the hinge structure could not be determined with certainty.

Remarks.—I have placed this species under *Chlamys*, but the nearly circular outline, wide apical angle, fine concentric striation, and waxy lustre suggest a relationship to *Syncyclonema*. Discovery of the right valve might throw further light on the affinities of the species.

Subgenus **PSEUDAMUSSIUM** H. and A. Adams. 1858.

Pseudamussium candidus sp. nov.

Pl. I., fig. 9 ; Pl. II., figs. 13, 14.

The material examined consisted of ten specimens in varying states of preservation, including one of both valves, from Molecap ; one nearly complete left valve from " the North Chalk " ; and portions of the disks of four valves from McIntyre Gully.

Dimensions :—

	Syntype. Left Valve. Molecap. mm.	Right Valve. Molecap. mm.	Left Valve. Nth. Chalk. mm.	Both valves. Molecap. mm.	UWA17202 Left valve. Molecap. mm.	Syntype. Right valve. Molecap. mm.
Height....	8.3	7.4	5.8	5.6	5.15	4.8
Length	9.3	8.4	6.7	6.3	5.5	6.0

The average proportion of height to length of eight specimens is 100 to 114.5. The thickness of the specimen of united valves is 2.0 mm.

Diagnosis.—Shell small, thin, smooth, hyaline to porcellanous, length greater than height, a little inequivalve, both valves slightly to moderately convex, the left valve on the average a trifle more so than the right ; inequilateral, produced anteriorly. Antero-dorsal margin a little longer than postero-dorsal and slightly concave towards the umbo, postero-dorsal slightly convex, both merging imperceptibly into the ventral margin. Hinge-line straight or slightly concave ; ears small, the anterior a little larger than the posterior and more sharply marked off from the disk, the posterior ear being obsolete ; byssal sinus small. Umbones not very sharp and rarely rising above the hinge-line ; apical angle variable, ranging from about 95° to 120° but usually about 109°. Ventral margin entire. Valves closed ; lateral portions of commissure slightly curved, convexly on the right valve, concavely on the left. Interior of shell smooth ; pallial line obscure ; details of hinge not seen.

Right valve nearly flat to moderately convex ; ornament, barely discernible even with a lens, consists of very fine concentric striae and a few slightly more noticeable evenly-spaced growth-lines. Anterior ear rather larger than posterior, produced, distal margin convex, ventral margin descending obliquely to a well-defined but small byssal notch ; ear depressed at the junction with the disk to form a narrow, radially triangular groove, the margin of the disk bending abruptly to meet the ear at approximately a right angle ; at the junction, the concentric ornament becomes much more pronounced to form a narrow band of cross ridges and furrows which extend for a short distance on the ear itself, the termination of the cross ridges on the ear and the disk being less abrupt than on the fasciole of *Chlamys*. Posterior ear small, triangular, oblique, not sharply differentiated from the disk.

Left valve slightly more convex than the right, with similar concentric ornament. Anterior ear slightly larger than posterior, triangular, distal margin straight and very slightly oblique ; junction of ear and disk sharply defined as on the right valve and similarly marked by abrupt accentuation of the concentric ornament, but without a defined groove. Posterior ear oblique ; its junction with the disk rather better defined than that of the right valve.

ribs higher and much narrower on the median half of the disk, but becoming lower, wider and obsolete as they approach the submargins, the difference between the median and outer ribs being very marked. Closely spaced incremental lines pass over the ribs as very low threads, those near the ventral margin imbricating slightly. Anterior ear of moderate size, distal margin slightly convex ; it appears smooth except for very fine incremental lines. Posterior ear not seen.

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Remarks.—This species shows a fairly close resemblance to the North American Tertiary species *P. defuniak* Gardner (**7**, p. 49, Pl. XII., figs. 10 12), but its ears are relatively smaller and the two species differ in their proportions, the Gingin shell being longer than high and more markedly inequilateral. The only Australian Cretaceous species which would appear from the descriptions to resemble the Gingin species in any way is *Pecten psila* Tenison-Wood (**15**, pp. 239, 240), which, judging by the description and Etheridge's figure (**10**, p. 446, Pl. 21, fig. 5), may be referrable to *Pseudamussium* ; *Pecten psila* is, however, higher than long, its byssal notch is apparently very shallow and its ears are described as radially ribbed.

Pseudamussium candidus is the least rare of the Gingin pectens. The Molecap specimens are from the lower half of the *Marsupites* subzone, between 3 and 5 feet above the base of the chalk in that locality. The North Chalk specimen is from the corresponding horizon. So far as I am aware, no specimens have been found in the *Marsupites* subzone at McIntyre Gully, the four imperfect specimens from that locality having been obtained from about 15 feet above the top of the *Marsupites* subzone. A specimen (11363F) from One Tree Hill is in the Geological Survey collection.

Although small and usually milk-white and translucent, the glossy surface of this shell serves to distinguish it from the surrounding chalk.

PECTENS FROM THE LOWER GREENSAND.

Two very imperfect specimens were recently found by Dr. R. W. Fairbridge in the Lower Greensand of McIntyre Gully, at about 10 feet below the base of the Chalk. They consist of a small shell recognisable as the left valve of a *Chlamys* and the cast, with traces of ironstained test, of a somewhat larger shell which may also represent a *Chlamys*, but which is insufficiently preserved for determination. Its description is as follows :—Height 23.5 mm.; length about 21 mm. Shell of moderate size, thin, ovate, height greater than length. Dorsal margins long, about 15 mm. ; apical angle less than 90°. Ventral margin probably slightly scalloped. Ventral arc includes a relatively small angle. Valve decorated with about 30 rounded ribs and occasional secondary ribs in the furrows, which are about equal in width to the ribs. Traces of concentric threading present. No marked difference between the median and lateral ribs.

The smaller shell, which has portion of the anterior ear remaining, is sufficiently well-preserved for specific diagnosis.

Chlamys fairbridgei sp. nov.

Pl. II., fig. 12.

Height of specimen approximately 15.8 mm. ; length 13.9 mm.

Diagnosis.—Shell small, thin, ovate, height greater than length, inequilateral. Dorsal margins long, antero-dorsal straight, with pronounced shoulder at its junction with the ventral margin ; apical angle probably greater than 90°. Ventral margin slightly scalloped.

Left valve moderately convex, depressed near ventral margin, compressed at anterior submargin. Disk ornamented with 23 or 24 low, narrow rounded ribs separated by interspaces usually nearly twice as wide as the ribs ; occasional secondary riblets interpolated in the interspaces. The main

PLATE I.

Figs. 1-3: *Syncyclonema (Ctenioplеurium) subserratus.*

1. Syntype; a slightly weathered right valve.
2. Syntype; a left valve, somewhat crushed near the umbo but with well preserved glossy surface.
3. Another left valve.

All from Molecap.

Figs. 4, 5: *Syncyclonema (Ctenioplеurium) subreticulatus.*

4. Holotype; a partly decorticated right valve, McIntyre Gully.
5. Assembled fragments of a smaller right valve, Molecap.

Figs. 6-8: *Syncyclonema (Ctenioplеurium) perspinosus.*

6. Holotype; a large left valve.
7. A smaller left valve.
8. Interior of another large left valve.

All from Molecap.

Fig. 9: *Pseudamussium eandidus.*

9. Syntype; a small right valve, Molecap.

Figs. 1-8 x 1½; fig. 9 x 3.

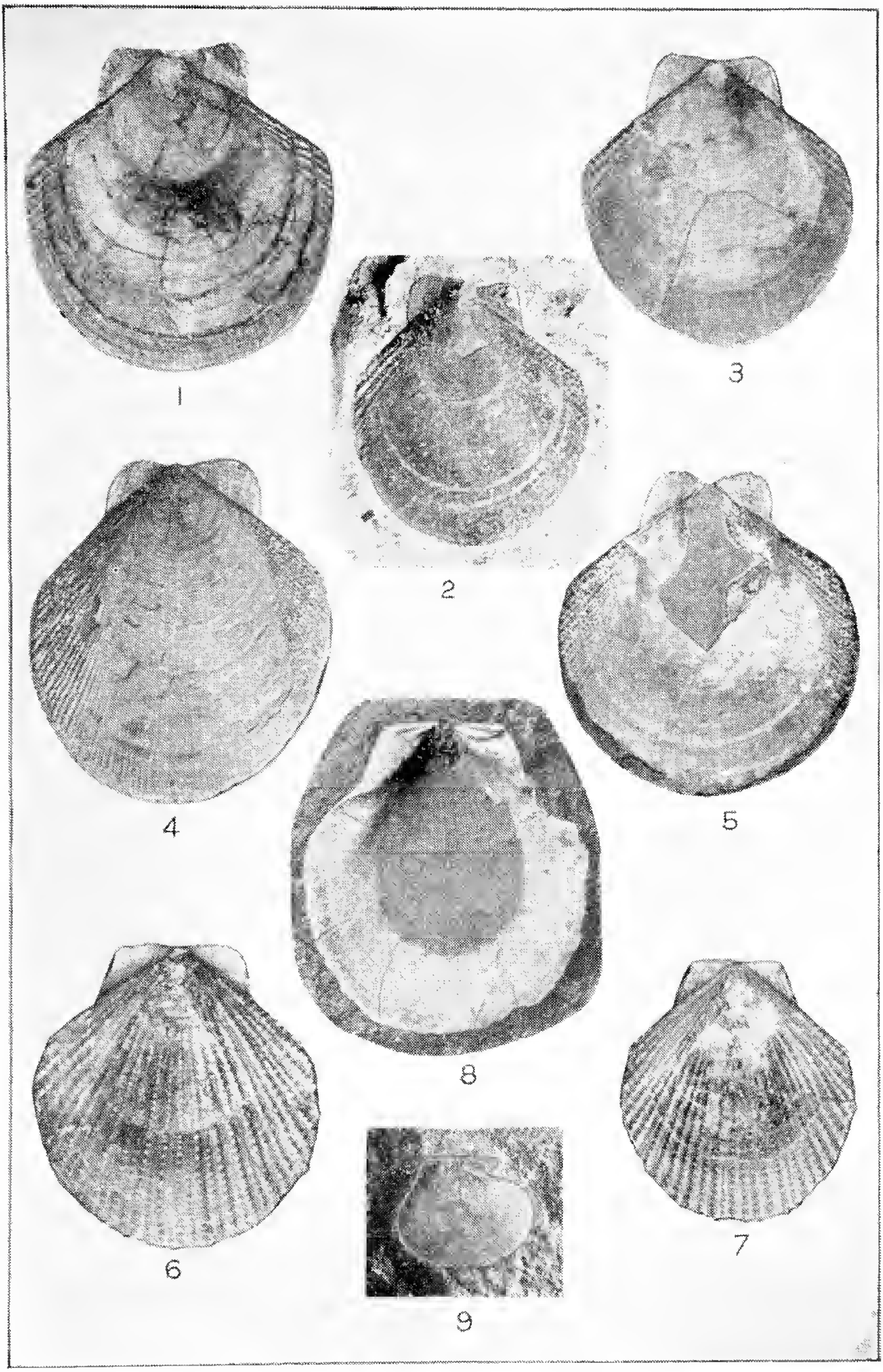


PLATE I.

PLATE II.

Figs. 1-3: *Chlamys subtilis.*

1. Holotype; a slightly damaged right valve.
2. A large left valve.
3. A small right valve.

All from Molecap.

Figs. 4-6: *Chlamys ginginensis.*

4. Cotype; an imperfect right valve, outlines of ears restored.
5. Cotype; portion of another right valve; 5a. Interior and mould of same shell.
6. Portion of a large left valve; 6a. Interior of same shell.

All from Molecap.

Figs. 7, 8: *Chlamys clarkei.*

7. Holotype; a right valve with well preserved ears.
8. Interiors of two small valves, the right valve superimposed upon the left. Both specimens from Molecap.

Figs. 9, 10: *Chlamys curvicosta.*

9. A well preserved mould with portions of the interior of a right valve, outline of anterior ear emphasised; probably from Molecap.
10. Postero-ventral portion of a right valve, apparently of the same species, from Molecap.

Fig. 11: *Chlamys (?) teicherti.*

Cast and portion of shell of a left valve, from Molecap.

Fig. 12: *Chlamys fairbridgei.*

A very imperfect left valve from the Lower Greensand, McIntyre Gully; outline partly restored.

Figs. 13, 14: *Pseudamussium candidus.*

13. Syntype; a left valve, the largest specimen found.
14. A well preserved small left valve.

Both from Molecap.

Figs. 1 2, 4-9 and 12 x $1\frac{1}{2}$; fig. 3 x 2; figs. 10, 11, 13 and 14 x 3.

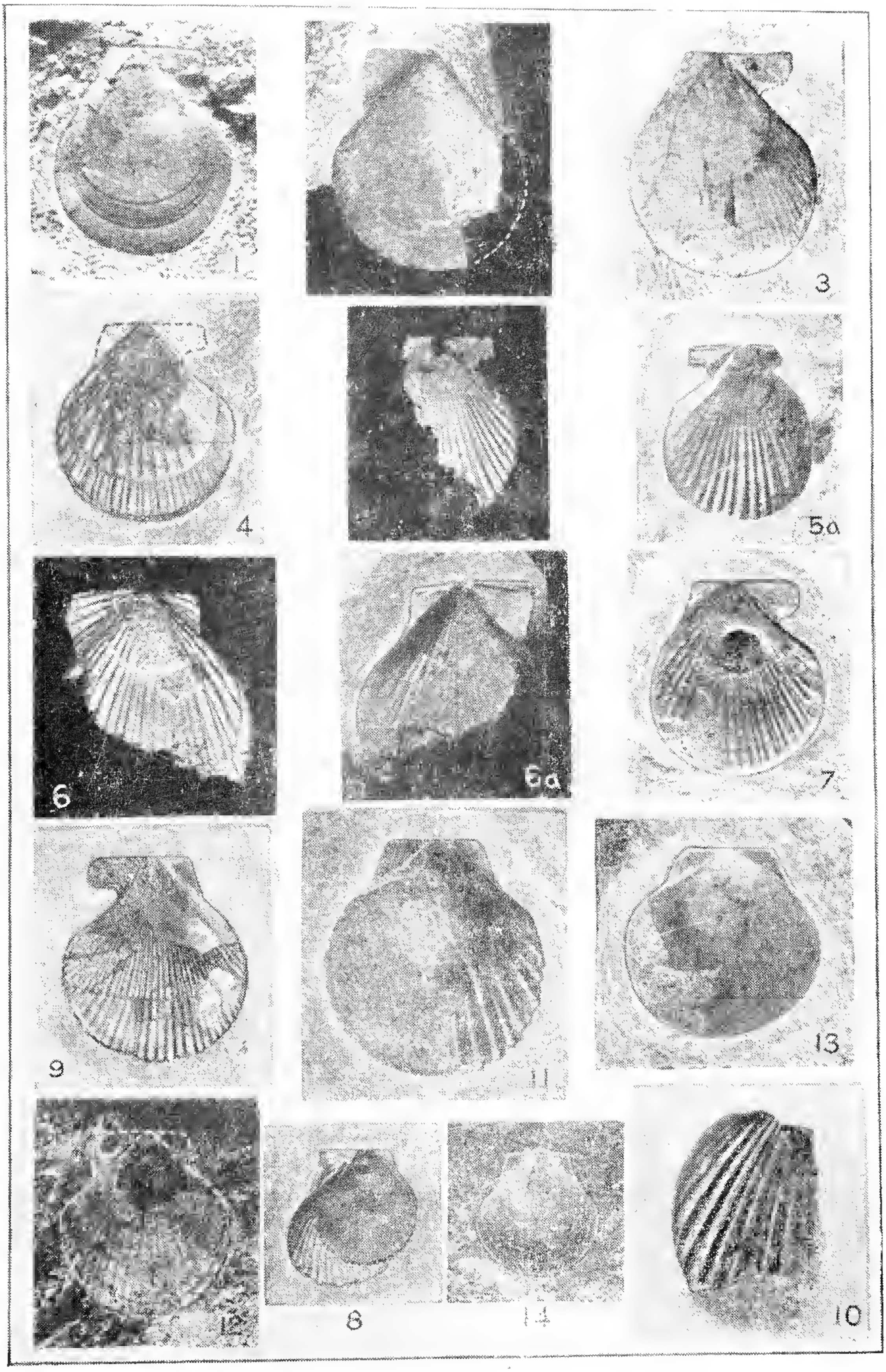


PLATE II.

3.—PERMIAN SUCCESSION AND STRUCTURE IN THE NORTHERN PART OF THE IRWIN BASIN, WESTERN AUSTRALIA

by

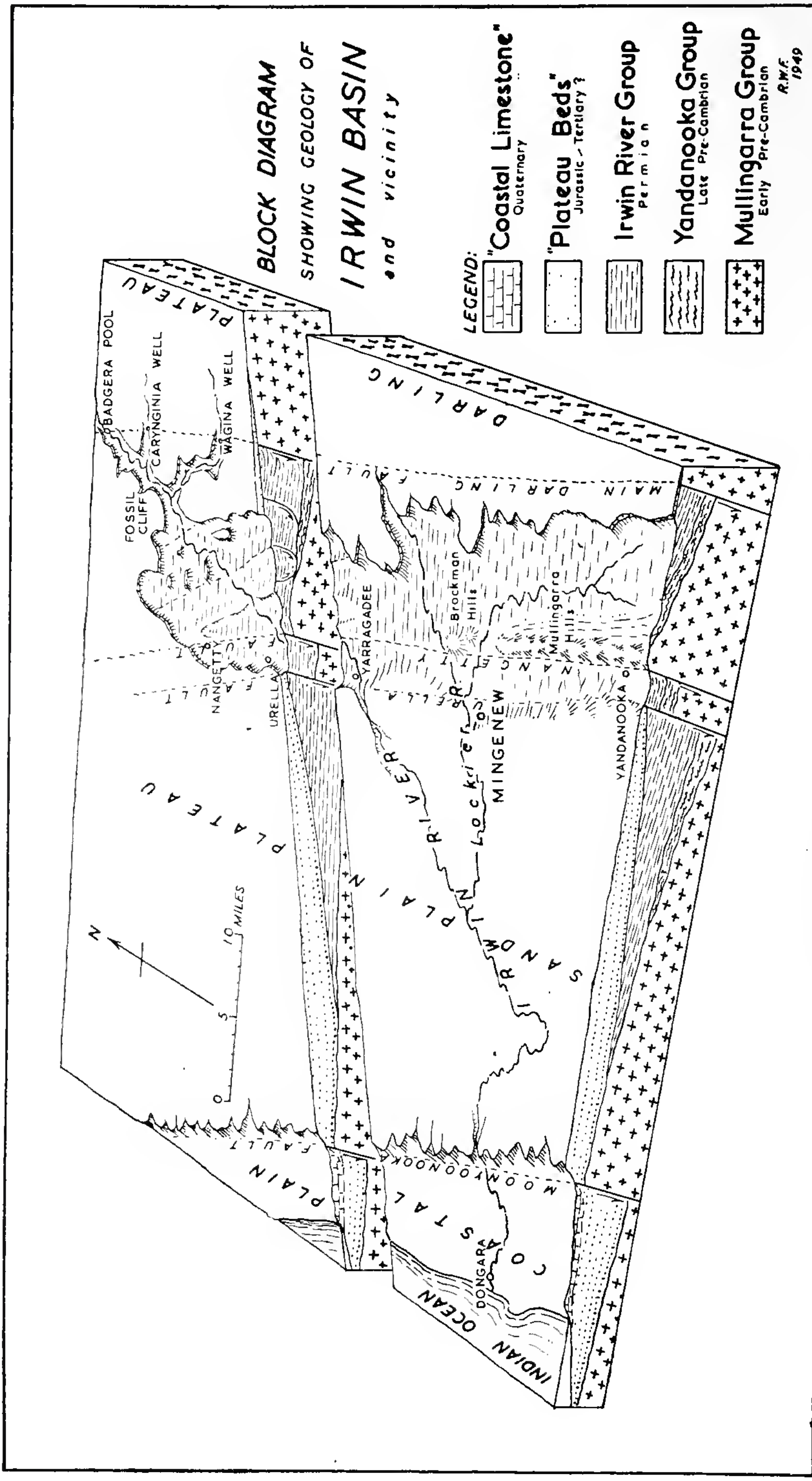
E. DE C. CLARKE, K. L. PRENDERGAST, C. TEICHERT, AND R. W. FAIRBRIDGE.

Read: 14th June, 1949.

CONTENTS.

I.—INTRODUCTION.

The part of Western Australia described in this paper is about 250 miles north of Perth, and has been mentioned in various papers dealing with the Permian and Carboniferous succession in the Southern Hemisphere. It covers an area of about 75 square miles and is, essentially, a varied sequence of Permian sediments of not less than 3,500 and probably about 4,000 feet in thickness. Structurally the beds lie tilted gently on a heavily faulted basement of Pre-Cambrian, and are further faulted in themselves along numerous minor lines (*see* text fig. 1). No folding is recognised.



Text fig. 1—Block diagram, showing geology of Irwin Basin and vicinity.

The mapped area lies in the northern part of a physiographic basin, intersected by the Irwin River, and surrounded by undulating plateau lands standing about 1,000 feet above sea-level. The thin sandstone beds of the plateau, resting unconformably on the peneplaned Permian, have been classed variously as Jurassic and Tertiary ; that problem will be discussed in another paper.

This paper presents the results of the geological mapping done by many parties of students of the University of Western Australia during the last 25 years, notable years being 1934–37, 1939 and 1948–49. This work was directed and co-ordinated by the senior author (E. de C. C.). The final map was prepared by the junior author (R. W. F.) largely from air photographs based on the control of the military survey (1 in. to mile) of 1942, and information supplied by the Lands and Surveys Department, to which have been added details from a very large number of chain and compass traverses by students, supplemented by work with plane table and telescopic alidade. It should be noted, however, that the photographs do not cover the area east of a line from Fossil Cliff to Holmwood. Some reference to results obtained was made by Clarke (1937)* and Teichert (1939, 1941, 1947).

Unpublished official records were made available to us by the Lands and Surveys Department and the Geological Survey of Western Australia. Mr. J. Butcher, of Nangetty Station, the Mungedar Pastoral Co., and Messrs. J. J. R., and W. Holmes, of Holmwood Station, not only allowed the various parties of students free access to their properties, but also took a very keen and practical interest in the progress of the work and the welfare of the students.

It is not possible to mention by name the many students whose work has formed the basis of this contribution which has covered so many years. Thanks are due to the Senate of the University of Western Australia for the award of a Hackett Studentship to one of us (K.L.P.) which made possible her share in this work.

Work in 1939 was in part financed from the Commonwealth Research Grant to the University of Western Australia. Additional assistance from this source was received in 1949.

II.—PREVIOUS INVESTIGATIONS.

On 9th September, 1846, the Gregorys (A. C. and F. T. Gregory, 1884, p. 8) discovered two seams of coal in the bed of the Irwin River—the first record of coal in Western Australia. To quote the original words : "We therefore entered the bed of the river to examine it, and found two seams of coal—one five feet thick and the other about six feet thick—between beds of sandstone and shale. Having pitched the tent and tethered the horses, we commenced to collect specimens of the various strata, and succeeded in cutting out five or six hundredweight of coal with the tomahawk, and in a short time had the satisfaction of seeing the first fire of Western Australian coal burning cheerfully in front of the camp, this being the first discovery of coal in the western part of the Continent."

Next year, or early in 1848, Ferdinand von Sommer was appointed to "investigate and report on certain coal deposits in the colony." He stated that he had traced the Irwin River Coalfield from the heads of the Irwin River to those of the Moore, a distance of about 160 miles, and he described the coal

* In this publication, reference was made to a manuscript by K. L. Prendergast and N. Luck, which was never published, but served as the starting point for the present paper.

seams as dipping to the N.N.W. "under an angle of 72°." As those in the North and South Branches of the Irwin have a dip of 10° to the east, they cannot be identical with von Sommer's seams. He may, however, have found outcrops, now perhaps obscured, near the main fault in Carynginia Gully where north-west dips of 70° are recorded in Coal Measure facies.

From then onwards, many reports, most of them short and on special features, have appeared. Reference to some of these will be made later, but no summary would be adequate without mention of the following :—

A preliminary sketch-map of the area was made by Maitland in 1903 and his first impression of the structure was published. At the same time he noted Etheridge's report on the "Carboniferous" *Dielasma-Aviculopecten* fauna from one mile east of Mingenew, discovered by Simpson (Maitland, 1904).

C. F. V. Jackson made an examination of the district in August, 1904. No record of his work can be found, but he collected the first specimens of the cephalopod *Metalegoceras jacksoni*, originally described as a *Gastrioceras*, from a spot about 24 chains east of Mesa No. 3. R. Etheridge (1907, p. 26) expressed the opinion that the facies of the fossils collected by Jackson "is eminently that of the Carboniferous as distinguished from the higher Permo-Carboniferous."

The geologist who first mapped the whole Irwin River district was W. D. Campbell, of the State Geological Survey (1910). He considered that the sandstones, limestones and shales which Nicolay (1886) had noted underlying the coal seams on the east side of the broad valley of the Irwin River, outcrop also on the other side of the valley, are about the middle of the series, are underlain by tillitos, and that the whole series is folded into a broad anticline whose axis runs west of north.

The presence of boulder beds here had already been noticed by Maitland in 1897, but at first he was not positive that they were glacial ; true tillites were confirmed in the Gascoyne area to the north in 1900 and Campbell found abundant striated boulders in the Irwin area in 1908 (Maitland, 1912).

Campbell's was a very notable contribution to the knowledge of Australian geology. Although he was required to report on about 2,000 square miles of country which is even now difficult to examine geologically and was very much more so under the conditions thirty years ago, yet his general conclusions regarding the stratigraphy are still accepted, and our admiration and envy are roused by his acute observations and thorough collecting in the 75 square miles with which we are concerned and in which he could only have spent a small fraction of the time represented by the united efforts of our parties.

In 1924, Woolnough and Somerville carried out a rapid, though more detailed survey of the northern part of the Irwin Basin, dividing the sequence into a number of individual formations, most of which we have been able to recognise. They also identified the essentially block-faulted nature of the regional structure, but, encouraged by a new discovery of "*Gastrioceras*" beds on the west side of the basin, followed Campbell in interpreting the main structure of the basin as anticlinal.

The area has been referred to since then in numerous publications, most of which have dealt with brief reconnaissances, aspects of the palaeontology (*see* below, under "Permian Succession"), or with problems of regional correlation (which will also be referred to under the appropriate headings).

III.—TOPOGRAPHY.

1. General Description of Area.

The average annual rainfall of the district is about 15 inches, and practically all the rain falls in winter. The natural vegetation was probably a moderately dense growth of "jam" (*Acacia acuminata*), "reminder" (*Hakea recurva*), on the higher ground and river terraces, "sheoak" (*Casuarina glauca*) and "river gums" (*Eucalyptus rostrata*) in the watercourses. Clearing and over-stocking have led to the destruction of most of the larger plants with resultant rapid soil erosion. During the winter and spring, however, the country is covered with a luxuriant growth of annuals, some native and some introduced, and is acknowledged to be some of the best pastoral country in the State, stock thriving on the dry herbage, seeds and shrubs during the dry season if a sufficiency of water is available. The chief source of water supply is from excavated earthen tanks ("dams"), springs being of very minor importance. Bores for water have only been successful near the extreme margins of the basin, that is in aquifers lying above the saline formations.

The area with which this paper deals is really the middle portion of the valley of the Irwin River. The Irwin has a total length of about 60 miles and rises on the Great Plateau of Western Australia at a height of about 1,000 feet above sea level. Its upper part, known as the North Irwin, flows, in general, south-west for about 35 miles, and passes, without deviation, over the junction between the Pre-Cambrian and the Permian rocks. The upper part of the course of the North Irwin in the Permian rocks is in a fairly narrow gorge, bounded by cliffs about 100 feet high (*see* text figs. 11 and 12). The gorge ends where the river is met by a large tributary (the South Irwin) which comes in from the south-east. Below this junction, which will be referred to as "the Junction" in this paper, the cliffs which bound the gorge recede from the river, which now flows in a series of meanders through a valley eight or more miles wide, bounded everywhere by low cliffs, or breakaways (*see* text figs. 2, 3 and 4), which are continuous with the more imposing cliffs of the upper gorge.

South of the area with which we are concerned, the Irwin, without deviating from its general trend, is joined by an almost equally long river—the Lockier. A short distance below the junction the river turns and flows west for about 20 miles to enter the sea at Dongara. Jutson (1934, pp. 179–80) comments on the unsolved physiographic problems presented by the Irwin River.

The area over which we worked—too restricted to render possible any general explanation for the features described above—consists of the broad shallow valley of the Irwin and of the tableland in which this valley lies.

The brief physiographic notes which follow may be arranged under the headings: Watercourses, Springs, Lowlands, Plateaux, and Hills.

2. Watercourses.

The Irwin River resembles most of the rivers of Western Australia in that it, and its tributaries, are intermittent, flowing only for a short time after heavy rains, when it carries relatively large amounts of silt and sand towards the sea (Carroll and Clarke, 1941, p. 174).

The principal tributary of the North Irwin is known as Caryngimia Creek, and a small one passing near Bigarra (" Dog Hole ") Spring is named after that spring. In the South Irwin there are only very small tributaries, of which we have named for convenience: Research Creek, Monday Creek, Trio Creek. Below the Irwin Junction, only the largest tributaries have been named: Eagle Creek, Gnoolowa Creek, Cat Creek, Mullewa Creek (with Tillite Creek joining it), Beckett's Creek and Nangetty Creek. Being dry for so much of the year, many of these watercourses are often more appropriately referred to as "gullies."

3. Springs.

The perennial springs, which occur at different geological horizons, are inconspicuous though some are of practical importance. They are of three types:—

(a) Those in the Permian, from various horizons, particularly in the Coal Measures and at the base of the Fossil Cliff Formation (*e.g.*, Warraga Spring, at Fossil Cliff). These are almost all saline and gypseous, being generally quite unfit for stock or human consumption.

(b) Those issuing from the base of the plateau beds, occurring at various points along the breakaways which border the Irwin River valley. The " Dog Hole " (Bigarra Spring) in the North Irwin is an example of this second type; another and larger one lies a mile WNW of Nangetty Homestead and several smaller springs occur along the sides of Mesas 3 and 4. It was near such a spring north of Coal Seam Homestead that we found some native land snails, corresponding closely to *Sinumelon vagente* Iredale. Near other soaks beneath the breakaways is sometimes found a small variety of *Bothriembryon.*

(c) A third type, issuing, it has been suggested, along a fault (Woolnough and Somerville, 1924, p.105), lies almost outside the area dealt with in this paper, but is mentioned briefly in our discussion on Structure (Section V.).

Text fig. 2—Looking from Fossil Ridge past the south end of Bluff Mesa over the Lowlands of the Irwin River Basin. Boulders of Fossil Cliff Limestone in foreground, with Upper Holmwood Shales beyond. Note flat-topped mesa of post-Permian "plateau sandstones" resting on the epi-Permian duricrust (black band about 20 feet below the top). (Photo: R. T. Prider.)

4. Lowlands.

In a distant view of the low-lying country all surface irregularities, and even streams and badlands seem to mingle into a wide area of uniform level, with only occasional residual mesas and buttes breaking the general flatness (*see* text fig. 2). Plate I (folding map) shows that the lowlands are composed mainly of shales with minor developments of limestone. Destruction of natural vegetation by settlers has exposed the shales to rainwash which has converted them into miniature badlands, and we have to thank the smallness of the rainfall for the preservation, even for this short time, of these small-scale models of physiographic features. The limestone bands, where persistent enough, form low ridges, asymmetric in cross section, which strike in a general north-westerly direction. The gentle dip-slopes of these ridges are characteristically dimpled with shallow depressions (known locally as melon or crab-holes) from six inches to a foot deep, and as much as 10 feet in diameter.

Text fig. 3—Eagle Hill, north of the Coal Seam Homestead. A typical small mesa capped by duricrust, blocks of which may be seen in various stages of undermining along the "breakaways." Photo taken in summer, showing only bare shrubs and small trees; in winter the ground is covered with abundant herbage. (Photo: R. T. Prider.)

5. Plateaux.

The low cliffs marking the edge of the plateau which has been incised by the Irwin River, owe their existence to a hard cap on the Permian rocks, rarely more than 12 feet thick, which is traversed by vertical joints (*see* text figs. 2, 3 and 4). This hard cap of duricrust (Woolnough, 1927) is very resistant to weathering, and undercutting and breaking away of large blocks often results (*see* text fig. 4). The name " breakaway " is thus quite appropriately applied in Western Australia to such cliffs, which occur in many regions and in varied geological formations.

The plateau behind the breakaways is covered with sand which supports a fairly dense growth of shrubs and small trees. In front of the breakaways are talus slopes formed by disintegration of the detached blocks, but in many places the soft shales and sandy shales underlying the duricrust are exposed and are cut into miniature badlands which extend down to the " lowlands."

Text fig. 4—Typical "breakaway" of the Irwin Basin. Soft strata beneath the duricrust are progressively undercut by weathering till large blocks fall away, as shown in the photo.
(Photo: R. T. Prider.)

In some localities the water, seeping out from below the duricrust along an underlying, gently dipping bed of shale has caused blocks of the duricrust to slip; a large slip thus formed lies on the west side of the valley near Nangetty Homestead. Others occur around Mesas Nos. 2 and 4 and around Bluff Mesa.

In many parts of the Irwin River district the duricrust is siliceous and has a structure which simulates horizontal bedding. Woolnough and Somerville considered the nature of the hard cap (1924, p. 99) to be similar to that of the Darling Plateau laterites, and to be caused by deep weathering followed by concentration of hydrated silica near the surface of "an almost perfect peneplain"; over the shale the cap is porcellanous, over sandstone it is almost a quartzite.

Overlying this epi-Permian duricrust, one may often observe a formation of ferruginous conglomerates, gravels, sandstones and silts. We cannot agree with Woolnough and Somerville that these "Plateau Beds" are purely residuals. They do not vary directly with the underlying Permian lithology; on the contrary, the "boulders" in the basal conglomerate are mainly extremely well-rounded pebbles of quartzite and other Pre-Cambrian rocks. Campbell (1910) regarded these beds as continuous and contemporaneous with the Jurassic rocks known to the west; Woolnough and Somerville rejected this correlation and regard them as Tertiary. While we agree with Campbell that the "Plateau Beds" represent an ordinary unconformable sequence resting on the Permian, we cannot at present suggest any precise age determination. In different places they appear to range through from Jurassic to Tertiary.

An interesting second duricrust is often found capping the ferruginous sandstones of the Plateau Beds; it generally takes the form of a thin pisolitic laterite. The two indurated layers are well exposed, one over the other, in the cliffs $\frac{1}{2}$-mile south of the junction of the North and South Irwin, where there are only six to 10 feet of the Plateau Beds. Up to 50 feet of them are to be seen overlying the epi-Permian crust elsewhere, for example, on Mesa No. 4.

6. Hills.

Island-like remnants of the plateau (*see* text fig. 3) rise from the lowlands and owe their form to the protective duricrust. Most of them are of the mesa type, though it is to be noted that their tops are not everywhere strictly horizontal. A careful comparison of the spot heights around the plateau margins suggests that there is a very gentle undulation in the epi-Permian peneplain (of Woolnough and Somerville, 1924, p. 99), and that the depressions in the latter correspond closely with the general course of the present drainage pattern. Numerous examples of buttes occur—Bugallie Hill, Gnoolowa Hill, Prider's Lookout, etc.

As mentioned previously, the limestone lenses have not weathered so easily as the shales and they have formed low cuestas running parallel to the general strike. These are particularly noticeable in the eastern part of the area just to the west of the elongated Bluff Mesa. In the western part the flatness of the lowlands is varied by the hummocky ground occupied by the glacial tillite, through which Mullewa Creek and its branches have cut.

The central, most resistant part of the Nangetty Glacial country, the Nangetty Hills, stands as a series of flat-topped hills, which are 100-200 feet above the surrounding country, being capped by resistant bands of "Fontainebleau" sandstone and residual boulders of the tillite.

IV.—PERMIAN SUCCESSION.

The succession of rocks exposed in the northern part of the Irwin Basin is as follows:—

7. *Wagina Sandstone:* Mottled red and white sandstones, with intercalations of conglomerate, quartz grit and shale; the shale contains plants but the rest is unfossiliferous. Thickness: 300 feet (plus)
6. *Carynginia Shale:* Rhythmically banded jarositic shales, passing up into fine banded sandy silts; locally with fossiliferous marine lenses and conglomeratic lenses and packets of erratics near the base. Thickness: 800 feet
5. *Irwin River Coal Measures:* Sandstones and shales with lenticular coal seams and plant fossils. Thickness: 160 feet
4. *High Cliff Sandstone:* White and red sandstones and conglomerates. Thickness: 110 feet
3. *Fossil Cliff Formation:* Sandy siltstones, shales and mudstones, with lenticles of limestones. Rich in marine fossils. Thickness: 180 feet
2. *Holmwood Shale:* Rhythmically banded shales and mudstones, with ferruginous and calcareous concretions (some septarian nodules), and increasing amounts of jarosite and gypsum towards the top. Infrequent thin bands of limestone and calcareous mudstone containing marine fossils, otherwise generally unfossiliferous except near the top. Thickness: 1,650 feet
1. *Nangetty Glacial Formation:* Tillites, glacial shales, fluvioglacial sandstones, locally with calcareous grits and sandstones showing "Fontainebleau" structure, underlain by further glacial shales and basal conglomeratic grits. Thickness: 800 feet estimated

Total thickness: 4,000 feet

The entire sequence may be followed without any clear indications of an unconformity, but is sharply separated from the Pre-Cambrian below and the " Plateau Beds " above by angular unconformities.

1. Nangetty Glacial Formation.

This name is proposed for beds which form a group of low hills, the Nangetty Hills, beginning N.N.W. of Nangetty Woolshed (lat. 28° 58½′ S., long. 115° 26′ E.) and extending thence S.S.E. beyond the limits of our map towards the Brockman Hills and beyond. The hills are entirely covered with residual boulders, likened by one observer to a gigantic moraine. Infrequent outcrops disclose tillites, glacial shales and fluvio-glacial sandstones.

The Nangetty Glacials disappear to the N.N.W. beneath the sand plain, but occurrences of tillitic boulders, in small outcrops or bores (*e.g.*, in Kockatea Gully, Balla, Dartmoor, etc.), here and there along this trend seem to confirm Maitland's correlation of these rocks with the Lyons conglomerate on the Gascoyne and elsewhere in the North-West Basin (1912).

A precise definition of the formation is difficult to give at present, since the basement is not well known. Woolnough and Somerville (1924, p. 77) believed that there are " Basal Grits and Boulder Beds " (resting on Pre-Cambrian in the Yandanooka-Arrino area), followed by " Sub-Glacial Beds," an unknown thickness of shales underlying the " Main Glacials."

The upper limit of the Nangetty Formation is marked by a transition from the glacial shales (with angular fragments and occasional boulders), into the dark grey shales of the Holmwood Formation.

Since the base of the glacial beds is not exposed in our area, or encountered in bores, it has been impossible as yet to measure the maximum thickness developed. Campbell (1910, p. 39) estimated that not less than 430 feet outcrop in the Irwin Basin. David and Sussmilch (1931, 1936) estimated that tho main tillito beds were about 200 feet in thickness, the underlying shales 450 feet, and the basal glacial beds (fluvio-glacial) 150 feet. Teichert (1941) gave the thickness of glacials as 200 feet.

On the present survey it was confirmed that approximately 200 feet of tillites and fluvio-glacial beds occur at the top of the formation, and these are underlain by shales with small argillaceous limestone lenticles, while the basal conglomerates are beyond the limits of our area. Since the general character of these beds is essentially glacial, and no sharp divisions have presented themselves, it seems best to classify the whole sequence under the Nangetty Glacial Formation, taking the thickness as 800 feet.

The lowest glacial shales, which form the core of the structure depicted on our map, outcrop in a broad wedge south of Mungaterra Homestead. Since the shales contain lenticular bands of argillaceous limestone, they are in this aspect similar to the Holmwood Shales which overlie the Nangetty Formation, but differ from them in containing in places coarse, angular and fresh mineral fragments in a " rock flour " matrix. These are well exposed in several places in the bed of the Irwin from Mungaterra Homestead for some two miles downstream. When fresh they are quite hard and poorly stratified but weather readily, often in a spheroidal manner. A bore at the homestead penetrated 50 feet of these shales. At a point 600 yards south of Mungaterra they may be observed to be intersected by a number of sedimentary dykes filled with the argillaceous limestone commonly found in concretions ; the limestone dykes are affected by cone-in-cone structures from either side, and apparently follow minor faults which have been identified on the air photographs.

The shales are succeeded by tillites and fluvio-glacial beds, which outcrop mainly in the Nangetty Hills between Mungaterra and Nangetty. Woolnough and Somerville (1924, p. 81) describe the glacial beds *in situ* south-east of Nangetty Woolshed as: "bedded tillites of sandy nature, strongly cemented by carbonate of lime containing many erratics. Large and small lenticles of tillite are interbedded in the main mass of boulder clay." The boulder-bearing glacial beds are in places completely unstratified and may thus be terrestrial, but the evidence of banding in other sections indicates some degree of water-sorting. No varve shales were encountered.

Text fig. 5—Glacially striated surface of a large Pre-cambrian boulder, embedded in the top of the fluvioglacial sandstones of Tillite Creek, 50 yards east of the large silicified limestone erratic. The direction of the striations would indicate a northerly ice-movement if the boulder still occupies its original position. (Photo: R.W.F.)

In a small valley, one of the tributaries on the west of Mullewa Creek, named by us "Tillite Creek," the following section may be recognised in spite of some complication by faulting: hard tillite at the base followed by 20 feet of soft fluvio-glacial sandstones, capped by three feet of hard Fontainebleau sandstone, in which is cemented a large erratic boulder, and overlain in turn by a soft unstratified tillite. The large erratic is evenly striated over the whole of its upper surface (*see* text fig. 5) and may possibly have been already cemented *in situ* in the hard sandstone when a second glacial advance took place, over-riding and crumpling the fluvio-glacials and depositing the second tillites on top. The fluvio-glacial sandstones exhibit also subaqueous slump structures and cross bedding, which suggests current movements in a north-easterly direction. Some 20 feet of the second tillites reappear immediately to the east, in a down-faulted section (*see* text fig. 6). Down-stream and farther east, beyond another fault, there are stratified shales with small septarian nodules, of cannon-ball type, which may be mistaken at first sight for erratics. These shales are not glacial in character, and are thus taken to be near the base of the Holmwood Formation. Contact with the rest of the Holmwood Formation to the east is once again obscured by faulting.

Text fig. 6.—Characteristic exposure of unstratified tillite in situ in the bank of Tillite Creek. Boulders include true facetted boulders (of various Pre-cambrian rocks), as seen on the right, as well as water-rounded boulders of an earlier hardened tillite, seen on left. This older, more hardened tillite is exposed deeper in the section.

(Photo: R.W.F.)

Comprehensive surveys have not yet been carried out in these glacial beds and further work may disclose better sections.

The Nangetty Hills are plentifully strewn with boulders, and in some places where the streams are deeply incised the steep bank is seen to be composed of such boulders, fairly closely packed. The abundance of boulders on the hills and along the water-courses is partly due to concentration by removal of the smaller fragments by rain and wind, and is not an original feature of the tillite. The little cliffs of boulder material are due to excavation by streams of the alluvium which they themselves accumulated when the run off was restrained by vegetation, and consequently, deposition rather than transport was their major activity. We have not seen places where " there is a very strong suggestion that small erratics have been dumped in heaps by the capsizing . . . . . . of small rock laden floes " (Woolnough and Somerville, 1924, p. 81), and therefore agree with the alternative suggestion (*op. cit.* p. 82) that " the apparent grouping is everywhere a secondary feature."

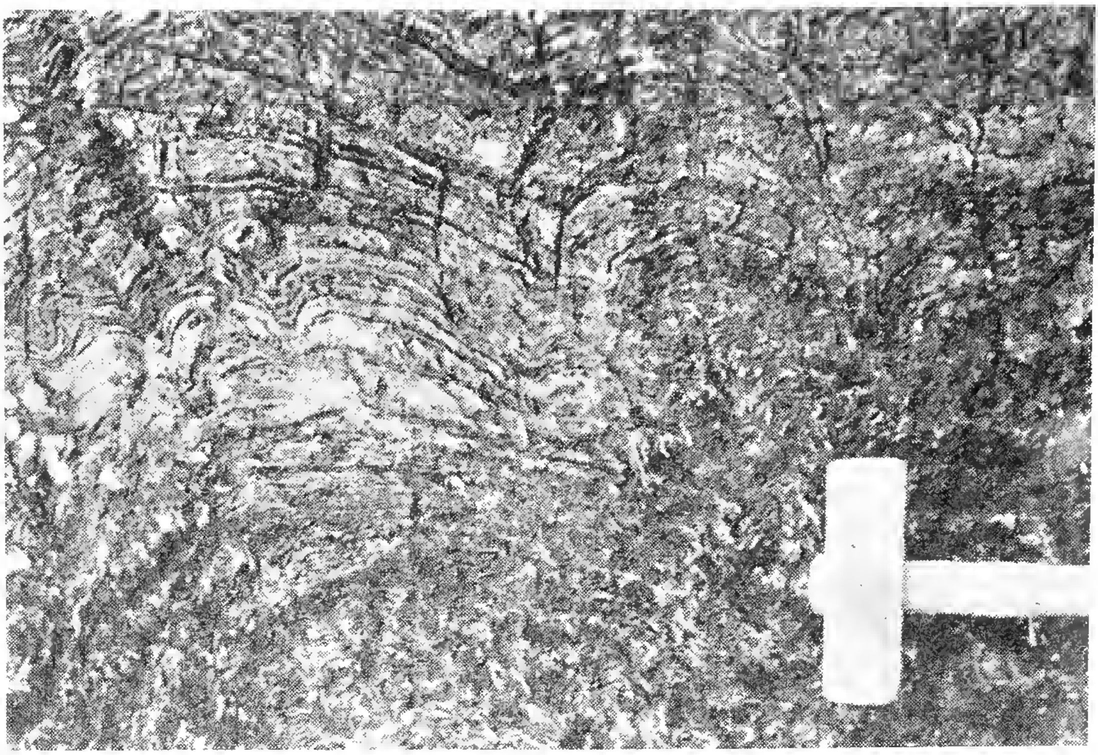
The boulders include many rock types (almost all Pre-Cambrian). Only two or three have been microscopically examined, but the following list of field determinations gives some idea of their variety (the types are placed more or less in order of frequency) : reddish or blackish hard fine-grained mudstone, granite (four varieties), epidiorite (three varieties), chert, gneiss, pegmatite, quartz with epidote, mica schist (some much contorted), banded and brecciated quartzites, " contorted " silicified limestone, quartz schist, sheared conglomerate, quartz felspar porphyry, agglomeratic tuff.

Text fig. 7—The "White Horse" Erratic, situated one mile south-east of Mungaterra Homestead. It is a block 20 x 9 x 9 feet of faintly banded quartzite, which in places is brecciated, and may be partly a replacement product. It is believed to be of Pre-cambrian origin, for similar rocks of this character have recently been traced through the Yandanooka Group between Yandanooka, Coorow and Moora.

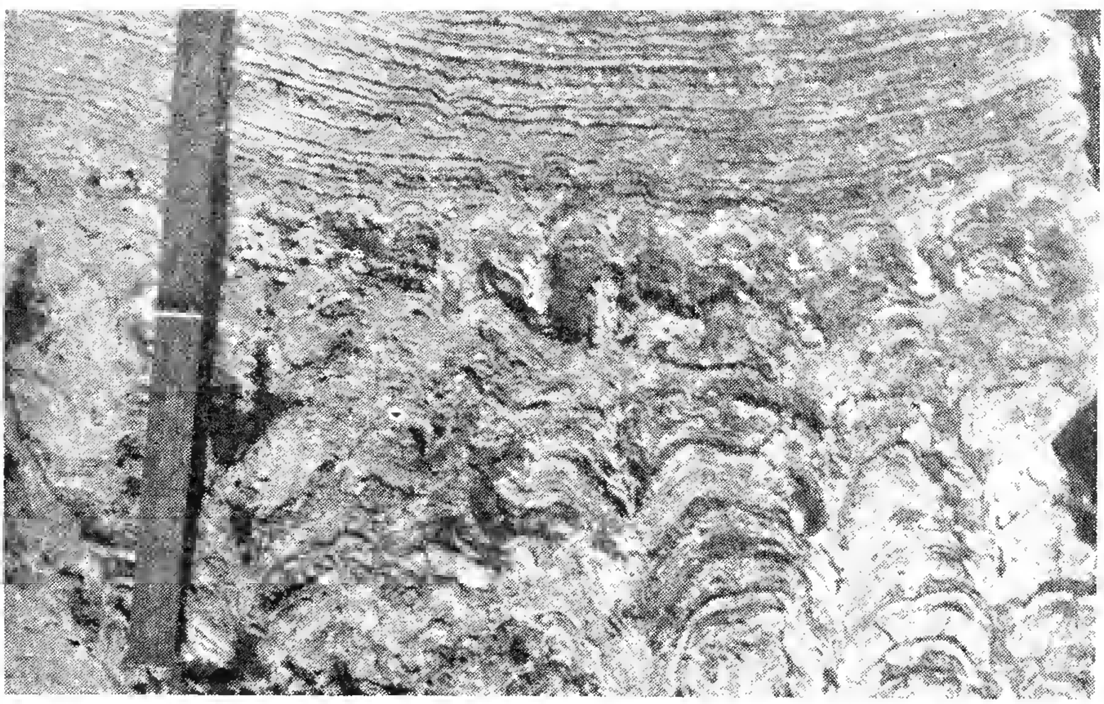
(Photo: R.W.F.)

Most of the boulders are rounded, but a few of the smaller ones show faceting and soleing, and some of the finer-grained varieties—particularly the mudstones—show characteristic striae. Nearly all the boulders are less than a foot across, but a few of gneiss and granite are as much as four feet in diameter, and a very few attain dimensions exceeding 10 feet in length. These last are always of the quartzite or silicified limestone mentioned above, the "White Horse" type (*see* text fig. 7), the original of which measures 20 x 9 x 9 feet. The rock composing these great boulders is sometimes referred to as a "cherty quartzite," and there appears to be a number of varieties of it grading into the banded and brecciated quartzites. These rocks, generally known as the "White Horse" type, after a prominent example of the partly brecciated massive quartzite, have long been the subject of discussion. Recently, the counterparts *in situ* were identified in the Pre-Cambrian Yandanooka Group, to the south, at several points between Yandanooka, Coorow and Moora. The varieties range from a scarcely banded quartzite, to a brecciated cherty quartzite, finally to the contorted silicified limestone. The brecciated rock may have been an intraformational breccia of thinly banded dolomites, or possibly cherts, in a calcareous shale, now replaced by silica, while the contorted rock is considered to be a silicified algal limestone, in which the contortions are taken to be stromatolitic algal structures, being very similar to those found in the late Pre-Cambrian in other parts of the world, and corresponding to the genus *Collenia* (*see* text figs. 8 and 9). Various stages in the replacement of the original limestone by silica have been found and examined under the microscope, but so far no cellular structure has been seen (samples 9102/3, 25133, 29956).* The best examples of this silicified algal limestone known *in situ* in the Yandanooka Group were found at milepost 157

*Numbered specimens in the collection of the Geology Dept., University of Western Australia, are thus denoted in this paper.



Text fig. 8—Detail of a large silicified limestone erratic, situated in Tillite Creek, showing the alternate bands replaced by quartz. The concentric (stromatolitic) banding corresponds closely to the type of development of some algal reefs (Collenia) known elsewhere in the Pre-cambrian rocks.
(Photo: R.W.F.)



Text fig. 9—Same type of rock, photographed in situ near Gunyidi, 75 miles to the south, in rocks of the Yandanooka Group.
(Photo: R.W.F.)

on the Geraldton road, about 70 miles to the south (R.W.F.).† A limestone boulder of the same stromatolitic algal banded type was recently found also in the Lyons Tillite (C.T.).

Occurrences of those very large boulders are, as far as we know, confined to three localities: the "White Horse," one mile S.E. of Mungaterra Homestead; Tillite Creek, where closely clustered large blocks occur, and a spot

†A paper describing the Collenia rocks and their distribution in the Yandanooka Group has been presented elsewhere (Fairbridge, 1950).

a mile farther N.N.W. A glance at the map shows that these three localities lie in almost a straight line running N.N.W. Ordinary sized boulders of this particular rock are rather common along this line, and a few were noted in other parts of the field. It was thought at one time that these giant boulders might be the traces of a buried ridge, but from the present mapping, they appear simply to be characteristic of one of the important tillite members.

The development, noted by Woolnough and Somerville, of sandstone of "Fontainebleau" type (with the cementing calcite in crystal continuity) is particularly noticeable in the beds forming the more or less flat-topped hills north-west of Mungaterra. A laboratory examination of a three foot thick band of this "Fontainebleau" sandstone (sample 25727), resting on top of the fluvio-glacial sandstones in Tillite Creek, showed that it contained 22 per cent. calcite, while the underlying sandstones showed only 0.2 per cent.; on the other hand, the insoluble minerals, mainly quartz, fresh felspars and a few heavy minerals, are almost identical in the two rocks. The grains are mainly angular, some slightly rounded, but are poorly sorted, consisting mainly of quartz grains with smaller amounts of felspars; the latter are quite fresh and clear as a rule, only a few being somewhat kaolinized. There is some alignment in the grains. These observations confirm initial interpretation of the rock as a fluvio-glacial sediment.

2. Holmwood Shale

This name is proposed after the pastoral station (lat. 29° 02′ S., long. 115° 32′ E.) where these beds outcrop, for a succession of dark grey to buff-coloured shales (with minor developments of thin limestone bands) occurring both east and west of the Nangetty glacial beds. The boundary on the west is heavily faulted; that on the east is also partially obscured by minor faulting and partly by alluvium, but there appears to be a conformable contact with the highest of the glacial shales of the Nangetty Formation. The uppermost limit of the Holmwood Shales is designated as the base of the fossiliferous limestones, siltstones, sandstones or their equivalents, of the Fossil Cliff Formation. The sharp change in lithology associated with the Fossil Cliff beds is taken as an indication of the formation boundary, not the appearance of stunted marine fossils near the top of the Holmwood Shales.

It was originally calculated that the total thickness of the Holmwood Shales, had there been no repetition by faulting, would have been 1,500 feet, according to Raggatt (1936), 2,200 feet according to David and Sussmilch (1936), and even 2,500 feet according to Teichert (1941). Recent work on the structure with the aid of air photographs, however, confirmed the existence of very considerable strike faulting (far more even than suspected by Prendergast and Luck, *see* Clarke, 1937), and the thickness is now calculated at about 1,650 feet.

Woolnough and Somerville differentiated six lithological members in this formation from top to bottom, namely, Olive Shales, *Gastrioceras* Bed, Buff Beds, Bull Paddock Limestone, Grey Limestone, and Spheroidal Marls. They note that these grade into one another, but state that the Bull Paddock Limestone constitutes a fairly persistent horizon and marks a transition in the conditions of sedimentation; below it the beds are dominantly grey; above it decidedly yellowish. They find that another change takes place immediately above the *Gastrioceras* bed, the Olive Shales being much less calcareous than the lower beds. Thus, according to these writers, the character of the sedimentation changed from dominantly calcareous in the lowest zones to calcareous and sideritic in the middle and to dominantly argillaceous in the upper zone.

The question of the subdivision of the Holmwood Shale needs further investigation. We have not been able to follow out the precise lithologic distinctions indicated by Woolnough and Somerville, but we recognise broadly an upper and lower division, with certain characteristic members :—

(a) *Lower Holmwood Shales*, outcropping immediately west of the Nangetty Glacials, around to the northern end of the Nangetty Hills and along their east flank, also in the valley of Mullewa Creek, Gnoolowa Creek, and in the lower part of Cat Creek. On the Irwin itself the exposures are generally rather poor. The thickness of the Lower Holmwood Shales is about 950 feet.

As noted above, the exact contact at the base is not seen, but in Tillite Creek, to the east of what appears to be a fault of very small throw, the soft grey tillite of the Nangetty Formation is succeeded by dark grey shales, weathering to a pale grey, of very similar external appearance to the tillite, except that the "boulders" in the shale are actually concretions, some of them septarian. The shale is greasy to the touch (even at the close of the dry season) and appears to be carbonaceous ; only locally does it contain marcasite or other ferruginous matter, in notable contrast to the Upper Shales. Laboratory examination (sample 25214 from Tillite Creek) confirmed that it was a poorly bedded clay to silty shale with occasional angular quartz and felspar grains or small pebbles. The felspars were rounded and moderately kaolinized. There was no calcium carbonate.

Another shale sample, taken near Cat Creek Dam (stratigraphically about 100 feet below the *Metalegoceras* horizon), was similar to the lower one, but very few grains were retained even by the 60 mesh Tyler sieve. Both calcium carbonate and ferruginous matter were absent. Associated with this shale were some large irregular concretions of limestone with cone-in-cone structure.

These lower shales were described by Woolnough & Somerville as highly calcareous, with a notably spheroidal weathering (their "Spheroidal Marls") ; neither of these features, however, are sufficiently continuous or widespread to be used as distinguishing characteristics. (The Upper Holmwood Shales are also calcareous in places and certain bands weather spheroidally.)

The concretions appear to be of three types :—

(i) The "Cannon-ball" type, more or less spherical, ranging from three to 12 inches in diameter, containing an angular nucleus of shale or tillitic clay. These are apparently restricted to the horizons immediately above the tillite, and probably indicate that the tillite was being slightly eroded for a short time before burial in the advancing sea. The "cannon-ball" concretions are not banded spirally or concentrically, but appear to be perfectly homogeneous except for the "exotic" angular core. The latter appears to have acted as a nucleus for the precipitation of a calcareous-clay gel.

(ii) "Bun" or "Biscuit" type, more or less flat, circular in outline, superficially wrinkled to simulate the "culinary dainties" of Woolnough & Somerville. These mostly range from one to four inches across and are uniform in texture, but apparently lack any nucleus According to these authors they are probably secondary, being possibly "due to slightly different permeability of two adjacent shale bands, the concretion lying partly in one band, partly in the other." This type appears to be commonest in the vicinity of Urella.

(iii) Large ellipsoidal concretions, from one to six feet in diameter, and flattened to about one-third of this in height. These are found in the lower shales but are more common near the top of the upper shales (*q.v.*). They are often concentrically banded, without apparent nuclei, though somotimes they show septarian cracks partly filled with crystals of calcite. They occur on the Urella Block, half a mile above Yarragadee on the Irwin, near Copley's Mill, along Mullewa Creek, and in Cat Creek.

The origin of these various concretions has boen briefly discussed by Campbell (1910, pp. 43–45) and by Woolnough & Somerville (1924, p. 85), but they clearly offer a subject for further research. The discussions in Twenhofel (1932, p. 708, etc.) present sufficient indication of some of the problems involved. An analysis by Simpson (in Campbell, *op. cit.*) shows that one example consisted of 73 per cent, $CaCO_3$, 13 per cent. silica, and 8 per cent. alumina, with a little iron, etc., so that they are strictly " cementstones " in character, having the composition approximately of Portland cement.

About 200 foet above the base of the Lower Holmwood Shales there begin to appear thin bands of grey crystalline limestone varying to olive-brown calcareous mudstone which generally weathers yellow. Generally they do not exceed one foot in thickness, but may reach five feet. Some of these are little more than large irregular concretions, but about half-a-dozen bands are very constant in their appearance at certain horizons, and some of them are almost continuous across the basin. These bands continue to the top of the lower shales. One of the lower bands, forming a prominent outcrop on the west side of Nangetty bull-paddock was called by Woolnough & Somerville the " Bull Paddock Limestone," and one near the top the " *Gastrioceras* Bed " after the goniatite (now named *Metalegoceras*).

A characteristic feature of most of these limestone bands in the Lower Shales, but apparently lacking in the Upper, is the widespread occurrence of cone-in-cone structure. Apical angles in the cones vary from 60 to 90 degrees. This structure is beautifully developed and exposed here. The general consensus of opinion nowadays indicates that cone-in-cone develops in a limestone where the calcite is fibrous, under conditions of vertical pressure assisted by slow downward solution (*see*, for example, Twenhofel, 1932, p. 732). It may be that the limestones in the Upper Shales are more sandy and do not favour this process ; or perhaps the structure is due to the increasing vertical pressure towards the base of the sequence. These cone-in-cone structures in the Irwin Basin, like the concretions, should repay further research.

About 20 feet below the highest band of cone-in-cone limestone which lies about 950 feet above the base of the formation, and which is takon, rather arbitrarily, as the top of the Lower Shales, there is a band of olive-brown calcareous mudstone containing tho large goniatite *Metalegoceras jacksoni*, partly replaced by siderite, calcite and silica. The species is of considerable size : the largest specimen on record (No. 23405)—and even this is fragmentary—measures 205 mm. in diameter (Teichert, 1942). An even larger whorl has now been found, which belonged to an individual probably 260 mm. in diameter (No. 24794). This species was earlior referred to the genus *Gastrioceras*, and a single " *Gastrioceras Bed* " was marked by Woolnough & Somerville at this horizon. Careful mapping showed that in places in the eastern part of the basin there appeared to be several parallel bands, possibly distributed over a vertical thickness of 700 feet or so. One of us (K.L.P.) expressed the opinion that these actually represented a single horizon, repeated by strike faulting, and this has subsequently been demonstrated both on the air photos and in the field (R.W.F.).

On the western side of the basin, on the other hand, we have found *Metalegoceras* along one line only. Here the outcrops extend over less than a mile at the foot of the breakaways from one mile west of Nangetty to north of Macaroni Hill (*see* text-fig. 10). No fault duplication was found here, but in any case, on this side of the basin much of the country is obscured by alluvium or the plateau deposits.

Text fig. 10—One mile north-west of Nangetty Homestead. Showing breakaways capped by "plateau beds," overlying the Upper Holmwood Shales, with a band of calcerous mudstone containing *Metalegoceras jacksoni* in the foreground, just beneath Macaroni Hill.

(Photo: R.W.F.)

We were aware of the risk of mistaking for specimens *in situ* those which have been discarded by previous parties, and we have not shown any occurrences on the map which may not be verified both by being associated with the characteristic claystone and by being on the strike of a large number of other specimens. A further confirmation is found in the fact that specimens occur along the scarps of the cuestas, half way down the scarp in each case.

This unmistakable marker band may be clearly followed across the east side of the basin in a N.W.-S.E. direction from the vicinity of the Mullewa Road, four miles north of Nangetty, almost without interruption down to Holmwood Homestead No. 1, a distance of nearly 10 miles.

Probably visiting geologists, since Woolnough & Somerville examined the field, have taken away the goniatites more quickly than they were laid bare by weathering, but even so we cannot subscribe to published statements regarding their abundance. The *Metalegoceras* specimens are indeed found lying on or, much more rarely, embedded in, a richly calcareous buff-coloured mudstone, but even given the right outcrop, a search is generally necessary before specimens can be found.

Metalegoceras jacksoni has played an interesting role in discussions on the age of the glacial beds in Western Australia, and indeed in Australia as a whole. First described as a *Gastrioceras* (Etheridge, 1907), it was for some time considered to be a representative of the Upper Carboniferous genus *Paralegoceras* (Thomas, 1929, David & Sussmilch, 1931), until its true affinities were revealed by Miller in 1932. It is closely similar to early Permian representatives of the genus in other parts of the world (Teichert, 1941, 1942*a*).

One specimen of an orthoceroid and one fragment of a crinoid stem have been found in association with *Metalegoceras*.

Apart from the limestone and calcareous claystones, the highest 100 feet perhaps of the Lower Holmwood Shales show a distinctly yellowish or buff colour in the field, a feature which led Woolnough & Somerville to name them the " Buff Beds " (*op. cit.*, p. 87). There is no doubt that siderite plays an important role in the *Metalegoceras* beds, and these authors claim that it, with calcium carbonate too, occurs in greater amounts in the " Buff Shale " beds.

* * * * *

We turn now to the description of the upper half of the Holmwood sequence :—

(b) *Upper Holmwood Shales*, exposed from one to three miles below the junction of the North and South Irwin, about Gnoolowa Hill, in Eagle Creek, in Beckett's Gully and north-west of Bluff Mesa : light to dark grey shale and mudstone (Woolnough's " Olive Shales "), weathering to characteristic bands of olive-brown and grey soils. The shales are rythmically banded with layers of gypsum and reddish-brown ferruginous matter, which appears to be weathered marcasite. Large plates of selenite up to an inch thick and two feet across are secondarily deposited in joint planes. They are well seen one mile below the Irwin Junction.

The Upper Shales are, like the Lower, complicated structurally by faulting, but, according to the present measurements, reach 700 feet in thickness. Only two shallow bores have been put down in the eastern part of the Holmwood Shale area; these are Prest's No. 5 (176 feet) and No. 6 (24 feet), situated on the south side of the Irwin, half a mile and one mile respectively, south-west of the junction. As may be seen from the logs (*see* Appendix) they were not nearly deep enough to test the sequence of the Holmwood Shales.

On the extreme western side of the basin, very little reconnaissance has been carried out, but it may be surmised that the Upper Shales are represented beneath the breakaways and plateau beds west of Nangetty and west of Urella, since the *Metalegoceras* horizon (one mile west of Nangetty) represents the top of the Lower Shales. A series of bores was put down here near the edge of the plateau by the W.A. Boring Co. (Mr. Odgaard) in 1934, some details of which are :—

No. 1 (one and a half miles W. of Nangetty Homestead) passed through 13 feet of sand, (" Plateau Beds ") seven feet of duricrust, and then through sandy shales till reaching the " blue shale " (Holmwood Shale) just above bottom at 74 feet.

No. 2 (one and a half miles WNW of Nangetty) passed through 16 feet of plateau beds, reached the base of the kaolinized (epi-Permian) crust at 33 feet, and then passed a similar sequence of grey and yellow sandy shales to the blue shale at 64 feet, being abandoned at 83 feet.

No. 3 (one and three-quarter miles NW of Nangetty) passed through the base of the duricrust at 38 feet, and reached the blue shale shortly before 61 feet). All three bores brought in very small supplies of good water, just above the blue shale.

Finally, No. 4 (four and a quarter miles due N of Nangetty) was rather different, since after leaving the duricrust at 16 feet, it entered yellow and white sandstones and shales down to 38 feet (carrying water) before entering a grey shale which was penetrated to 45 feet ; this hole lies near the strike of the Nangetty Glacial Beds, but until more is known of this part of the area, it would be difficult to correlate these sandstones.

A series of bores has also been put down in the plateau lying to tho north of the Irwin Basin on tho Woongoondy and Mendel Estates (off the limit of our map), by the Public Works Department. While the bores, nine in number, are well-scattered, they appear to lie more or less along the strike of the Holmwood Shales, though some may penotrate the higher Permian formations. Almost without exception, they cut between 50 and 150 feet of red and white sandstones before entering alternating dark shales and mudstones. None of the bores exceeded 300 feet in depth.

To the south, between Yarragadee and Mingenew, numerous bores were put down by the Army about 1943–44. Of these, only one, A45, three and a quarter miles S by E from Yarragadee, seems to have penetrated the Holmwood Shales ; the log shows " blue shales " from 170-375 feet, but no water. The rest are either too shallow or lie farther west, and may be involvod in a down-faulted block (*see* also under " Structure").

Near the top of the shales on the east side of the basin, alternating bands and small nodular concretions of pale yellow jarosite ($K_2\ Fe_6\ (OH)_{12}\ (SO_4)_4$) occur, and this may be redeposited as a yellow powder over some of the gully slopes. A third sulphate, alunite ($K_2\ Al_6\ (OH)_{12}\ (SO_4)_4$) is found associated with gypsum in concretions, *e.g.*, near the Coal Seam Homestead*. The shales appear to become more and more micaceous towards the top.

A laboratory examination of the shale (Sample 25728) collected three-quarters of a mile west of Toothagunna (" Nannygoat ") Swamp, stratigraphically about 25 feet below tho lower of two prominent limestone bands there, showed fine clay minerals forming the bulk of the specimen, much in the form of small clay pellets, some 15 per cent. as gypsum crystals, negligible $CaCO_3$, and perhaps one per cont. carbonaceous matter. The sparce insoluble minerals included quartz, magnetite, ilmenite, limonite, loucoxene, brookite and kyanite (in 120 and 250 mesh Tyler sieve grades). A second sample (No. 25628), taken about 100 feet stratigraphically above the other, from about half a mile south-west of Toothagunna, was rather similar, containing 80 per cont. fine clay minerals, but no gypsum. The balance consisted of 19 per cent. very small angular grains of quartz and fresh felspar, with a few tourmaline and muscovite grains. $CaCO_3$ was about one per cent., and there was a trace of carbonaceous matter.

Rather large concretions of argillaceous limestone, associated with gypsum and alunite, are intercalated here and there at certain horizons in the shale. These are well-exposed in the gullies south of the river, one mile below Irwin Junction ; near the small butte, half a mile south-west of Toothagunna swamp ; and in Beckett's Gully, 200 yards above the road crossing. They

* Both the alunite and jarosite here are secondary minerals, resulting from the breakdown of pyrite or marcasite nodules under neutral or acid conditions (Simpson, 1948).

are ovoid, ranging from one to six feet in diameter and are flattened to not more than 18 inches in height. The outermost layers are more clayey and weather spheroidally. The centres are extremely hard, but are not septarian as a rule, and no nuclei were found. The top is often puckered and ridged in the manner illustrated by Campbell (1910, fig 21). They appear to be chemical and syngenetic in character, *i.e.*, not due to contemporary rolling on the sea-floor, but to precipitation from an originally supersaturated solution of calcium carbonate and colloidal clay minerals, but, as noted earlier, there is clearly a need for further research on this interesting subject. Some small calcareous mudstone pebbles were found in Beckett's Gully (below the road crossing) with what appear to be sun-cracks on the surface (Sample 24636).

There are also five or six horizons of limestone, generally about one foot in thickness, varying from a grey crystalline limestone to a buff-coloured sandy limestone. These are more or less continuous though some long gaps may indicate that they are lenticular ; on the other hand, the broad alluvial fans, obscuring the outcrops, may explain some of these gaps.

Fossils are not common in these Upper Holmwood Shales, being mainly restricted to small pockets in some of the limestone bands, particularly the more sandy facies, and to thin bands in the shaley mudstones towards the top of the section. The fossiliferous limestone concretions were found in 1939 in Beckett's Gully, and on the 1949 excursion fossiliferous mudstones were discovered in a single band in the gullies south of the Irwin River, one mile below the Junction (Sample 25631). On the same trip fossils were found in the limestone bands 600 yards east of Eagle Creek and 1,100 yards west of Toothagunna (" Nannygoat ") Swamp ; and again, in the creek just west of the track 1,000 yards north of that swamp. These fossils are all rare and dwarfed, and include *Chonetes pratti*, *Chonetes* sp. nov., *Linoproductus foordi*, *Linoproductus* sp., *Conularia*, *Bellerophon*, *Soleniscus*, a small pelecypod, a nautiloid, and markings which appear to be coprolitic (Samples 25726, 29961).

The stratigraphic position of these fossiliferous limestone and shale horizons may extend as much as 500 feet below the base of the Fossil Cliff beds, but the possibility remains that unseen strike faulting has caused us to exaggerate the thickness. (This part of the section is not covered by air photographs, and in any case is not well exposed.)

Another very important fossil band was found on the 1949 excursion at about 550 feet below the Fossil Cliff Formation and 150 feet above the band of *Metalegoceras jacksoni*. So far it has only been found in the paddock, 200 yards west of the Nangetty/Holmwood boundary fence, almost exactly one mile north-west of Prider's Lookout (Sample 25632). It contains two new goniatites, which are as small (10-15 mm.) as *Metalegoceras jacksoni* is large, together with a nautiloid, *Chonetes pratti*, certain pelecypods, gastropods, and *Conularia*.

On the west side of the basin, the lenticular limestones have also been found, but only in one locality—one of the foothills lying against the western breakaways about one mile north-west of Nangetty Homestead—have fossils been found in any abundance. The hill is marked by a band of dense limestone through which ramify calcareous tubes filled with yellow material. Although the tubes twist about they do not appear to branch. They are evidently serpulids. The late E. Eckermann, formerly manager of Nangetty Station, who discovered this and many other geologically interesting features of the Irwin River district, named this limestone hillock Macaroni Hill, for obvious reasons, and it is given this name on our map.

This serpulid reef appears to lie somewhat higher stratigraphically than the *Metalegoceras* horizon and thus occupies a position near the base of the Upper Holmwood Shales. It contains a rather peculiar pelecypod and gastropod fauna, on which very little work appears to have been done to date (Samples 9101 and 16419). This fauna is quite different from that of the Fossil Cliff Formation. Brachiopoda are absent, and the most abundant fossils are nuculid pelecypods and a species of *Conocardium*. Foraminifera, as yet unidentified, are also present. The reef is restricted in this locality to the single little hill, outcropping over about 50 feet along the strike and up to three feet in thickness. Immediately underlying the reef facies is a blue gypseous shale with *Fenestella* sp.

A second lens of an identical serpulid reef limestone was found in 1949 by Mr. L. de la Hunty of the Geological Survey of Western Australia (personal communication) in the south-eastern part of the basin, four and a half miles south-east of Mt. Budd (12 miles east of Mingenew). Further surveys here have (R.W.F.) proved the extension of these lenticular outcrops over four miles along the strike; they contain, besides serpulids, goniatites, orthoceratids, brachiopods, pelecypods, gastropods, crinoids and *Conularia*. This additional fauna suggests a correlation of the Macaroni Hill member with the goniatite limestone which lies one mile north-west of Prider's Lookout.

The lower limit of the Upper Holmwood Shales may be conveniently taken at the limestone horizon which lies 20 feet above the *Metalegoceras jacksoni* band. Woolnough and Somerville (1924, p. 88) indicated that this was a very abrupt break, but it hardly seems as sharp as they suggested. Admittedly the gypseous character of the shales becomes rather suddenly important but no sudden change in the calcareous constituents was noticed. Allowing for "rolls, folds and faults" in these upper beds, Woolnough and Somerville reckoned that they probably reached 1,100 feet in thickness, and after further mapping and the precise delineation of many of these structural disturbances, we are able to give the thickness as 700 feet, but again, there remains a possibility that there are still unrecognised structural complications.

The country composed of the shales is generally flat, but is broken to the east of the glacial beds by low cuestas around Bluff Mesa. The hard limestone bands influence the development of these cuestas and seem also to control the gentle undulations in the less deeply weathered country to the north-west of Bluff Mesa ("Charlie's Hill").

The gypseous shales weather very easily to a fine powder and solution has developed "melon" holes in the flat country, *e.g.*, north of Cat Creek, and an underground drainage with sink holes and miniature canyons around the foot of the breakaways, and near the edges of the gullies, producing a well-developed bad-land topography.

3. Fossil Cliff Formation.

The gypseous shales of the Holmwood Formation are conformably overlain by dark, poorly fossiliferous, carbonaceous shales, mudstones, and brown and white sandy siltstones, which contain lenticular occurrences of richly fossiliferous limestone. The shales and siltstones often contain appreciable amounts of gypsum, jarosite, and marcasite, which suggests a continuance of special conditions of sedimentation (*see* discussion under "Geological History"). Thus, in sections where the limestone facies is absent, it has often proved difficult to distinguish the base of the Fossil Cliff shales from the very similar beds of the Upper Holmwood Formation. The gypsum and other soluble salts probably account for the presence of highly saline springs at approximately the base of the formation on the North Irwin (Warraga Spring), at the foot of the breakaway three-quarter mile north of Coal Seam Homestead, in Beckett's Gully, etc. This formation was named already by Woolnough & Somerville (1924, p. 91), the "Fossil Cliff Beds" after the occurrence at Fossil Cliff (lat. 28° 56½'S., long. 115° 32½'E.). It is succeeded conformably by the white and red sandstones and conglomerates of the High Cliff Formation.

The formation is most easily distinguished in places where the limestone facies occurs. Thus, in Beckett's Gully, gypseous shale of the Holmwood Formation is overlain by two feet of richly fossiliferous, yellow sandy marl, succeeded by a six inch band of hard crinoidal and brachiopod limestone, passing up into a sandy limestone, sandy shales and brown siltstone, which forms the gentle escarpment of Fossil Ridge and which outcrops nearby in the south branch of Beckett's Gully below Round Hill. Fossils are difficult to collect in the hard grey limestone, but are readily found where weathered out from the underlying yellow sandy marls, where dozens of corals, crinoid stems, etc., may be collected in a few minutes.

Text fig. 11—Fossil Cliff on the North Irwin, looking north-west. Shows alternating bands of fossiliferous limestones and gypseous shales. Note landslips in the latter. This is one of the best known and most oft-visited fossil localities in Western Australia.

(Photo: A. J. Glance.)

The type section is on the North Irwin at the locality called Fossil Cliff (*see* text fig. 11), where the fossils are in a friable and in part gypseous mudstone or sandy shale, from which good specimens are easily obtained. These fossiliferous bands are intercalated in a general sequence of friable sandy and gypseous shales and mottled blue and brown shales with jarosite and marcasite (or pyrite). Some current bedding is seen in the sandy beds. A narrow band of blue fossiliferous limestone occurs near the base of the shales which outcrop for 200 yards on the west bank. This section has been illustrated by Campbell (1910, p. 50) and measured (in part) by Raggatt (1936, p. 150), who gave the thickness as 75 feet. This was increased to 190 feet by Teichert (1941, p. 376), since when there has been no further study of these beds, except that we have placed the topmost beds in the High Cliff sequence, thus reducing the thickness to 180 feet.

On the opposite bank from Fossil Cliff, about 300 yards downstream, there is another impressive outcrop know as High Cliff (*see* text fig. 12), which does not expose the fossiliferous limestone, but only poorly preserved fossils, especially *Fenestella* and *Linoproductus* in brown, szndy siltstone, intercalated in the shales and mudstones (*see* fig. 26, in Campbell, 1910). The upper part of the cliff shows the contact with the white sandstones of the overlying High Cliff Formation (marked in part ? Jurassic, by Campbell).

About three-quarters of a mile to the south, in the bank of the South Irwin, immediately west of the outcrop of the Coal Measures, there is a re-appearance of these soft brown siltstones*, with bands of bright yellow jarosite, and several beds were found to be highly fossiliferous, being packed with crinoid stems, *Spirifer*, *Productus*, etc., the typical Fossil Cliff assemblage. Woolnough (*op. cit.* pp. 91–92) described the beds as "soft kaolinised sandstones" but only recorded part of an *Aviculopecten* ; we were able to confirm his comment that the hard limestone band at the base of the formation seems to be quite lenticular.

The connection between the South Irwin and the Fossil Ridge—Beckott's Gully outcrops is hidden beneath the overlapping beds of the plateau, east of the Coal Seam Homestead. However, the strike in both places would not indicate a direct connection between the two, but suggests displacement by strike faulting (*see* under "Structure"). To the S.S.E. of Beckett's Gully and Round Hill the beds disappear once more beneath the escarpment on which Holmwood No. 2 Homestead stands.

Just to the north of this spot, in 1949, a rich fauna was discovered in shales and siltstones on either side of Bangarra Hill (samples 29949 and 29951).

The rich fossil fauna of the Fossil Cliff Formation has not yet been described in full. It is almost certain that, with the exception of *Metalegoceras jacksoni*, all earlier records of fossils from the "Irwin River District" are from these beds, and fossils of that age are among the earliest ever recorded from Western Australia (J. W. Gregory, 1849) ; in 1861 T. Rupert Jones (in an appendix to F. T. Gregory's paper) reported the presence of *Spirifer*, *Productus*, *Pleurotomaria*, *Nautilus*, *Cyathophyllum*, and crinoid stems among Gregory's collections from the Irwin River.

Since that time, work on Fossil Cliff fossils has proceeded intermittently and some groups are now better known than others (Etheridge, 1889, 1907 ; Foord, 1890 ; Hinde, 1890 ; Newton, 1892 ; Howchin, 1893, 1895 ; Chapman, 1904 ; David, 1905 ; Glauert, 1910 ; Prendergast, 1934, 1943 ; Hill, 1937,

* A laboratory analysis of the fossiliferous brown siltstone (sample 25623) showed it to be extremely well-sorted with about 35 per cent. fine clay minerals and 14 per cent. $CaCO_3$; of the heavy fraction there was 55 per cent. gypsum, 40 per cent. marcasite, and 5 per cent. accessories (staurolite, tourmaline, etc.), while in the light fraction 70 per cent. was quartz and 30 per cent. moderately weathered felspars. No foraminifera were detected.

1942 ; Teichert, 1941, 1944, 1949 ; Stubblefield, 1944 ; Crespin, 1947). In the following, therefore, generic and specific names are included in so far only as they are based on modern revisions of the fauna. In addition, general characteristics of the composition of the various groups are given :—

Foraminifera (Crespin, 1947) :

Ammodiscus millettianus Chapman
Calcitornella stephensi (Howchin)
Trepeilopsis cf. *grandis* Cushman & Waters
Hemigordius schlumbergeri (Howchin)
Endothyra cf. *media* Waters
Nodosaria irwinensis Howchin
Nodosaria sp.
Frondicularia woodwardi Howchin

Anthozoa (Hinde, 1890 ; Hill, 1937, 1942) :

"*Amplexus*" sp.
Gerthia sulcata (Hinde)
Plerophyllum australe Hinde
Euryphyllum trizonatum Hill

Echinodermata :

Calceolispongia digitata Teichert (1949) is the only species of crinoids so far described. In addition, crinoids of actinocrinitid and platycrinitid affinities are known to occur (Glauert, 1910). Crinoidal stems and columnals are fairly common in the limestone.

Bryozoa :

This group has not been studied, but our collections include representatives of *Fenestella, Polypora, Rhombopora, Hexagonella* and *Streblotrypa*. *Stenopora leichardti* was recorded by Chapman in 1904.

Brachiopoda :

This class is most abundantly represented in the limestone facies and certain species also occur in the shaley facies. Most common are productids and spiriferids, of which only some of the former have been treated more recently (Prendergast, 1934, 1943). These include *Dictyoclostus callytharrensis* Prendergast, *Linoproductus bellus* (Etheridge), *Linoproductus cora* var. *foordi* (Etheridge), *Strophalosia etheridgei* Prendergast, *Strophalosia* cf. *gerardi* King, *Strophalosia tenuispina* Waagen, *Chonetes pratti* Newton.

The Spiriferacea are richly represented by several species of *Spirifer* (s.l.) and by *Cleiothyridina macleayana* (Etheridge). In addition there are species of *Streptorhynchus, Dielasma* and other genera.

Pelecypoda :

Next to the Brachiopoda this is the fossil group which is best represented, but all the species are either undescribed or in need of revision. Among the genera now recognised in our collection are *Edmondia, Sanguinolites, Stutchburia, Aviculopecten, Deltopecten, Conocardium, Schizodus,* and *Allorisma*.

Gastropoda :

These include several species of *Bellerophon, Macrocheilina, Ptychomphalina,* and *Conularia*.

Cephalopoda (Teichert, 1941) :

Nautiloidea are rare and include undescribed species of *Pseudorthoceras, Euloxoceras, Domatoceras* and *Stearoceras*.

Trilobitae (Stubblefield, 1944) :

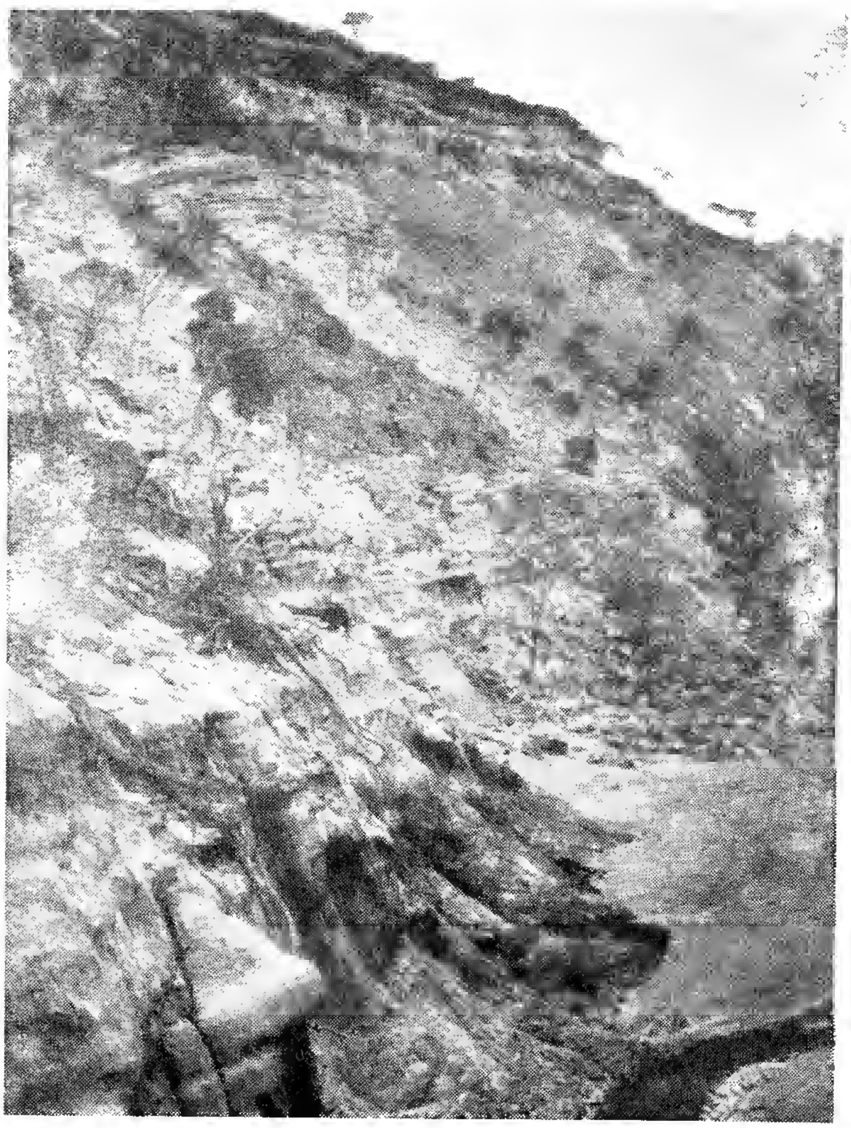
Ditomopyge sp. is the only trilobite known.

Ostracoda :

This group is represented by a number of undescribed species, some of which belong to the genera *Bairdia* and *Healdia*.

4. High Cliff Sandstone.

Overlying the Fossil Cliff shales and limestones, with a notable change in lithology, follows a sequence of white and red sandstones and conglomerate, which are best exposed at High Cliff (lat. 28° 56½′S., long. 115° 32½′E., on the east bank of the North Irwin, 1,100 yards above the junction) (*see* text fig. 12). These rocks were named the " High Cliff Beds " or " High Cliff Sandstone " by Dorothy Carroll (1945, pp. 86–7), but were not clearly defined. We are including therefore, an additional 15 feet of sandstone which she placed at the top of the Fossil Cliff Formation, apparently under the impression that there was a discordance above this sandstone. Insufficient evidence for such a break has led us to group all the sandstones together. The suspicion of such a discordance seems to have come first to Prendergast and Luck (*see* Clarke, 1937) on account of the sporadic occurrence of the Fossil Cliff limestone and certain apparent differences in strike between the upper and lower formations of the basin. The former is now regarded as due to facies changes and the latter to strike-fault displacements.



Text fig. 12—View of High Cliff, on the east bank of the North Irwin, looking south. Shows contact of High Cliff formation of red and white sandstone with the blue-grey shales and brown siltstones of the Fossil Cliff Formation in lower third of section.

(Photo: R. T. Prider.)

The High Cliff section was illustrated by Campbell (1910, fig. 26), but in the measured sections listed by Raggatt (1936), Teichert (1939, 1941, etc.) and other authors, it has either been partly omitted or included with the Coal Measures. The section measured by the Geology Department, 1939 excursion (according to Carroll, *op. cit.*) is interpreted as follows :—

Coal Measures—	Carbonaceous shale, etc.	
High Cliff Sandstone	Sandstone (shaley)	28 ft.
	Grit or fine conglomerate	6 ft.
	White sandstone	56 ft.
	Current-bedded sandstone	8 ft.
	Fine white sandstone	15 ft.
	Total	113 ft.
Fossil Cliff Formation—	Blue, micaceous shale, etc.	....

Text fig. 13—Notable band of cross-bedded sandstone close to the base of the High Cliff Sandstone, on the east bank of the North Irwin, about a quarter of a mile north of High Cliff. The direction of the cross-bedding indicates a current direction from the north. The figure is that of Sir T. W. Edgeworth David, whose early work on the correlation of the Irwin River Permian is acknowledged in the text. (Photo: E. de C. C.)

Incomplete exposures of these rocks were found in both North and South Branches of the Irwin, dipping 10° east beneath the Coal Measures. In two deep bores P.W.D. Nos. 1 and 2, put down in 1920–21 farther up the South Irwin (*see* map), the same formation has been identified at the base of the Coal Measures, but the upper boundary is not sharp, passing gradually, it appears, into the sandy and carbonaceous shales of the Coal Measures type (*see* text fig. 14). Thus in bore No. 1 there are 70 feet of sandstones followed by 51 feet of sandy shales (total 121 feet), and in No. 2 there are 76 feet of sandstones followed by 23 feet of sandy shales (total 99 feet). In bore No. 2., below the first true seam, there are 17 feet of shales with thin coaly bands which appear to be transition beds. The average thickness may be taken as about 110 feet.

These sandstones are quite unfossiliferous, the only characteristic being the cross bedding, which suggests a current-source to the north (*see* text fig. 13). The angle and thickness of the inclined beds suggest water-laid conditions.

According to Carroll's work (*op. cit.*) on the petrology of the sediments, the High Cliff sandstones at High Cliff are quite distinct from those higher up in the section, in being composed of well-rounded grains and having a small proportion of non-opaque grains to opaque grains in the heavy residues. Almost all the sandstones in the High Cliff and Coal Measures are very high in felspars, so that they are strictly "felspathic sandstones."

Following the strike to the south, the High Cliff sandstones form a prominent white bluff on the south side of the South Irwin, and then disappear beneath the breakaways to occur once more as the crest of Fossil Ridge to the east of the Fossil Cliff limestone outcrops south-east of Coal Seam Homestead, in Beckett's Gully, and on the top of Round Hill. They disappear finally beneath tho breakaways below Holmwood No. 2 Homestead. The thickness in Beckett's Gully is difficult to measure precisely, but is of the order of 100 feet.

To the N.E., in Caryngìnia Gully, there is a formation of sandstones and conglomeratic grits found up against the Darling Fault, dipping at 70° W.N.W., which appears to correspond to the High Cliff sequence (*see* text fig. 16). It underlies a thickness of plant-bearing shales and sandstones which are probably equivalent to the Coal Measures Formation, and those in turn underlie the Caryngìnia Shales in the lower part of the valley.

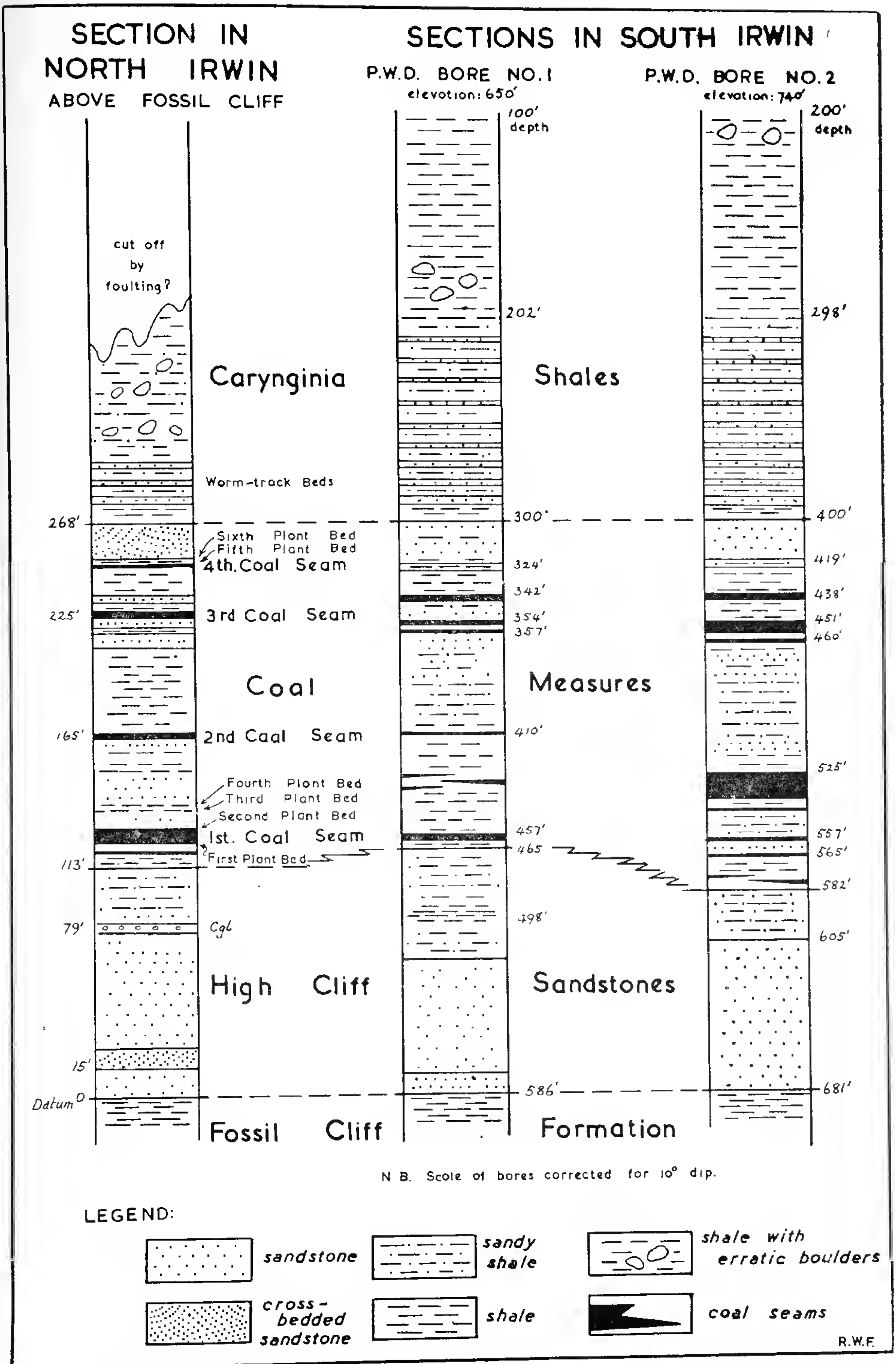
5. Irwin River Coal Measures.

The High Cliff Formation is overlain by a succession of shales and sandstones with some interbedded coal seams. This sequence of rocks has long been more or less loosely referred to as the Irwin River Coal Measures, a name which is here accepted and which it is proposed to define somewhat more precisely. The type section is taken to be on the North Irwin from one-quarter to half a mile above Fossil Cliff. The formation is conformably overlain by the jarositic shales of the Caryngìnia Formation.

Outcrops of the coal measures were studied in the North and South Branches of the Irwin River, but the better known section is that in the North Branch (*see* text fig. 14).

The two deep bores (P.W.D. Nos. 1 and 2) put down farther up the South Irwin, and already referred to above (*see* also Appendix and text fig. 14), each disclose complete sequences of the Coal Measures, which not only correlate closely with those in the bed of the North and South Irwin, but also permit an accurate control of thicknesses to be made. Owing to seasonal movements in the alluvium of the two rivers, different sections of the bed are exposed from time to time, so that descriptions of the section by Campbell, Woolnough, Raggatt and others, are all somewhat incomplete.

The base of the Irwin River Coal Measures here is taken to be the carbonaceous shale, three feet below Coal Seam No. 1 in the North Branch (in Carroll's section, 1945, p. 86). This coal seam was found to be continuous in all available sections and bore logs (*see* text-figs. 14 and 15). Below it there is a gradual transition into the High Cliff Sandstone, which changes from a highly quartzose white sandstone upwards to a grey shaley sandstone, even showing



Text fig. 14—Stratigraphic sections of High Cliff Sandstones, Irwin River Coal Measures, and lower part of Caryngina Shales, as exposed in the North and South Branches of the Irwin River.

some carbonaceous partings near the top. The selection of the junction of the two formations had perforce, therefore, to be somewhat arbitrary. As noted above, Raggatt (1936) and others took a massive current-bedded sandstone, in our High Cliff sequence, as the base of the Coal Measures. It seems better stratigraphic practice, however, to reserve the Coal Measures Formation boundaries to the range of the essentially carbonaceous facies, although it is clear that the fundamental facies change to non-marine conditions, after the Fossil Cliff limestones and gypseous shales came abruptly with the unfossiliferous sandstones of the High Cliff Formation.

Text fig. 15—The best-known coal seam on the North Irwin. Looking north-east across Coal Seam No. 1. Geologists on the 1947 A.N.Z.A.A.S. excursion are seen collecting fossils from Plant Bed No. 2, which occurs near the top of the coal seam. Note also the well-developed terrace 10 feet above the river bank.

(Photo: R.W.F.)

Details of the North Irwin section are given in text fig. 14. In 1939 four coal seams could be seen in the river upstream from Fossil Cliff, separated by soft sandstones and shales in which six separate plant horizons were found. The distribution and character of the *Gangamopteris* flora were discussed already by Teichert (1942*b* ; 1943).

The *first plant bed* occurs just below the lowest coal seam near the base of the coal measures, and is crowded with leaves of *Glossopteris browniana* Brongniart.

The *second plant bed* is found in tho top part of the lowest seam, eight to nine feet higher up in the section. It also contains *Glossopteris browniana.*

The *third plant bed* is found in sandy shale a fow feet above the first coal seam and about 30 feet above the base of the coal measures. This is a richly fossiliferous horizon from which the following species were identified in our collections : *Phyllotheca australis* Brongniart, *Sphenophyllum speciosum* (Royle), *Glossopteris browniana* Brongniart, *G. indica* Schimper, *G. angusti-*

folia Brongniart, *G. decipiens* Feistmantel, *G. spathulo-cordata* Feistmantel, *Gangamopteris cyclopteroides* Feistmantel, *Sphenopteris lobifolia* Morris, *Cladophlebis roylei* Arber.

Just below the outcrop of the bed in tho river bank there is a heap of harder white shales, most likely dorived from the same horizon, containing well preserved plant impressions. It was probably from this occurrence that Glauert (1923) quoted *Glossopteris ampla* Dana and *Noeggerathiopsis*? sp., in addition to somo of the species listed above. Furthermore, in correspondence some years ago, Dr. A. B. Walkom, recognised *Sphenophyllum* cf. *emarginatum* Brongniart and *Bothrodendron* sp. from collections made at the same locality.

A *fourth plant bed* is present three feet above the third. It is crowded with leaves of *Glossopteris browniana* and also contains *Vertebraria* sp.

In the sueceeding beds no plants were found for a vertical distance of ovor 100 feet, but at about 149 feet above the base of the coal measures, a *fifth plant bed* was found in sandy shales just above the highest coal seam. This eontains *Phyllotheca australis* Brongniart, *Sphenophyllum* sp., *Glossopteris browniana* Brongniart, *G. indica* Schimper, *Sphenopteris*? sp.

The *highest* (*sixth*) *plant bed* was found only two feet higher in the section. It is a purplish shale which contains poor remains of *Phyllotheca australis* Brongniart, *Glossopteris* sp., *Gangamopteris*? sp., *Bothrodendron* sp.

About one or two feet higher up follows a 16 foot layer of current-bedded and gritty sandstone, which forms the top of the sequence.

All the shales and sandstones, as well as the coal seams, appear to be rather impersistent, as is shown by comparison with conditions in the south branch of the river, though a similar grouping of seams is recognizable. Thus, in P.W.D. Bore No. 1 (*see* appendix and map) six eoal seams, each one foot thick, were reported, while in P.W.D. Bore No. 2 there are said to be seven seams, one of which is 12 ft. 6 in. thick. Traces of some of these seams outcrop in the river bed of the South Irwin, though they are far from well exposed. It is clear, therefore, that the seams change somewhat in thickness and number over a distance of little more than two miles.

The same conditions of rapidly changing lithology apply to the shales and sandstones, and tho fossil plant horizons are also lenticular. We did not recognise all the characteristic plant beds of the North Irwin section in the South Irwin, though admittedly we made less detailed investigations here.

Nevertheless, as may be seen from the vertical sections (text fig. 14), a eareful comparison of the outcrops and bore logs shows that the overall thickness of the Coal Measures Formation is fairly constant, and if the High Cliff Sandstones are taken in with the Coal Measures, the figures (uncorreeted for dip in the bores) are very similar :—

	North Irwin.	P.W.D. No. 1.	P.W.D. No. 2.
Coal Measures	155 ft.	165 ft.	182 ft.
High Cliff Sandstone	113 ft.	121 ft.	99 ft.
Total	268 ft.	286 ft.	281 ft.

When the figures for the bores are eorreeted for dip, whieh appears to be about 10 degrees, a 5 per eent. reduction must be made, whieh reduces the No. 1 bore total to 271 feet and that of No. 2 to 267 feet. These eorrections have been allowed for in the text figure (14). The average thickness of the Coal Measures is thus given as 160 feet.

As observed before, the smaller thickness of High Cliff Sandstone in P.W.D. Bore No. 2 appears to be due to a transition into Coal Measure facies, which formation is correspondingly thicker. However, the preciso height of the lowest true coal seam above the base of the High Cliff Sandstone (*see* text fig. 14) shows that this is simply a lateral facies change.

It will also be seen that, owing to insufficient bore data, the top of the highest sandstone in the Coal Measures in Bore No. 1 had to be selected somewhat arbitrarily in the alternation of sandstones and shales which succeed the topmost coal seam.

To the south, the Coal Measures disappear beneath the beds of the plateau east of the Coal Seam Homestead. These reappear in the little amphitheatre about the head of Beckett's Gully, where the sequence is well exposed in the south (main) branch of the creek. Here we recognised no coal seams at all (they may be deeply weathered), only a thick series of completely bleached jarositic shales, with thin bands of sandy grit every few feet and with the prominent High Cliff Sandstones at the base (resting, in turn, on the mottled grey shales, siltstones and limestones of the Fossil Cliff Formation), and at the top overlain by the sandstone recognised farther north. The latter is transgressed unconformably by the horizontal beds of the plateau. The section is calculated to be about 150 feet thick.

The Coal Measures may be followed in the cliff bolow these breakaways for over a mile to the south, almost to Holmwood Homestead No. 2. At half a milo south of Beckett's Gully there is an exceptionally fine section, exposing 15 feet of brown carbonaceous shales with traces of plants at the base, followed by a band of cross-bedded sandstone with small slump structures and worm tracks, succeeded by alternating fine-grained ferruginous and micaceous sandstone and shale for eight feet, above which come bands of coarse quartz grits and white shale, before reaching the duricrust. A glacial erratic of hard quartzite over two feet in length was found at the base of the cliff.

Another quarter of a mile to the south, a point quarter of a mile northeast of Bangarra Hill, a slightly lower section is found. Underneath the brown carbonaceous shales come two feet of leaf beds, resting on a six inch seam of poor coal. Below this follows six feet of white sandstone and siltstones, resting on a ferruginous grit. In the leaf beds were recognised *Glossopteris, Gangamopteris* and *Noeggerathiopsis* (sample 29966). Numerous spore cases occur.

Almost in the direct line of the striko, in a well about two miles south-east of Holmwood No. 1 Homestead, the following strata (from above downwards) are reported :—

(1) Yellow clay.
(2) Red sandstone poorly cemented, with clay and mica.
(3) Laminated carbonaceous shale, containing leaf impressions.
(4) Sandstone and shale, with some leaf impressions.

Thicknesses were not given, but the first two sediment types are almost certainly belonging to the plateau beds, and numbers 3 and 4 appear to be of Coal Measure type.

In the other direction along the strike, there has been very little reconnaissance, but some of the deep embayments in the plateaus north of the North Irwin may be excavated in this formation.

The bores put down along the North Irwin and Dog Hole Creek (Prest's Nos. 1–4) were all singularly unfortunate in that each appears to have stopped just short of the topmost coal seam or to have gone down on the "wrong" side of an important strike-fault here. Nos. 5 and 6, though intended to search for coal, were begun in beds stratigraphically lower than the Coal Measures (below the Irwin Junction) and were thus more or less doomed from the start.

The principal result of the 1948 survey was the discovery of plant-bearing shales and sandstones reappearing farther east in Caryngina Gully, nearly in the line of the Darling Fault where they dip steeply to the west. Results of the work are as yet incomplete, but Permian fossil plants (including *Glossopteris*, *Gangamopteris* and *Noeggerathiopsis*) occur on both sides of the valley, and are associated with nearly 300 feet of sediments of lithology very similar to that of the Irwin River Coal Measures and the High Cliff Sandstone (*see* text-fig. 16). Occurrences in both localities are complicated by strike faulting, which fact would also explain the disappearance of most of the (less competent) coal seams.

Text 16—Near Caryngina Well No. 1. Quartzitic sandstones and conglomerates, probably equivalent to the High Cliff Sandstones, sheared, and dipping a 70° to the north-west against the main Darling Fault (which follows the small gully on the right). In the breakaways above the gully on the left there are plant beds, which probably correspond to the Coal Measures Formation.
(Photo: D. Sanders.)

In 1949 these outcrops near the Darling Fault were traced northwards to the large creek (unnamed) which joins the North Irwin one mile below Badgera Pool. Here there is a well-exposed sequence of alternating carbonaceous shales, silts and sandstones, dipping steeply west near the main fault, but severely dismembered by secondary faults downstream. Again, the coal seams, if originally present, have been lost owing to severe crushing.

Information concerning the coal seams of this stage of the Upper Palaeozoic rocks is too fragmentary to allow of much estimate of their value. It is known that several exist, ranging in thickness from a few inches to 12 feet and that their calorific value is low. Simpson (1929) states: "On the Irwin River field, five seams have been provod, all of poor quality." Ho gives the following analyses :—

	*Tunnel.	†Bore, South Irwin.
Thickness of Seam	5 feet	12 feet
Fixed carbon	36.83%	28.75%
Volatile hydrocarbons	26.89%	26.81%
Ash	13.92%	22.63%
Moisture	22.36%	21.81%
Sulphur	00.99%	....
B.T.U. (as received)	7690	6154
B.T.U. (ash and moisture-free basis)	12,068	11,076

* Probably No. 3 Adit, North Irwin.
† P.W.D. Bore No. 2, at 525 feet.

More recent samples have been analysed by Dr. C. R. Kent for the Midland Railway Company, whose kind permission to publish the results is gladly acknowledged. The first sample was collected in 1941 from a 30 foot vertical shaft in the South Irwin, three-quarters of a mile east of the crossing and one chain south of the river ; it was cut from a four foot seam, which is separated by a "flint" layer from another seam of sooty coal. This sample was carefully taken and packed to avoid exposure, so that the moisture content as given will be reasonably accurate. The second sample, from No. 3 Seam in the North Irwin, was collected by Dr. Carroll in 1939, but as no special precaution was taken against exposure it may have lost much of its original moisture.

Dr. Kent's analyses are as follows :—

	Irwin River, South Branch, 1941.	Irwin River, North Branch, No. 3, 1939.
Proximate Analysis as Received—	%	%
Moisture	32.17	18.5
Ash	7.24	19.0
Volatiles	25.44	27.05
Fixed Carbon (by difference)	35.15	35.45
	100.00	100.00
Calorific Value, B.Th.U. per lb. as received	7,725	7,195
Ultimate Analysis Dry, Ash-free—	%	%
Carbon	74.5	69.25
Hydrogen	4.95	4.6
Nitrogen	1.65	*
Sulphur	1.25	*
Oxygen (by difference)	17.65	26.15
	100.0	100.0
Calorific Value, Dry, Ash-free	12,775	11,510
Sulphur distribution— Calculated on dry, ash-free basis :	%	
Organic S.	0.44	
Pyritic S.	0.67	
Sulphate S.	0.12	
	1.23	

Carbonate : Slight trace only.

* Nitrogen and Sulphur not determined.

Commenting on the results, Dr. Kent indicates that the Irwin River coals must be classified as *black lignites*, thus a stage slightly below the sub-bituminous coals, but the two analyses show that these coals are up to the level of the Griffin No. 1 and Cardiff Seams from Collie (based on ultimate analyses and classified on the Ralston system).

Finally, there is a report by Bowley (1946) of the old tunnel (believed to be that in the North Irwin No. 3 Seam) being opened up once more in 1944–45 when it was driven through to 180 feet along the seam. It was systematically sampled and proximate analyses given, but it was considered too high in ash for most commercial uses.

It would appear, however, that neither geological surveys nor drilling programmes have been sufficiently comprehensive to enable a just estimate of the value of the Irwin River coal seams to be made.

The heavy minerals of the Coal Measures sandstones have been made a special object of study by Carroll (1945), who came to some remarkably interesting conclusions. Most striking of her results was the recognition of a " flood " of garnets in the sandstones midway between coal seams Nos. 2 and 3 in the North Irwin ; the same horizon was picked up in the South Irwin. This feature distinguished this sandstone from all others in the area and should prove a valuable marker horizon in any future drilling. At the same time there is an increase in the proportion of non-opaque to opaque minerals in the upper beds. Carroll believes this sudden addition was due to the exposure to contemporary erosion (partly glacial) of the belt of garnetiferous gneisses, at present known in the Northampton-Greenough block, the nearest present exposure of which is 40 miles to the west. The rest of the Coal Measures sediments are such as one would expect to come from the Pre-Cambrian rocks immediately to the east of the present Irwin Basin.

Another interesting aspect, to which Carroll has drawn attention, is the way in which the grains in the sediments become progressively more angular, rising up in the Coal Measures. The fact that the felspars are fresh and unweathered, coupled with the reappearance of glacial erratics in the succeeding Caryngínia Shales, could possibly be used to support the contention of Woolnough and Somerville (1924, p. 108) that " there is evidence of continued glacial action contemporaneous with coal deposition." Angularity and freshness of mineral grains may be accepted as evidence of rapid deposition, but not necessarily of refrigeration. However, the appearance of some large erratic in the Coal Measure may support this glacial idea.

6. Caryngínia Shale.

The beds lying above the Coal Measures have not previously been very thoroughly examined. We propose the name Caryngínia Shale Formation for them, after Caryngínia Creek (lat. 28° 55½′ S., long. 115° 33½′ E.), which joins the North Irwin two miles north-east of Fossil Cliff and in which the beds are well exposed. They consist of a monotonous succession of jarositic and micaceous grey shales and silts, with thin bands of ferruginous sandstone and grit. The formation rests on the highest sandstone of the Coal Measures sequence and clearly represents a break in the freshwater succession, probably a return to the barred basin environment of the beds preceding the Fossil Cliff Formation, with their limited connection with the open sea. They are conformably overlain by the continental sandstones of the Wagina Formation (q.v.). Floating ice is suggested by the occurrence of occasional " dumped " erratics, especially in the lower part of the formation.

The presence of marine beds above the Coal Measures was already suspected by Woolnough and Somerville (1924, p. 96), who referred to these beds as the " Upper Marine." It was confirmed by David and Sussmilch (1931, p. 509, 1936), who reported the presence of 450 feet of mudstones " with Aviculopectens and *Anthracosia*-like shells and occasional fish." They also mention the occurrence of small erratics. Raggatt (1936, p. 150) described this upper series as " shale varying from sandy and micaceous to brown and carbonaceous, and with sandstone bands up to 18 inches in thickness near base." He confirmed the occurrence of erratics.

The base of the formation is well-exposed in three localities: in the North Irwin, immediately upstream from the Coal Measures; in the South Irwin in a similar relationship (also in the two Public Works Department bores there); and in the upper part of Carynginia Gully where the westerly dip brings the Coal Measures up again near the Darling Fault.

There is a fairly abrupt change from the uppermost sandstone of the Coal Measures to a succession of jarositic shales with interbedded sandstone and lenticular ferruginous bands, as seen in both the North and South Irwin exposures. Only one pelecypod (unidentified) was found in these beds, and some of the shales contain indeterminable plant fragments.

Some of the ferruginous bands are ripple-marked and worm tracks are fairly abundant in them (sample 23147). The worm tracks are reminiscent of those found in the Permian of the Kimberley (Teichert, 1941, fig. 3). These tracks are so numerous in the lower sandstone band (12 feet above the base) that Carroll (1945, p. 86) referred to it as the " Worm Track Bed." They are exposed near the sharp bend of the North Irwin, half a mile N.E. of Fossil Cliff; on the dip slopes of the western side of the valley, quarter of a mile to the north again; on the east side one milo S.W. of Badgera Pool; and in the South Irwin near the junction of Monday Creek, ono mile S.E. of the Junction.

Farthor south again, below the western breakaways of the South Irwin, the finely laminated micaceous silty shales (with jarosite, and thin bands of sandstone, grit and conglomerate) are exposed, dipping gently oast. Micro-cross-bedding and small slumps of irregular orientation suggest the changing currents of a shallow-water sea.

In Caryngimia Gully, on the northern breakaway, 800 yards N.N.W. of Caryngimia Well No. 1, there is a band of micaceous silty sandstone close to the base of the jarosite shales which was found on the 1948 survey to contain abundant though rather poorly preserved marine fossils, most of which seem to belong to species already known from the Fossil Cliff Formation.

The following is a list of certain tentative identifications:—

(a) Brachiopoda:
- *Chonetes pratti*
- *Cleiothyridina* sp.
- *Linoproductus cancriniformis*
- *Linoproductus* sp.
- *Spirifer* cf. *curzoni*
- *Streptorhynchus* sp.

(b) Pelecypoda:
- *Pachydomus*, sp.
- *Parallelodon* sp.

Also, *Fenestella*, sp.

The lithologic sequence of these lower beds of the Caryngimia Shales is well shown in the two P.W.D. bores in the South Irwin. These confirm the alternation of silty or sandy jarositic shales and thin sandstone bands for about 100 feet above the Coal Measures, above which are less sandy jarositic shales without sandstone bands. In No. 2 bore there are nearly 300 feet of these non-sandy shales. This same sequence, seen in Caryngimia Gully, seems to continue, with very little change in character, right up to the top of the formation.

An interesting feature of the Caryngiuia Shales is the reappearance of occasional large erratic boulders, which appear to be ice-rafted, although none with glacial striae were noted. These are particularly common within 50 feet of the base in both the North and South Irwin but were struck in P.W.D. No. 1 bore 100 feet above, and in No. 2 bore nearly 200 feet above the base. In addition to the large erratics, occasional conglomeratic pockets of smaller pebbles occur. The largest erratic block measured two feet four inches in diameter.

The upper part of the formation is difficult to follow in the North and South Irwin valleys, where important strike faulting is suspected (leading to a sudden reversal of dip from about 10°E. to 10–14°W. and the appearance of the Wagina Sandstones overlying the shales). In Caryngiuia Gully, however, working downstream from Well No. 1, we encountered in 1948, an apparently undisturbed west-dipping sequence. The base crops out in the creek-bed about 400 yards below Well No. 1 and may then be followed right down the valley, to be capped about half-way up to the breakaways near its western end by the white sandstones and quartzitic conglomerates of the Wagina Formation. The same contact may be seen near the head of Dog Hole (Bigarra) Creek and along the eastern slopes of the South Irwin, at the head of Research Creek and about one mile N.W. of Wagina Tank.

Earlier estimates of the thickness of these "Upper Marine" beds have been given by David & Sussmilch (1931, 1936) as 450 feet; by Teichert (1939) as 120 feet. However, these estimates were based on the impressions gained by very rapid reconnaissances, and not by an actual survey. Thus, unless there has been strike faulting that has been missed in Caryngiuia Gully, the steady westerly dips there would indicate a total thickness for the Caryngiuia Shales of 800 feet.

Examination by Carroll (1945) of the sandstones, her so-called "Worm Track Sandstones," near the base of the Caryngiuia Shales in the North Irwin, showed that the ratio of non-opaque to opaque minerals was considerably higher than in the Coal Measures. Of the significant minerals, garnet is less common than in the Coal Measures, likewise kyanite and staurolite; limonite and zircon are most abundant. Quartz and felspars are in about equal quantities and the latter are generally fresh. Carroll believed that a sedimentary source from the west was indicated.

7. Wagina Sandstone.

Overlying the jarositic shales and silts of the Caryngiuia Formation, conformably but with a fairly rapid transition, there follows a succession of mottled red and white sandstones, with intercalations, higher up in the sequence of carbonaceous shales and of creamy white clay-shales, and at various levels bands of grit and conglomerate. The pebbles are rather small and probably not glacial. We propose to call this sequence the Wagina Sandstone, after Wagina Well in the South Irwin (lat. 28° 59½'S., long. 115° 35'E.). The top of the formation is not known, since it is cut off by the epi-Permian peneplain and the transgressive beds of the plateau.

Plant fossils are found in profusion, and beautifully preserved, in one of the shaley intercalations about a quarter of a mile east of Wagina Well on the north side of the valley of the South Irwin, but the rest of the succession appears to be unfossiliferous. Plant forms recognised include: *Glossopteris, Gangamopteris, Noeggerathiopsis,* ? *Annularia.* (Examination of the material is still in progress). About 20 feet stratigraphically below this plant bed there is an 18 inch band of carbonaceous, "coaly" shale, but it was too weathered for any plant fossils to survive.

The type section selected is that along the South Irwin, from a point one and a half miles south-east of the junction with the North Branch, upstream and in the breakaways on either side, as far as half a mile east of Wagina Well, a short distance east of the track crossing the valley and leading up to Hector's Well and Carynginia Well, where the main Darling Fault cuts off the sequence. The thickness of the Wagina Sandstone in the South Irwin is not less than 300 feet, but a complete section, as noted above, is not available.

The white sandstones may also be seen resting on the Carynginia Shales at the head of Research Creek (farther down the South Irwin); at the head of Bigarra ("Dog Hole") Creek; around the foot of the breakaways, east of the North Irwin and south of the Carynginia Creek; and farther north again extending up towards Badgera Pool. This area has not yet been thoroughly examined.

Discussion of the character and origin of the sandstone must be deferred until it has been examined petrologically.

Some idea of the subsurface distribution of the Wagina Sandstone in the North Irwin may be obtained from the logs of Prest's Bores Nos. 3 and 4 (*see* Appendix). Prest's Bore No. 3, near Bigarra ("Dog Hole") Spring, passes through the base of the sandstone at 108 feet. The next bore, No. 4, 660 yards east of No. 3, lies on the plateau, and after 31 feet of laterite and reddish sandstone ("Plateau Beds"), passes the base of the sandstone at 52 feet, thus suggesting a westerly dip. That the Wagina Formation is not all sandstone is indicated by the presence of shales (apparently lenticular) above the sandstone in bore No. 3. Bores Nos. 1 and 2 lie half a mile west and north-west respectively of No. 3, and only seem to penetrate Carynginia Shales.

V.—STRUCTURE.

The first note on the structure of the area comes from Gibb Maitland (1904), who wroto: "The north-western (? north-eastern) boundary of the field is marked by a fault, which throws the bed against the crystalline rocks. In the vicinity of the fault the strata have been thrown into a series of gentle folds but the series has a prevailing dip to the eastward. To the west the beds dip at a slight angle, towards the sea, in such a way that the coal seams of the Upper Irwin should, if continuous, pass beneath the Mesozoic rocks of Mingenew and Depot Hill." This was the first recognition of what we now know as the main Darling Fault in this region.

Campbell (1910, Pl. V.) in his cross-section interpreted the general structure of the Permian in the Irwin Basin as a broad anticline, trending N.N.W. His interpretation was based on the fairly uniform easterly dips east of the Nangetty Glacials and the reappearance of the Holmwood Shales to the west of them. He did not describe any faulting in the Permian rocks except (p. 14) faulting and "crushing" against the granite in Carynginia Gully. In his section, however, on the east side of the basin he showed the east-dipping Permian formations abutting against the Pre-Cambrian along a steep contact but without a fault. Subsequent observers have tacitly accepted Campbell's anticlinal interpretation.

Further work by Woolnough & Somerville (1924), both here and in the surrounding country, made them suspect the existence of important normal faulting in meridional to N.W.-S.E. trends along the western borders of the Western Australian Pre-Cambrian plateau. They concluded that the "probability of the existence of a series of major step-faults throwing towards the Indian Ocean, is therefore reasonably well established." Recent work by one of us (R.W.F.) on the water-bore records of this coastal belt, including those completed by the Army during the war, as well as work on the regional geomorphology, has gone far to confirm Woolnough's preliminary suggestion.

The question of folding was not mentioned by Woolnough & Somerville, but both their map and section clearly depicted a broad anticlinal warp of symmetrical pattern, disposed along the N.N.W.-S.S.E. axis of the Pre-Cambrian ridge which runs through Yandanooka and Arrino, forming the Mullingarra and Brockman Hills. The feature was referred to by them as the "Mullingarra Axis."

It is possible, therefore, that this axis might extend northwards as a "buried hill." The gentle dips on the flanks, hardly to be seen at all on the west, would thus be interpreted at initial dips, modified to some extent by compaction. The fact that the easterly dips continue at 5–10° for some eight miles east of the axis may, however, be regarded perhaps as rather excessive for a "buried hill."

We thus possessed two working hypotheses prior to the recent surveys (1948–49)—the concept of a normal folded anticline, or of a buried hill, modified perhaps to some extent by strike faulting. The arrival of air photographs, coupled with further investigations, has, however, disclosed a far more complex structural pattern. In essence we must abandon the folding idea and return to Woolnough's general conclusion, that there are successive meridional fault-blocks of considerable dimensions, stepped down from the great Pre-Cambrian plateau in the east.

First of all, the Pre-Cambrian plateau is cut off by what is believed to be the northern extension of the *main Darling Fault*. It strikes very uniformly N. 20°W. Its throw, as noted by Woolnough & Somerville, must be not less than the thickness of the entire Permian, to which we may add that of the younger Pre-Cambrian sediments of Woolnough's Yandanooka Beds: these would be perhaps 4,000 and 3,000 feet, respectively, thus conservatively not less than 7,000 feet. The last movement on it in this sector would be post-Permian and probably pre-Jurassic (*see* also Raggatt, 1936). Earlier movements probably go back to Pre-Cambrian times. Today the fault-line possesses no physiographic expression, except where re-excavated by youthful stream revival, since both Permian and Pre-Cambrian rocks were peneplaned and later transgressively overlapped by a continental formation of partly Jurassic age which now occupies the flat-topped plateau. (These "Plateau Beds," as noted earlier, appear to range through from Jurassic to Tertiary.)

Secondly, there is what we have called the *Nangetty Fault*, which runs nearly parallel to the Darling Fault, about 10 miles to the west. It was first recognised on the air photographs running from west of Bugallie Hill through Nangetty Homestead to the S.S.E., following a rectilinear trend "like a railway line," till it disappears beneath the alluvium of the Lockier Basin, but appears to be continued in the line which abruptly truncates the Yandanooka-Mullingarra Pre-Cambrian ridge on the west side. The line disappears under Jurassic or younger sediments at either end, but even then is over 40 miles in length. In the Nangetty area it cuts off the Nangetty Glacials on the west, bringing in sediments apparently fairly high in the Holmwood Formation. Here the throw may be somewhere about 200 to 500 feet, and it may be dying out towards the north. Around Yandanooka, however, it may be much greater. Like the Darling Fault in this area the Nangetty Fault is probably pre-Jurassic in age.

Woolnough & Somerville did not recognise this Nangetty Fault, but indicated the *Urella Fault*, which lies closely parallel to the former about two to three miles farther west, running west of Urella, through Yarragadee, just east of Mingenew, and through Eyragulla Springs in the direction of Yandanooka. Our surveys have not covered this area very thoroughly, but it may be that in the south the two lines are one and the same.

The significant feature of this fault is that it involves fossiliferous Jurassic and possibly Cretaceous rocks ; in places they stand vertically. No Jurassic-Cretaceous movements are known in this region, and the displacement may well be Tertiary in age. However, the fault is truncated and overlain by the highest " Plateau Beds." Its character will be discussed further below.

It is also worth mentioning here, perhaps, in order to illustrate the regional pattern of this great step-faulting, that there is a fourth major line, Woolnough's Moonyoonooka Fault, which parallels the others 25 miles to the west again. It may be followed from just north of Geraldton, through Irwin House Station (on the railway six miles east of Dongara), apparently to die out in the Mesozoic sand-plains north-west of Moora (*see* text fig. 1). Like our Nangetty-Yandanooka ridge, this block also possesses a core of Pre-Cambrian rocks, which outcrop on the Greenough River and in the Northampton area. Its throw is not less than several thousand feet. Like the Urella Fault it is probably Tertiary in age.

It may be noted that in both cases the Pre-Cambrian basement comes to the surface near the *western margin* of each fault block, while the overlying sedimentary rocks may be seen (in the Irwin Block) to dip very gently to the east. Steep westerly dips are only found just along the fault zones. The tectonic picture presented is thus one of successive parallel step-faults, with the down-throws towards the Indian Ocean, and with each successive fault-block tilted so that the easterly side has slipped down and the westerly margin has tended to rise up antithetically.

There is thus no broad folding tendency in the region, and the only structures observed in the Irwin Basin are such as may be explained by major gravity faulting in the hard Pre-Cambrian basement, with minor adjustments in the soft sedimentary cover.

Thus, in detail, there is much of interest. Apart from the major fractures, numerous strike faults, of relatively minor throw (50-100 feet), have now been recognised. These, for the most part, appear to be not more than a few miles in length and generally die out on curving planes. They probably do not penetrate the Pre-Cambrian basement, but are taken up in the slippery shales. They are thus secondary and quite distinct in character from the major basement fractures.

Some overturning and dragging of the shales occur near these faults, and, in fact any dips much over 10° are found to be connected with them.

Most of these secondary faults throw down to the west, like the major fractures, but whereas the latter have near-vertical dips, the former generally dip gently to the west. Antithetic faults are rather uncommon, but are noted in the Holmwood Shale Formation. The only systematic east-throwing faults are those along the eastern border of the Nangetty Glacial Formation, so that the Nangetty Hills are a minor horst.

Reviewing the structural data, then, from the east to west, we find first of all the main Darling Fault, which brings the High Cliff Sandstone, Irwin Coal Measures, Carynginia Shales and Wagina Sandstone down against Pre-Cambrian. Owing to the softness of the sediments, the contact is generally rather poor. As noted by Campbell (1910, p. 14) the granite generally leads to slight falls or " rapids " on the river tracts, as at Badgera Pool on the North Irwin and in Carynginia Gully. It is less noticeable on the South Irwin. In all three a considerable drag in the sediments is recorded, resulting in fairly steep westerly dips (30° to 70°), which are most developed in Carynginia Gully. Westerly dips of 10°–15° persist down the length of this valley. In the South Irwin, however, west dips are seen only within a few hundred yards of the fault and are replaced downstream by gentle east dips.

About one and a half miles west of the main fault, in the valley of the North Irwin, there appears to be a secondary fault throwing east, which results in the Wagina Sandstones and upper Carynginia Shales being thrown down against the lower Carynginia Shales and Coal Measures. The throw would be about 200 feet near Bigarra Creek, 100 yards east of the North Irwin, and there is a flattening of the dip, from 10°E. in the Carynginia Shales and Coal Measures, to a westerly dip in the Wagina Sandstones.

There is some important faulting of easterly throw (apparently related to the above) along the South Irwin, where the dips are mainly 3° to 4° E., especially to be seen just below the breakaways, one mile west of Wagina Tank. Minor displacements were found one and a quarter miles south-west of Toothagunna (" Nannygoat ") Swamp, where one fault, in the sandy shales of the Carynginia Formation, shows a near-vertical movement, trending north, with indurated slickensides, but the displacement must be slight, since no change of lithology is to be seen. A few yards to the west there is a small antithetic fault, curving upwards to the south-west, and showing even vertical dips in the dragged up strata of the footwall.

Similar faulting of antithetic character is well exposed in a creek one mile south of Badgera Pool, where steeply west-dipping Coal Measures are brought down against Carynginia Shales dipping 21°E.

Additional minor movements were noted in the Coal Measures Formation in both the North and South Irwin, near the coal seams, and about High Cliff. They appear to have no far-reaching significance, and throws of only a few feet were seen.

Farther west, in the upper part of the Holmwood Shale, there are gentle dips, north-east at 3° to 4°, to be seen in gullies along the south side of the Irwin and in the " badlands " east of Eagle Creek. Excessive soil erosion in this area has assisted the geologist by exposing fresh sections in the soft shales, which are effaced again after one or two seasons.

About one and a half miles down the Irwin from its junction between the North and South Branches, there occurs another strike fault of the secondary type, trending N.W. to S.E. and throwing about 300 feet down to the west. This line controls the main course of Eagle Creek and so is referred to as the Eagle Creek Fault. North of the Irwin it cannot everywhere be seen beneath the broad alluvial aprons of the northern breakaways, but seems to continue for five and a half miles, to disappear finally beneath the plateau about one and a half miles north of Gnoolowa Hill. Some minor low angle faulting is connected with the main (vertical) displacement. The contact was not identified in the field, but is extraordinarily clear on the air photographs. The western side is involved in a broad synclinal drag over a width of 600 yards, where there are west dips, estimated at up to 15° or 20°. Woolnough (1924, p. 90) noted exceptionally steep dips on this line. A slight regional plunge to the south-east is noticeable from the outcrop of the beds on the air photos. In that direction, the fault disappears beneath the breakaways just one mile north of the Coal Seam Homestead and is not seen again.

Farther south, one and a half miles south of the Coal Seam Homestead, an excellent section is exposed in Beckett's Gully, but here the easterly dip is considerably steeper near the top of the Holmwood Formation, increasing from about 3° near the road-crossing to 9° at the base of the Fossil Cliff Formation.

It would seem that the Eagle Creek Fault is responsible for this anomalous appearance of the Fossil Cliff Formation, overlain also by 250 feet of the High Cliff Formation and Coal Measures, etc., dipping at 8°–9° north-east. Here the strike is N.N.W–S.S.E., which would carry the Fossil Cliff horizon *west* of the Eagle Creek Fault, were it not for the southerly regional plunge mentioned above. As it is, this horizon may be traced on the ground or in air photographs directly through the Coal Seam Homestead, but then disappears beneath the debris of the breakaways. Under the plateau here it is believed to swing around to the east in the synclinal drag of the fault, as noted already farther north-west. Since the throw is to the west, the Fossil Cliff horizon would then be displaced some distance to the south-east on the east side of the fault and would thus fall into alignment with the strike of these beds, where last seen just above the Irwin junction.

Below the Fossil Cliff horizon in Beckett's Gully there are fairly good exposures of the upper part of the Holmwood Formation, and no other fault has been observed. There are highly saline and gypseous springs (noticeable even in very dry seasons) a short distance below the base of the Fossil Cliff Formation here, again below the breakaways three-quarters of a mile north of Coal Seam Homestead, and yet again in the bed of the North Irwin, three-quarters of a mile above the junction (Warraga Spring ; *see* Campbell, 1910, p. 70) ; all appear to be related to a stratigraphic horizon just below the Fossil Cliff Formation, not to faulting.

It may be observed also that the convergence of strikes in the south-east, about Holmwood, might suggest a steepening dip or a reduction in the amount of faulting. Both factors seem to play a part.

To the west again of the Eagle Creek Fault, the steep dips quickly flatten and " normal " dips reappear (2°–4° ENE to NE) and continue until cut off by further strike faults. These are so numerous with many branches which die out, that it seems easiest to refer to them simply as the *Holmwood Fault Zone*. The zone may be followed clearly over a width of two miles from the north-west corner of the basin to pass through Holmwood No. 1 Homestead, in the south-east, a distance of over 10 miles.

The details of this faulting are beautifully displayed on the air photographs in the area between the Irwin and Holmwood No. 1 Homestead. Interpretation of the photos indicates that the throws are small, and mainly to the west, but varying in dip from near-vertical to quite gentle inclinations. It would appear that those faults in particular are of quite shallow depth and curve off downwards and laterally into the incompetent shales.

Abrupt changes in soil coloration may be seen on the ground, corresponding to the lithologic breaks between the more ferruginous and the more gypseous shales. Dips here average 5°–6° north-east, but reversals are seen on some of the faults. Best field exposures of the Holmwood Fault Zone are found about the four mesas on the north side of the Irwin, lying between Gnoolowa Creek and Mullewa Creek. South-east of Mesa No. 4 in a tributary of Gnoolowa Creek a limestone band dips 20° south-west, while between Mesas Nos. 3 and 4, a dip of 25°E. was measured. Numerous other irregular dips may be seen in the deep gullies in this area.

One of the most interesting features of this zone is the way in which the faulting duplicates the most important fossiliferous marker horizon of the Holmwood Shale, the *Metalegoceras jacksoni* limestone band. This repetition was regarded by some as stratigraphic, though one of us (K. L. P.) felt that strike faulting east a more likely explanation, and this hypothesis was confirmed by the recent interpretation of the air photographs (R. W. F.).

Other limestone bands in this section are generally much less fossiliferous, and so far have not proved useful in the calculation of fault displacements. Such calculations are thus extremely difficult in the otherwise uniform shale sequence.

There next comes another fault zone, parallel to the last, but one to two miles farther west again. It may be followed from near the head of Mullewa Creek in the north-west to the South Holmwood Homestead in the south-east. We have called it the *South Holmwood Fault Zone*. It is notably rectilinear, with near-vertical dips, and is distinct from all other important series of faults in this part of the Irwin Basin, in that the throws are mainly to the east. In this way, the tillites of the Nangetty Glacial Formation are generally brought into contact with the Holmwood Shales, but since both formations are lithologically very soft, the fault planes are more obvious on the air photographs than on the ground.

In the tributary west of Mullewa Creek, which we have called "Tillite Creek," there is evidence of three of these minor faults. The most easterly of them, which is not well seen, brings the "cannon-ball" (concretionary) shale of the lower part of the Holmwood Shale, dipping about 2° north-east, against the soft unsorted Nangetty tillites, which also appear to be tilted about 2° north-east. The next fault plane, 150 yards upstream, is perfectly exposed trending 155° and dipping 60° north-east ; on the west side the fluvio-glacial sands and sandstones with an underlying hard tillite are dragged steeply over. These fluvio-glacial beds are very irregular and have suffered glacial disturbance, but appear to be generally dipping about 3–4° north-east. Some 300 yards upstream, a third fault causes dragging in the fluvio-glacials again to about 60° or even 70° north-east.

Immediately west of the last fault comes a group of very large erratics of what are known as the "White Horse type" (described above under "Nangetty Formation"). Not far from the line of this same fault some two and a half miles to the south-east, there is the largest of these giant erratics, the "White Horse" itself, one mile south-east of Mungaterra Homestead. Smaller blocks of the same sort occur elsewhere in the tillite series more or less on this same strike, and it has been suggested that these may be the crest of a barely covered ridge of Pre-Cambrian rocks, but the coincidence of the blocks along this line may be explained perhaps by their stratigraphic position—the strike of the beds and of the faults being almost identical.

The presence of these strike faults both east and west of the " White Horse " was determined already by Woolnough & Somerville (1924, p. 107), from the repetition of small scarps here, which indicated to them a *west* throw of about 50 feet. We were not able to explore this area carefully, but Campbell (1910) recorded *easterly* dips of 36° and 40° just here, which strongly suggests local drags on easterly throwing faults. The termination of the boulder beds south of the " White Horse " Woolnough & Somerville attributed to possible dip faulting, but of this we found no indication.

There is a general convergence of the strike faults from south to north, so that they appear to be progressively fewer, probably also reduced total displacement towards the north. The reason for the reversal of the usual westerly throws along this eastern margin of the Nangetty Glacials, leaving the Nangetty Hills as a low asymmetric horst, is puzzling, but may perhaps be due to differential compaction ; the massive tillites being far less compressible than the adjacent gypseous and saliferous shales of the Holmwood Formation.

As already indicated, the western side of the Nangetty Hills is marked by the Nangetty Fault, which has a remarkable rectilinear trend, and cuts right across our map area. The glacial beds are generally dipping gently to the east (where dips can be detected), but are dragged over to the west in the vicinity of the fault. On the downthrow side there are the Holmwood Shales in the north which are replaced by the upper beds of the Nangetty Formation in the south. In the north there is a fault-line scarp, while in the south it is reversed.

Towards the south, there are additional fault-lines diverging to the south-east from the main fracture, just as on the east side of the hills.

West of the Nangetty Fault there are very poor exposures, and in any case very little work has been done here. No further faulting was identified in the air photographs and dip readings are not clear. The beds seem to be nearly flat or gently undulating, except near the Nangetty Fault itself, where there are westerly dips clearly due to drag. A gentle west dip (about 2 degrees) is probably the explanation of the outcrops of the *Metalegoceras jacksoni* limestone north and south of Macaroni Hill, one and a half miles north-west of Nangetty Homestead. Woolnough & Somerville depicted successively higher beds of the Holmwood Shale appearing west of the Nangetty Glacials, thus implying the existence of regular dips. Of this no confirmation was made.

Finally, about one mile west of Urella Homestead, Woolnough & Somerville identified their *Urella Fault*, a major line, parallel to those described above. Their evidence, briefly, was this : a bore 200 yards north of Urella passed through 497 feet of saliferous " blue clays " (probably Holmwood Shales), while another, half a mile to the west, passed through 507 feet of soft sandstone (" certainly Jurassic " according to Woolnough & Somerville). Since these authors confirm that the general surface outcrops here are almost horizontal, only a fault would account for this displacement. Further bores put down for water by private firms and by the Army in 1943–44 in the Urella-Yarragadee-Mingenew area seem to support this evidence.

On the same trend as the Urella Fault there is a row of important, good fresh-water springs, quite different from the poor saline springs in the Permian. These include Nangade to the north-west, and Eyragulla, south-east of Mingenew. These Woolnough & Somerville quote in further evidence of their fault.

Curiously enough, it is almost unnecessary to introduce all this indirect evidence in favour of the Urella Fault, for the vertical limbs and slickensided surfaces are beautifully exposed at many points along the line. Woolnough & Somerville noted an abrupt break from Permian to Jurassic at a point two miles north-west of Urella Homestead, but standing on the hilltop only one mile south-west of the Homestead, one may observe the steep dips of the fault zone in the down-thrown Jurassic limb extending to the south-south-east across every hilltop as far as the eye can see.

Probably the clearest exposures are on the hilltops two miles south of Yarragadee (off our map area, *see* text-fig. 1) where an abundant Jurassic flora was found. Here the average slickensided fault planes strike N.N.W. and dip 70° west. The beds are much disturbed by drag folds and the structure complicated by smaller cross-faults ; the dips vary from about 20° to 70° west.

The notable difference in detail between this Urella Fault and the clear-cut fractures of the more easterly faults seems to be partly due to differences in lithology and partly to age ; the latter being probably immediately post-Permian and the former being probably Tertiary.

Also probably connected with the Nangetty and Urella Fault lines are the isolated outcrops of marine Permian in some low hills (" Fossil Hill ") two miles east of Mingenew and at Enanty Hill, three miles north-east of Mingenew, two points roughly midway between Urella and Yandanooka (Campbell, 1910, pp. 55–56). These hills rise from the broad alluvial plain of the Lockier River, so that the stratigraphical position of the beds is not clear, and to avoid confusion Woolnough & Somerville (1924, pp. 96–97) called them the " Mingenew Beds."

Special visits were paid to both localities in order to try and shed some light on the general structural problem. At Enanty Hill nearly 400 feet of ferruginous sandstones and grits, with thin shaley and silty bands, dip uniformly 15° N.N.E. Slickensided surfaces are fairly common in the shales, and the hill is cut off fairly sharply on both the west and east, apparently by major faults. Near the top is a highly fossiliferous band of Permian marine fossils, mainly spiriferids and productids (sample 29977).

The southern outcrop, " Fossil Hill " was found to expose a rather similar structure and lithologic sequence, but with more mudstones and siltstones, and near the top of the sequence were four important Permian marine fossil horizons (samples 29908–29). The thickness exposed was about 700 feet and the dip again averaged 15° N.N.E. We identified two important cross-faults trending W.N.W., one in the south and the other in the north of this outcrop ; the latter is partly marked by a large silicified sandstone dyke, as mentioned already by Campbell (1910, p. 55), and by Woolnough & Somerville (1924, p. 97).

It is significant that both these faunas suggest affinities to the higher Permian (Fossil Cliff Formation), and in any case the marine beds here would indicate a very great fault between here and the Nangetty Glacial country to the east. The line on the east is approximately where one would expect the southern extension of the Nangetty Fault, and a throw of over a thousand feet must be considered. The hills seem to be cut off just as sharply on the west, on a line where one would expect the Urella Fault to run. Thus both Enanty and " Fossil " Hills appear to lie between major fracture lines as narrow, distorted fault blocks.

In conclusion, therefore, on the question of structure, we may describe the Irwin Basin as belonging to part of a great series of fault-blocks, each down-thrown to the west and yet gently tilted up along its western edge in an antithetic manner. Thus the basement rocks come close to the surface along the western edge of each block while a fairly thick sequence of the soft overlying Permian cover rocks is preserved towards each eastern margin. Complex gravitational settling and faulting has occurred in these superficial sediments. There appears to be some differential compaction around the more massive glacial facies, possibly disposed over an irregularly eroded Pre-Cambrian surface in the basement, which suggests a small "buried hill" structure in the Nangetty Hills belt. There is, however, no trace of a broad anticline, or, for that matter, of any compressional folding in the Permian at all.

VI.—GEOLOGICAL HISTORY.

Brief interpretations of the geological history of the area have been given by Woolnough & Somerville (1924), by Woolnough (1937), and by Clarke, Prider and Teichert (1948, p. 173). The following notes are somewhat more detailed. The palaeontological facts bearing on the question of the geological age of this sequence have been discussed in some detail by Teichert (1941, pp. 389–391, 403–404). It was concluded that the *Metalegoceras* horizon corresponded to the late Sakmarian of the Urals and the Fossil Cliff Formation to the early Artinskian. The entire Irwin River sequence may thus be Lower and Middle Permian in age.

As has been pointed out, no Pre-Cambrian occurs *in situ* in the area west of the Darling Fault, and the nature of the sedimentary contact between the Pre-Cambrian and Permian rocks is not seen therefore in the northern part of the basin, but may be followed to the south in the Yandanooka area. There the younger rocks rest with a marked angular unconformity upon the irregularly eroded surface of the Pre-Cambrian (Campbell, 1910, p. 29). However, the alignment of the Pre-Cambrian Brockman Hills (*see* text fig. 1) and the Mullingarra Axis with the Nangetty Fault block (a horst) may suggest that the Pre-Cambrian basement is here not far below the present surface.

In very early Permian times sub-aqueous glacial shales, fluvio-glacial sediments and even continental tillites were deposited, indicating the presence at times of land ice in the area under consideration. This was, of course, part of the great ice-sheet which at that time must have covered much of the Australian continent.

After the deposition of the Nangetty glacials, the claystones and shales of the Holmwood Formation were deposited under rather abnormal conditions. Woolnough (1937, 1938) has advanced the theory that the formation was deposited in a barred basin. He imagines conditions to have been as follows (1938, p. 21):—

> "The area was occupied by an extensive bight separated almost, but not completely from the open sea, which probably lay to the north or west. The climate was sufficiently arid to cause an inflow current, with concentration of the salts in the water of tho basin, but not onough to develop typical redness of the formations. The sediment deposited consisted of a mixturo of fine-textured clay, together with a relatively considerable proportion of colloidal ferruginous and calcareous material precipitated from tho concentrating sea water. The access of sea water

through the bar openings was sufficient to preclude concentration to the point of deposition of gypsum or salt beds. The abundant gypsum in the upper beds is secondary, not primary in character.

"The waters were maintained at too high a pitch of salinity to permit the colonization of the area by marine organisms, thus accounting for the extraordinary barrenness in fossils, which is so surprising in a series of sediments of this character.

"The nature of the barrier separating the inlet from the ocean is problematical, since its actual existence has never been objectively proved, possibly because it has never been looked for specifically. The peculiarities of the *Gastrioceras* (*Metalegoceras*) bed point to a single catastrophic incident which, if correctly interpreted here, suggests the existence of a low bar, very little above sea level. I visualize the occurrence of a phenomenally persistent onshore wind, piling up the ocean waters on the lee shore until they broke into the basin and temporarily flooded it. By analogy with their modern representative, the pearly *Nautilus*, it may be assumed that the *Gastrioceras* (*Metalegoceras*) were floating forms inhabiting the open ocean. They were driven in enormous numbers into the highly saline waters of the basin, and the entire argosy of them was destroyed immediately and in one single act. Their remains encountered in countless thousands on one horizon, but not in the beds immediately above or below, prove definitely that we are not dealing here with any long-continued sojourn of the cephalopod types in the waters of a sea or bay. After the irruption of the sea water, the bar reasserted itself, and the former conditions of concentration by evaporation supervened. The large influx of normal sea water brought in a temporary accession of iron and lime, which is marked by the more ferruginous bed in which the cephalopod remains are preserved."

This theory accounts for the great scarcity of fossils, but does not explain very satisfactorily the absence of salt deposits in the lower part of the formation: to account for this absence it would be necessary to assume that throughout the early existence of this basin inflow and evaporation of sea-water had been so finely balanced as to result in salinity conditions which precluded the existence of life in the basin, but did not lead to the precipitation of salt. However this may be, it seems certain that the Holmwood Formation was deposited in a basin which did not communicate freely with the open sea.

We cannot agree with the Woolnough hypothesis as to the aridity (which, incidentally, is not related to "red beds"). We have evidence of a *cool climate* associated with the euxinic (Black Sea) conditions ranging to the super-saline (Caspian-type) conditions of a periodically barred basin. The sediments of the Holmwood Formation are rhythmically banded throughout and periodically there occurred an invasion of new marine water with a precipitation of lime muds. Towards the end of the Holmwood time the sea was probably becoming shallower and warmer; evaporation occurre and salt and gypsum were precipitated. (Certainly the selenite plates in the joint planes are secondary, but the calcium sulphate can only have originated by solution and reprecipitation of material already present in the sediments. Primary bands of gypsum were found.)

On closer examination, it has been found that at least nine or ten recognisable marine invasions occurred; each brought in varying number of pelagic animals. *Metalegoceras jacksoni* accompanied only one of these.

Others were characterised by other goniatites, nautiloids, the pelagic *Conularia*, and more eurytopic types of gastropod. The brachiopod *Chonetes* is not uncommon, even in the shales themselves near the top of the sequence. The fauna is restricted and dwarfed—suggesting unfavourable, perhaps cold conditions with inadequate foodstuffs.

Septarian nodules of limestone almost all through the sequence suggest precipitation of lime and colloidal clays, possibly in a periodically supersaline environment.

The unfavourable environment was probably accentuated by stagnant conditions on the sea-floor, in which only anaerobic bacteria could exist. The liberation of H_2S under reducing conditions resulted in the development of marcasite or pyrite (and later the secondary alunite and jarosite). At the same time sapropels were preserved, and in certain bands the shales exhibit a greasy texture and dark olive brown colour.

The nature of the original basin is suggested by the regional structure of this part of Western Australia, which appears to consist of a series of major fault blocks, each 10 to 25 miles wide, extending in N.N.W. to N.W. trends. These appear to be highest on the west and depressed on the east. Almost certainly tho movements along the faults started *before* the Permian (major Pre-Cambrian trends parallel them), and thus we might suspect that the ancestral fault blocks also controlled the Irwin Basin of deposition in Permian times. This almost land-locked basin lay to the east of a Pre-Cambrian ridge which rises today in the Northampton-Geraldton-Greenough region (where the Pre-Cambrian is now overlain directly by Jurassic). The ridge of Pre-Cambrian S.S.E. of Mingenew (the Mullingarra Axis) may then have been a partly submerged feature of the contemporary basin. The intermittent bar was thus probably not to the west of the present Irwin Basin, but to tho north via the southern parts of the North-West Basin.

The existence of a land barrier to the west is suggested by Carroll's heavy mineral analyses of the Coal Measure rocks which show characteristics of the Northampton-Greenough Pre-Cambrian ridge. On the other hand, there is a close lithological correlation with other Permian rocks towards the northwest (Teichert, 1941). (Similar periodically barred basins, with marcasite and sapropelic shales, etc., have now been recognised in similar fault block areas farther south, in the Perth " Sunkland " during Lower Crotaceous and Eocene.) Oceanographic conditions are thus to be compared with those off the Southern California coast today.

A serpulid reef, with a peculiar pelecypod fauna, forms Macaroni Hill, and quite early in this work it seemed likely that there were other such reefs during Holmwood times. Such a one was recently found in the south-east part of the basin. It is significant, perhaps, from the palaeogeographic point of view, that these reefs are situated near the extreme western and eastern parts of the present basin, a factor possibly suggesting a former shallowing in those directions.

Towards the end of Holmwood time a more varied invertebrate life began to find its way into the area, and by Fossil Cliff time rich animal communities were established in places over the sea floor. Tho predominating sediment was a dark carbonaceous mud which was only sparsely settled by Bryozoa (Fenestellids) and Brachiopoda (mostly *Linoproductus*). Limestone was being deposited in places where life was more plentiful and here were rich associations of Foraminifera, corals, crinoids, Bryozoa, Brachiopoda, Pelecypoda, and Gastropoda, in addition to scattered nautiloids and trilobites.

The presence of this rich and varied invertebrate life seems to indicate a marked warming in the temperature of the sea, which agrees with that noticed at the beginning of Artinskian time elsewhere in Western Australia (Teichert, 1941).

Nevertheless, alternating with the rich fossiliferous bands of the Fossil Cliff Formation, there is still a considerable proportion of sediment dominated by dark colours, gypsum, marcasite and secondary jarosite, indicating that closed basin conditions with stagnant bottom, rich in H_2S, periodically recurred. It would seem that the bar was being pretty thoroughly swamped, but that the deeper parts of the basin were still very poorly aerated.

The gradual invasion of well-rounded sands in the High Cliff Formation indicates an almost revolutionary change in conditions, which may correspond with some regional emergence. The sea had now disappeared from the area and the Irwin River Coal Measures were next laid down under lacustrine conditions. About 15 species of plants, all typical members of the Australian *Glossopteris* flora, have been identified from these beds. Many of the coaly lenses appear to be of drift origin, since underclays have not been seen.

Shortly after the formation of the highest coal seams the sea seems to have returned to the area to begin the deposition of the thick Caryngini Shales. Near the base these alternate with sandstone bands, in which worm tracks, current bedding and ripple-marks all suggest shallow water marine conditions. Only a few pelecypod remains were found in the North and South Irwin, but farther east in Caryngini Gully, a band containing a fairly rich brachiopod fauna seems to correspond to this horizon. The life was however very much the same as that of Fossil Cliff times.

The presence of erratic boulders and pebble bands, most probably dumped from drifting ice, indicates a deterioration of the climate, or at least a lowering of water temperature sufficient to have allowed ice flows to drift into the area. Also suggestive of cooler conditions are the increased angularity of sand grains and freshness of felspars, which was noticed by Carroll to begin high in the Coal Measures and to continue up into the Caryngini Formation.

Higher up in the shales the sandstone bands die out and a simple rhythmic sequence of ferruginous and jarositic shales continues. Just as in the Holmwood Formation, the presence of only partly oxidised ferruginous material and sulphate minerals suggests a return to partly closed and stagnant euxinic conditions.

Non-marine sands and silts eventually replace the marine shales upwards in the Wagina Formation, which finally becomes an almost purely arenaceous facies, except near the top where plant-bearing mudstone and thin lenticular " dirty " coal seams reappear once more.

The general sequence in the Permian of the Irwin Basin : Glacial (tillites)—Marine—Freshwater (coal)—Marine (some erratics)—Freshwater (plant beds), is so similar to that of New South Wales, that a correlation across the continent is rather tempting, as suggested by Teichert (1941) on lithological and general palaeogeographical grounds, and since supported palaeontologically by I. Crespin (1947).

Normal faulting appears to have followed close upon tho end of the sedimentation in the Irwin area, and after elevation the uneven surface was reduced to a peneplain. The truncated Permian beds were deeply indurated with the formation of duricrust, chiefly porcellanous in the case of the shales.

This peneplaned and indurated land surface was next transgressed by the basal conglomerates and continental sands of the "Plateau Beds," part of which may perhaps be Jurassic in age. Further faulting occurred during Tertiary times, notably with the development of the Urella and Moonyoonooka Faults and a considerable revival of erosion took place. These structures were partially masked by furthor planation and sedimentation, partially eolian, which has extended right into Quaternary times.

General erosion of the Irwin Valley began soon after the end of the Permian, but deep excavation of the basin began only after the elevations and revivals of tho Tertiary, and the Quaternary climatic oscillations.

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APPENDIX.

In 1912 Mr. N. L. Prest was privately employed to test the commercial value of the Irwin coal seams and put down bores for that purpose. Further bores were put down by the Public Works Department in 1920-21. The following information, which we believe to be unpublished hitherto, is taken from particulars on maps in the files of the Geological Survey of Western Australia. The positions of the bores are indicated on our map.

Prest's No. 1 *Bore—*

Depth. (feet)	
0— 10	Alluvium and red loamy soil.
10—148	Grey to black shales and sandy shales.
148—151	Hard sandstone.
151—154	Carbonaceous sandstone.
154—160	Hard sandstone.
160—161	Grey sandy shale.
161—167	Running sand.
167—176	Carbonaceous shale.
176—177	Hard sandstone.
177—182	Carbonaceous shale.
182—210	Grey sandy shale.
210	Carbonaceous shale.
211	Grey sandy shale.

Prest's No. 2 *Bore—*

Depth. (feet)	
0— 6	Alluvium.
6— 10	Red loamy soil.
10— 13	Grey sandy shale.
13— 20	Dark grey sandy shale.
20— 44	Dark grey shale.
44— 80	Dark grey shale with carbonaceous shale pipings.
80— 86	Light blue shale.
86—100	Dark grey shale.
100—101	Light grey shaley sandstone.
101—110	Very dark shale.
110—150	Grey sandy shale.
150—156	Dark grey shale.
156—164	Light grey sandy shale.
164—170	Dark grey sandstone with shaley partings.
170—190	Carbonaceous shale.

Prest's No. 3 *Bore—*

Depth. (feet)	
0— 10	Clay.
10— 21	Limestone.
21— 24	Shale.
24— 30	Very dark grey shale.
30—108	Sandstone band.
108—110	Shale.
110—135	Carbonaceous shale.
135—173	Black sandy shale.
173—204	Light sandstone.
204—206	Black sandy shale.

Prest's No. 4 *Bore—*

Depth. (feet)	
0— 31	Ironstone rubble.
31— 52	Reddish sandstone.
52— 60	Soft shaley sandstone.
60—143	Light grey shale.
143—180	Dark grey shale.
180—181	White sandy shale.
181—189	Dark grey shale.
189—191	Carbonaceous shale.
191	Dark grey shale.

Prest's No. 5 *Bore—*

Depth. (feet)	
0— 20	Alluvium and red clay.
20— 24	Light grey shale.
24— 58	Very hard slatey grey shale.
58— 74	Light grey sandy shale.
74—176	Grey sandy shale.

Prest's No. 6 *Bore—*

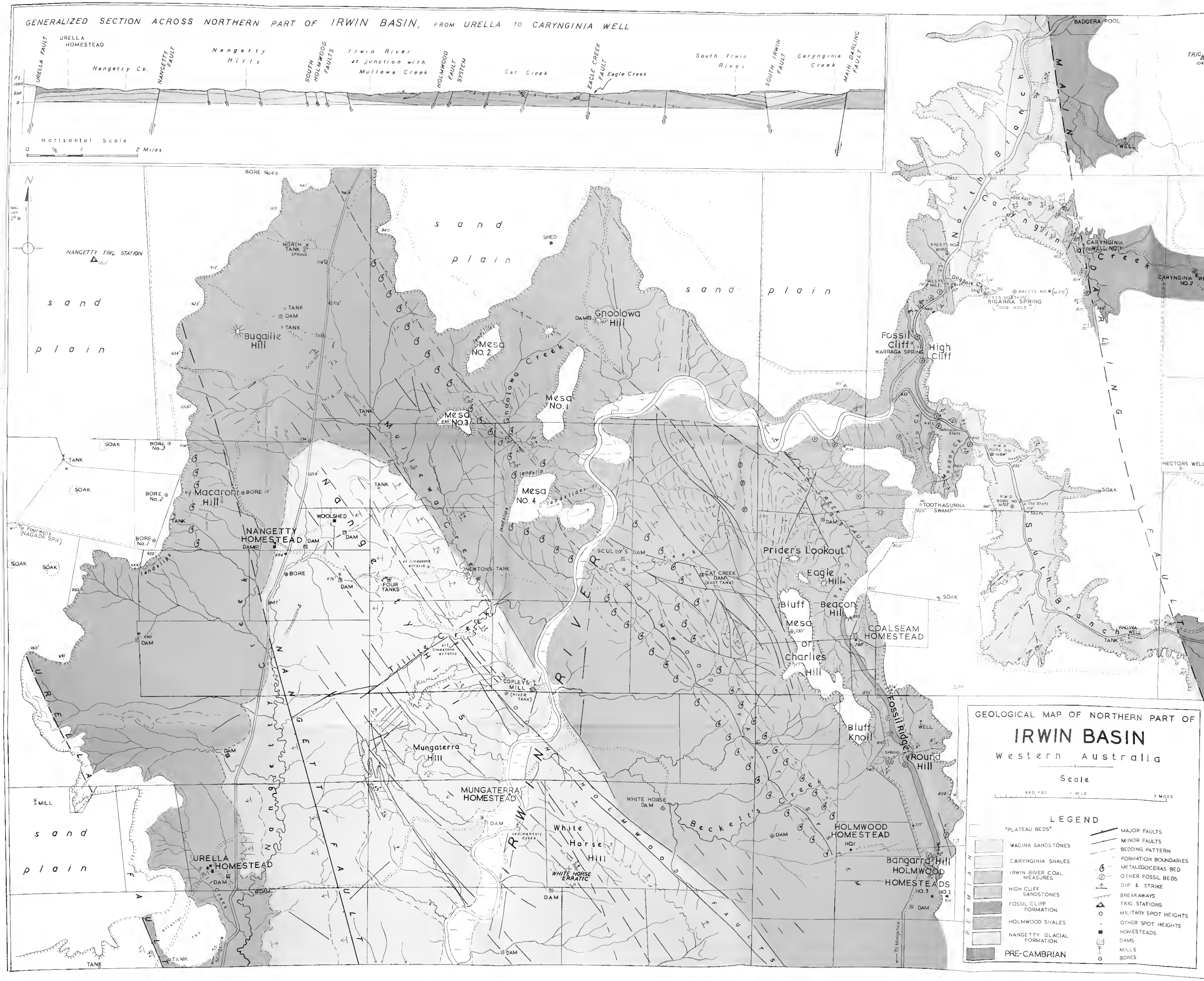
Depth. (feet)	
0— 5	Red loamy soil.
5— 19	Red clay.
19— 24	Grey shale.

P.W.D. Bore No. 1 (*put down by State in* 1920)—

Depth. (feet)	
0— 2	Soil.
2— 18	Ironstone.
18—170	Dark shale.
170—202	Shale with boulders and bands of grit.
202—230	Dark shale with bands of sandstone.
230—324	Sandy shale with bands of sandstone.
324—325	Carbonaceous shale.
325—335	Sandy shale.
335—341	Sandstone with shale bands.
341—342	Sandy shale.
342—343	Coal.
343—345	Sandy shale.
345—354	Grey sandstone.
354—355	Coal.
355—357	Sandstone.
357—358·5	Coal.
358·5—409	Grey sandy shale.
409—410	Grey sandstone.
410—411	Coal.
411—457	Grey sandy shale with many narrow bands of black carbonaceous shale.
457—458	Coal.
458—459	Carbonaceous shale.
459—460	Grey sandy shale.
460—461	Coal.
461—491	Grey sandy shale with pyrite nodules.
491—498	Grey shale.
498—516	Dark sandy shale with pyrite nodules.
516—580	Soft grey sandstone.
580—586	Sandstone with hard nodules.
586—587·5	Hard pyritic band.
587·5—605	Black puggy shale.
605—619	Fine grained shaley mudstone with small pyrite nodules.
619—670	Grey shale.
670—674·6	Hard band.

P.W.D. Bore No. 2 (*put down by State in* 1921)—

Depth. (feet)	
0— 7	Ironstone.
7— 10	Blue clay.
10—298	Dark shale (5 in. boulder at 205 ft.).
298—340	Tough shale with small hard bands.
340—390	Sandy shale.
390—400	Dark shale.
400—419	Sandstone.
419—423	Sandy shale.
423—435	Blue marl.
435—438	Sandy shale.
438—439	Coal.
439—451·5	Sandy shale.
451·5–457·5	Coal.
457·5—460	Sandy shale.
460—461·5	Coal.
461·5—463	Dark shale.
463—471	Sandstone.
471—495	Sandstone and shale.
495—525	Sandy shale.
525—537·5	Coal.
537·5–541·5	Sandy shale.
541·5–543·5	Coal.
543·5–557·5	Sandy shale.
557·5–559·5	Coal.
559·5—565	Grit.
565—566	Coal.
566—572·5	Shale.
572·5—582	Shale with narrow coal seams.
582—605	Sandy shale.
605—681	Sandstone.
681—723	Light grey shale.



GENERALIZED SECTION ACROSS NORTHERN PART OF IRWIN BASIN, FROM URELLA TO CARYNGINIA WELL
URELLA FAULT
URELLA HOMESTEAD
Nangetty Ck.
NANGETTY FAULT
Nangetty Hills
SOUTH HOLMWOOD FAULTS
Irwin River at junction with Mullewa Creek
HOLMWOOD FAULT SYSTEM
Cat Creek
EAGLE CREEK FAULT
Eagle Creek
South Irwin River
SOUTH IRWIN FAULT
Carynginia Creek
MAIN DARLING FAULT
Horizontal Scale
0 1/2 1 2 Miles
sand plain
NANGETTY TRIG. STATION
Bugalie Hill
Macaroni Hill
NANGETTY HOMESTEAD
WOOLSHED
FOUR TANKS
NEWTONS TANK
Mesa No. 1
Mesa No. 2
Mesa No. 3
Mesa No. 4
Gnoolowa Hill
Gnoolowa Creek
Mullewa Creek
IRWIN RIVER
SCULLY'S DAM
CAT CREEK DAM (EAST TANK)
Prider's Lookout
Eagle Hill
Beacon Hill
Bluff Mesa or Charlies Hill
COALSEAM HOMESTEAD
Bluff Knoll
Round Hill
Fossil Ridge
Fossil Cliff
WARRAGA SPRING
High Cliff
TOOTHAGUNNA SWAMP
BIGARRA SPRING ("DOG HOLE")
CARYNGINIA WELL NO. 1
CARYNGINIA WELL NO. 2
Carynginia Creek
North Branch
South Branch
BADGERA POOL
HECTORS WELL
WAGINA WELL
MAIN DARLING FAULT
COPLEY'S MILL (RIVER TANK)
Tillite Creek
Mungaterra Hill
MUNGATERRA HOMESTEAD
White Horse Hill
WHITE HORSE ERRATIC
WHITE HORSE DAM
Beckett's Creek
HOLMWOOD FAULTS
HOLMWOOD HOMESTEAD NO. 1
Bangarra Hill
HOLMWOOD HOMESTEADS NO. 3 NO. 2
URELLA HOMESTEAD
URELLA FAULT
NANGETTY FAULT
Nangetty Creek
Mingenew
To Mingenew
PERMIAN
GEOLOGICAL MAP OF NORTHERN PART OF
IRWIN BASIN
Western Australia
Scale
LEGEND
"PLATEAU BEDS"
WAGINA SANDSTONES
CARYNGINIA SHALES
IRWIN RIVER COAL MEASURES
HIGH CLIFF SANDSTONES
FOSSIL CLIFF FORMATION
HOLMWOOD SHALES
NANGETTY GLACIAL FORMATION
PRE-CAMBRIAN
MAJOR FAULTS
MINOR FAULTS
BEDDING PATTERN
FORMATION BOUNDARIES
METALEGOCERAS BED
OTHER FOSSIL BEDS
DIP & STRIKE
BREAKAWAYS
TRIG STATIONS
MILITARY SPOT HEIGHTS
OTHER SPOT HEIGHTS
HOMESTEADS
DAMS
MILLS
BORES

4—NEREIDAE AND EUNICIDAE OF SOUTH WESTERN AUSTRALIA; ALSO NOTES ON THE ECOLOGY OF WESTERN AUSTRALIAN LIMESTONE REEFS.

BY

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READ : 14th June, 1949.

During the course of a systematic study of Polychaete worm fauna along the coast of Western Australia the following relationships were observed and it is felt that their discussion here is of interest in consideration of general habits and geography of the particular groups concerned (viz., Eunicidae and Nereidae).

Methods of Collecting.

Specimens were collected by members of the Zoology Department of the University of Western Australia at definite intervals along a series of transects on the reefs. Rock washings, weed washings and sand washings in formalin were made at each station and relative numbers and families of worms living in different habitats and at different distances from the edge of the reef could be ascertained, together with their relationships to other marine fauna collected.

Relationship to the Reef.

Particular interest was found in reef worm fauna and their relation to the very heavy undercutting of the reefs in these area, a condition found frequently in coastal reefs in Australia. The rocks were, in some parts, heavily impregnated with worm tubes and with the living worms themselves. It seems possible that below datum or low tide level, that is, on the vertical face of the reef, the worms find conditions particularly suitable. This, together with the eroding action of waves, of sand, and of Sargassum weed which grows plentifully in this region, was a contributing factor in the undercutting of the reefs.

On this point S. Gardiner (1902) states : " Polychaeta are the most important borers in corals and rocks and the chief cause of the breaking up of the reef flat "—and further quotes McIntosh : " The action of Tropical Polychaete borers is probably greater than Northern forms and their action on calcareous rocks most destructive in wearing away the rocks."

Destructive action of worms on the reef flat could only be observed in regions well below low water mark, since reef flat constantly exposed would not provide a suitable habitat for sedentary or tubicolous worms and worm fauna in these regions is completely errant, living amongst seaweed.

Tubicolous Polychaetes were also found building up reefs in certain parts. The sheltered north reef of Point Peron is built up entirely of worm tubes. The erection of such friable reef was possible in this region sheltered from the stronger eroding action of the heavier seas on the west side of the Point.

Geographical Distribution.

Augener (1913) has given a full acount of the geographical relations of this area. The Indo-Malayan and tropical nature of tho fauna is particularly noticeable in all regions as far south as Point Peron, where a warm tropical current in winter keeps the temporature comparatively high and in summer the generally higher temperatures of coastal waters enable a more or loss constantly high temperature throughout the year. I have further observed an interesting gradation in the nature of the fauna from north to south along the coast. Eunicidao and Nereidae are the most plentiful families represented in all localities. At Nornalup the Nereids are large and plentiful, while there were only two Eunicidae of about 10 mm. in length. At Point Peron and Rottnest the Nereids and Eunicidae are equally plentiful and of comparable size, while at the Abrolhos Eunicidae are large and Nereidae small (an average of 15 mm. in length), although plentiful.

It is therefore concludod that more tropical waters favour Eunicidae while colder waters in the region of Antarctic current favour the development of Nereidae, which group is, however, also plentifully represented in tropical waters although by smaller forms. This conclusion is confirmed by an observation made by Benham (1921) to the effoct that Eunicidae are rare in Antarctic waters.

The total numbers of specimens from the families Nereidae and Eunicidae from all stations are more or less similar. Nereidae, however, were represented by 13 different species, while Eunicidae were represented mainly by *Eunice antennata* and rare specimens of other species. Thus it appears that Nereidae, while such a clearly defined group, are widely variable within their group and flourish under a wide variety of conditions to which they are easily adapted. This is also true of Eunicidae but to a very much lesser extent.

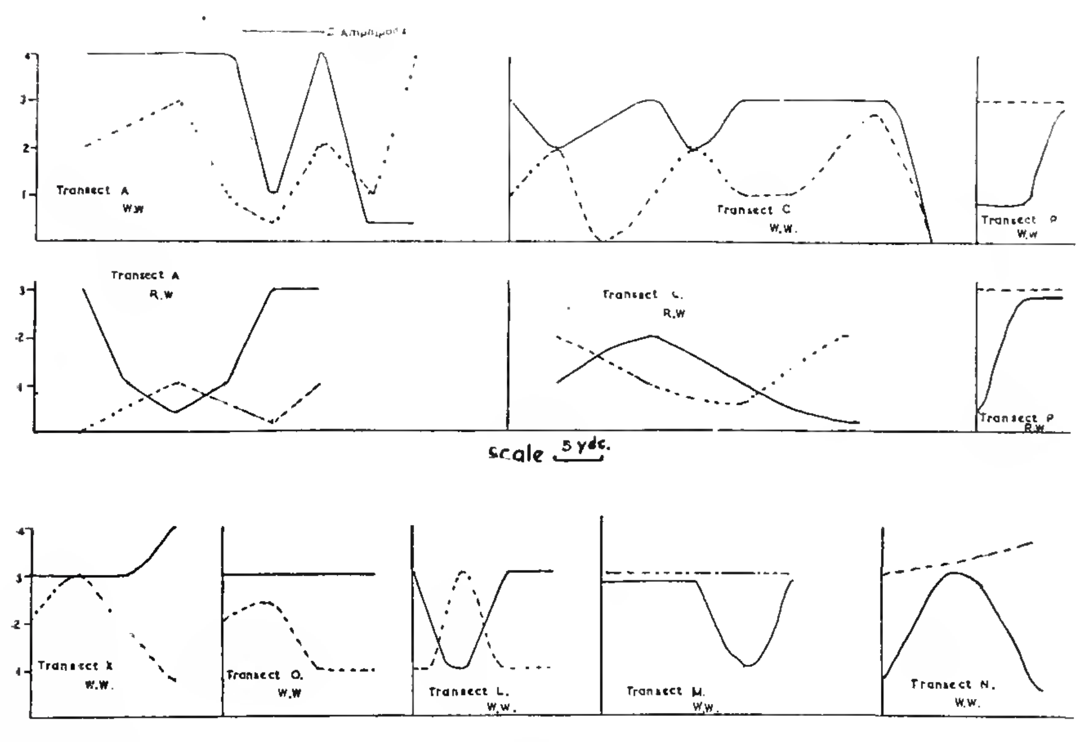
Relation to other Fauna on the Reef.

From graphs (text fig. 1) based on rough arbitrary measures of comparative populations on Point Peron reefs, the number of Polychaetes from rock washings were, where present, equally as plentiful as those collected from weed washings. Not as many washings, however, were made from rock as from weed since it was, in some cases, too hard to break off. This was especially the case in the centre of the reef where the rock had not been weakened by the undercut.

An interesting relationship between Polychaeta and Amphipods stands out very clearly from studies on these reefs. Whether it is of ecological significance or whether it is merely a coincidental relationship is a matter for further investigation. However, the condition was amazingly constant.

Where the population of Amphipods was greatly increased the Polychaete fauna were numerically small and with an increase in Polychaete fauna the Amphipods decreased in number. McIntosh (1910, p. 259) states that : " Nereids (in particular) eat algae, other worms, sponges, and crustacea," which may explain the variations. However, particles found in the pharynx of the worms examined seemed to be seaweed rather than crustacean in nature. Alimentary canals of the crustacea have yet to be examined. The possibility that conditions favouring amphipods were exclusive for Polychaetes seems most unlikely as the weeds were plentiful and, in many places, of similar nature. Nor is the explanation that conditions on the edge of the reef are unsuitable for either group possible since sometimes here the Amphipods are the dominants in the population and at other times the Polychaete fauna are dominant.

In the regions where Polychaete numbers were few in the weed, they showed a marked increase in rock. In the weed and rock there was little difference in the nature of Polychaete fauna, although Nereidae were more plentiful in weeds than in rocks. Other errant families Hesionidae, Syllidae, Amphinomidae, Aphroditidae, Chrysopetalidae, were found, each successive family fewer in number and showing no differences between distribution in weed and in rocks. Sedentaria were obtained mainly from rocks, as affording a firm and permanent base. From submarine light and N7OH hauls the majority of specimens were small *Platynereis dumerili*.



Text Fig. 1.

Graphs showing distribution of fauna along reef transects.

List of Western Australian Nereidae and Eunicidae.

Nereidae—

Previously recorded by Augener (1913).

Nereis ehlersi Aug.
,, *augusticollis* Aug.
,, *albanyensis* Aug.
,, *jacksoni* Kbg.
,, *cricognatha* Ehl.
,, *kerguelensis* McI.
,, *lapinigensis* Grube (syn. *N. costae* Grube)
,, *tentaculata* Kbg.
,, *aequisetis* Aug.
Perinereis amblyodonta (Schm.)
,, *vallata* (Gr.)
,, *heterodonta* Grav.
,, *variodentata* Aug.
,, *variodentata* Aug.
Platynereis australis Schm.
,, *dumerilii* Aud. & Ed.
Pseudonereis rottnestiana Aug.

Previously recorded by Fauvel (1922):

Nereis denhamensis Aug.
Pseudonereis anomala Grav.
Platynereis dumerili Aud. & Ed.

Previously recorded by Monro (1938):

Nereis oxypoda Marenzeller
,, *erythraensis* Fauvel

Species newly recorded from Western Australia:

Nereis callaona Grube
,, *nichollsi* n. sp.
,, *thompsoni* n. sp.

Eunicidae—

Previously recorded by Augener (1913)

Eunice aphroditois (Pall)
,, *antennata* (Sav.)
,, *tentaculata* Qfges.
,, *tubifex* Crossland
,, *siciliensis* Grube
Marphysa furcellata Crossland
Lysidice brevicornis Kbg.
,, *collaris* Gray.
Lumbriconereis sphaerocephala Schm.
,, *brevicirra* Schm.
Stauronereis australis Hasw.
,, *australiensis* McIn.

Previously recorded by Fauvel (1922):

Eunice tentaculata Qfgs.
,, *siciliensis* Grube
,, *antennata* (Savigny)
,, *australis* Qfgs.
Lysidice collaris Grube

Previously recorded by Monro (1938):

Marphysa sanguinea (Montagu)

Species newly recorded from Western Australia:

Eunice denticulata Webster
Marphysa bifurcata n. sp.

Relationships of Family Nereidae.

All species recorded below were found associated with one another at different places and there was no definite and constant association between any two or more forms. Platynereids were the most plentiful forms found in weed on the reefs. *Nereis nichollsi, Nereis jacksoni, Neanthes albanyensis, Neanthes thompsoni* were relatively more plentiful in rocks. Other forms recorded were comparatively rare.

An arbitrary ratio has been used below to indicate the relative occurences of the most common forms in rock and weed. It must, however, be noted here that the association between rock living and weed living forms is particularly close, and weed living forms may migrate to excavations made in the rocks by other forms, not necessarily Polychaeta.

The following ratio is used in the table below :—

$$\frac{\text{Number of Stations from which species taken}}{\text{Total Number of Stations from which collections taken}}$$

Species.	In Weed.	In Rock.
Platynereis dumerili	.76	.21
Nereis nichollsi	.12	.14*
Nereis jacksoni	.18	.28
Neanthes thompsoni	.12	.14*
Neanthes albanyensis	.24	.36

* This difference, however, in view of the few stations from which specimens were taken is of doubtful significance.

Perinereid, Ceratonereids taken were too few for their habitat to be significant.

These figures can be correlated with the types of jaw armature of the forms concerned. Platynereids are most modified for softer environment with their small paragnaths, while Nereids with large conical paragnaths are more particularly efficient in wearing a path within the limestone reefs. Here they are less subjected to the destructive action of waves which the Platynereids may escape due to smaller size.

Relationships of Family Eunicidae.

One species, *Eunice autennata* Sav., was collected in overwhelming numbers from all stations from which Eunicidae were taken. The comparative reduction of Eunicidae at more southerly stations has been already indicated; as has other data concerning the few species represented while individuals of the one species were plentiful.

EUNICIDAE AND NEREIDAE OF SOUTH-WESTERN AUSTRALIA.

Classification.

Variability of many characters and their changin from in different stages of contraction and extension of the body render them useless as specific criteria (Crossland 1903). Parapodia and setae are found to be the most dependable characters since environment affecting them is more constant and the latter are not affected by preserving agents (McI. 1885); arrangement of teeth in the pharynx is also, within certain limits, a dependable character, although there are certain changes, especially in number of denticles, from place to place, perhaps according to diet. Through the above characters intermediate stages may be traced (*viz.*, discussion below on *Nereis thompsoni* n. sp. ; *pelagica* L. and *cultrifera* Grube ; McIntosh 1910, p. 256).

Keys to species throughout this work have been prepared with some care to give a reliable means of identification and to provide an overall impression of the variations within the group. The majority of described species, where literature is available, have been included as so many forms are of cosmopolitan nature. Insufficient work has yet been dono to know which other forms may yet be proven to be world wide in distribution.

Where possible loss variable characters havo been used for wider groupings with more variable characters employed for finer specific distinctions. Thus it is hoped that the keys will give some idea of trends within any genus as well as providing useful and practical aids to identification.

Genus **NEREIS**.

Subgenera of this genus are differentiated according to presence or absenco of denticles in certain pharyngeal regions. However, as pointed out by Augener, Fauvol and Horst, " a group of paragnaths usually present may, by exception be absent " (Horst 1924) and certain species with other dependable characters in common (*e.g.*, *Neathes thompsoni* n.sp. together with *Nereis heirissonensis* Aug., *jacksoni* Knbg. and *mortenseni* Aug. all have identical and characteristic dorsal falcate setae) differ in the arrangement of pharyngeal paragnaths. Therofore it is maintained that division into subgenera as above does not imply a separation in terms of natural relationship but represents a means of dividing an unwieldy genus into a convenient working subdivision as no other constant character for distinction into subgeneric groups has yet been detormined.

The nature of the paragnaths should, where possible, be used for distinctions rather than the presence or absence of paragnaths in any area thus :

Nereis atlantica (McIntosh 1885) has paragnaths on all groups except VI and horny ridges in V. This should relate the form to *Perinereis*. McIntosh believes that it diverges from the lattor in lack of paragnaths on VI but in view of the nature of the horny ridges in V it would seem to warrant a new sub-division under Genus *Perinereis*.

Nereis patagonica (McIntosh 1885) also seems to warrant a new sub-genus of genus *Nereis* since there are paragnaths constantly in V and thoy are lacking in I, II and VI. Also related to this form is *cockburnensis* Augener (1913) which bears pargnaths in V but lacks them Group I. Although genus *Pisonoe* bears teeth in these regions they are typical and unlike characteristically widely separated cones typical of the genus *Nereis*.

Sub-Genus **NEREIS** sensu stricta

KEY TO SPECIES.

Chamberlain (1919) and Fauvel (1923, 1932) have already published keys to this group. The purely European forms of the coast of Franco have been omitted from this present key. Fauvel's (1923) key and that prepared by Chamberlain should be used as well as the following to completely account for all members of this group. *N. nonhuysi* Horst, a freshwater form, has been omitted from the key.

The reference given, following the specific name, refers to the latest published record to that species and will give further reference to synonymy and descriptions.

1.	No Eyes	*N. typhla* (Monro 1930)
	Eyes	2
2.	Simple hooks present	*N. onychylochaeta* Horst *N. onycophora* Horst (Fauvel 1932)
	No simple hooks present	3
3.	Spinigerous bristles only present	4
	Spinigerous and falcigerous bristles present	5
4.	Posterior parapodial lobes normal	*N. chringighattensis* Fauvel (Fauvel 1932)
	Posterior parapodial lobes elongated	*N. longisetis* McIntosh (McIntosh 1885)
5.	Dorsal homogomph falcate bristles in post feet	6
	No dorsal homogomph falcate bristles in post feet	20
6.	No spinigerous bristles in ventral division	*N. tydemani* Horst (Horst 1924)
	With spinigerous bristles in ventral division	7
7.	Terminal piece of dorsal falcate bristle smooth	8
	Terminal piece of dorsal falcate boldly dentate	15
8.	Dorsal ligule of post feet enlarged	9
	Dorsal ligule of post feet not enlarged	11
9.	Long dorsal cirrus	10
	Shorter dorsal cirrus	(Ehlers 1901) *N. callaona* Grube
10.	Anteriorly no setose bristles in ventral bundle of ventral division	*N. nichollsi* n. sp.
	Anteriorly has setose bristles in ventral bundle of ventral division	*N. coutieri* Gray (Fauvel 1932)
11.	Single row paragnaths in VII., VIII.	12
	More than a single row in VII., VIII.	13
12.	Paragnaths in group III., dorsal cirrus twice length dorsal lobe	*N. riisei* Grube (Monro 1933)
	Paragnaths in group III., dorsal cirrus only slightly longer than dorsal lobe	*N. eugeniae* Kbg. (Ehl. 1901)
13.	Group I., II., without paragnaths	*N. antillensis* McI. (McI. 1885)
	Group I., II., with paragnaths	14
14.	Short dorsal falcate bristle blunt toothed	*N. pelagica* L. (Fauvel 1923)
	Longer dorsal falcate bristle with curved tip	*N. falsa* Qfges. (Fauvel 1923)
15.	Single row paragnaths on VII., VIII.	16
	More than a single row paragnaths on VII., VIII.	19
16.	Prostomium notched anteriorly	18
	Prostomium not notched anteriorly	17

17.	Dorsal lobe reduced posteriorly	*N. jacksoni* Kbg. (Fauvel 1932)
	Dorsal lobe not reduced posteriorly	*N. denhamensis* Aug. (Fauvel 1917)
18.	With paragnaths on VI.	*N. kauderni* Fauvel (Fauvel 1932)
	Without paragnaths on VI.	*N. mortensensis* Aug. (Augener 1923)
	(*N. mortenseni* is synonymous with *Ceratonereis falcaria* Willey.)	
19.	Length of buccal segment less than twice succeeding segments	*N. zonata* Malmgren (Monro 1936)
	Length of buccal segment greater than twice succeeding segments	*N. fulchalensis* Langerhans (Monro 1933)
20.	No heterogomph falcate bristles present	*N. batjanensis* Horst (Horst 1924)
	Heterogomph falcate bristles present	21
21.	Single row paragnaths on VII., VIII.	22
	More than single row paragnaths on VII., VIII.	29
22.	Only aciculae in posterior feet	*N. heteromorpha* Horst (Horst 1924)
	Aciculae and other setae present in posterior feet	23
23.	No ventral heterogomph setose bristles	24
	With ventral heterogomph setose bristles	25
24.	Parapodial lobes flagellate	*N. longilingulis* Monro (Monro 1936)
	Parapodial lobes normal	*N. larseni* Monro (Monro 1924)
25.	Dorsal division of anterior feet bifid	26
	Dorsal division of anterior feet trifid	27
26.	Dorsal lobe increase posteriorly	*N. ruficeps* Ehl. (Ehlers 1904)
	Dorsal lobe does not increase posteriorly	*N. unifasciata* Willey (Fauvel 1932)
27.	Dorsal lobes more elongate posteriorly	*N. gisserana* Horst (Horst 1924)
	Dorsal lobes unchanged posteriorly	28
28.	Posterior dorsal divisions bifid	*N. kerguelensis* McI. (Augener 1927)
	Posterior dorsal divisions trifid	*N. glandicincta* Southern (Fauvel 1932)
29.	With a dorsal tubercle on dorsal border parapodium	*N. buitendijki* Horst (Horst 1924)
	Without dorsal tubercle on dorsal border parapodium	30
30.	Middle lobe and dorsal setigerous lobe on elongate base	*N. talehsapensis* Fauvel (Fauvel 1932)
	Middle lobe and dorsal setigerous not on elongate base	31
31.	Dorsal lobe enlarged	32
	Dorsal lobe not enlarged	33
32.	Without heterogomph setose bristles in ventral bundle, ventral division	*N. augusticollis* Aug. (Augener 1913)
	With heterogomph setose bristles in ventral bundle ventral division	*N. baliensis* Horst (Horst 1924)
33.	Falcate appendages short	*N. chilkaensis* Southern (Fauvel 1932)
	Falcate appendages long	34
34.	Falcate appendages curved	*N. indica* Kbg. (Fauvel 1932)
	Falcate appendages not curved	*N. sunbawensis* Horst (Horst 1924)

Inclusion of Horst's species in this key was impeded by incomplete descriptions of prostomium, parapodia and setae of all species.

Nereis nichollsi n. sp.

Text Fig. 2 a—k.

Text Fig. 2.
Nereis nichollsi n. sp.
a—head; b—ventral pharynx (dissected); c—dorsal pharynx (dissected); d—1st parapodium; e—3rd parapodium; f—13th parapodium; g—40th parapodium; h—posterior parapodium; i—dorsal homogomph setose bristle; j—ventral falcate seta; k—dorsal falcate seta.

From weed and rock at the outer edge of the reef ; Rottnest, Pt. Peron, Abrolhos. Thirty-six specimens, Atocous. Length 12–50 mm. ; breadth 1–4 mm. broadest anteriorly. Colour in alcohol from whitish pink to dark brownish pink or green, according to habit. Number of Segments ; 51–63.

Buccal Segment twice length of succeeding segments dorsally and three times their length ventrally. *Prostomium* (text fig. 2a) posterior part bearing the eyes twice as broad as long and with the frontal process and palps forms a square. Not notched anteriorly. *Palps* are large, arise from antero-ventral and latero-ventral region of the posterior part of the prostomium. Basal part is flattened laterally into a circular plate. Torminal appendix spherical. Shape and orientation of the basal part of the palps forms a well marked groove leading to tho mouth. *Peristomial cirri* of average length. Postero-dorsal the longest, reaches to three-fifth setigerous segment. Antero-dorsal four-fifth length of former and both bentral cirri are half the length of the corresponding dorsal cirri. *Eyes* set in a rectangle, anterior pair slightly further apart, contain lenses. In one specimen (text fig. 2a) the anterior pair have become a dispersed pigmentous mass in the prostomium ; and in other specimens both eyes havo lost their form and are represented by a pigmented area.

Pharynx (text fig. 2b, c). Jaws large and curved, dark brown, about nine teeth on each. Paragnaths large, conical in closely-packod rows ; absent in Area V. Arrangement of paragnaths as in text fig. 2b, c.

Parapodia (text fig. 2d-h) extend laterally to a distance equal to one-third of the body width. First parapodium without dorsal lobe and setigerous bundle, ventral and middle lobes extend the same distance laterally and are half as long as the ventral cirrus and one-third as long as the dorsal cirrus. Dorsal lobe and setigerous bundle appear on the third setigerous segment. Here the dorsal cirrus is twice the length of the dorsal lobe and of equal thickness and half the thickness of the middle lobe and the ventral lobe, setigerous lobe and cirrus ; the ventral cirrus is shorter than the ventral lobe. Further posteriorly the dorsal lobe extends slightly laterally, the dorsal cirrus is carried to its apex and reaches a maximum length of four times the length of the lobe at fortieth parapodium ; the more ventral lobes maintain the same relationships although they are reduced to the same thickness as the more dorsal elements ; the ventral cirrus is half as thick (text fig. 2d-g) as long as the ventral lobe at the thirteenth parapodium and thereafter slightly shorter. Anteriorly lobes are rounded with parallel sides, posteriorly they are conical and pointed. The shape of the parapodium changes from a base equal to its lateral extension, at the thirteenth parapodium the base is broader and posteriorly a decrease in the width of the base. Posteriorly gland cells in the lips of dorsal and middle lobes. *Setae* (text fig. 2i-k) anteriorly are dorsal homogomph setigerous bristles, ventral supracicular homogomph setigerous and heterogomph falcigerous bristles, and sub-acicular heterogomph falcigerous bristles. Posteriorly are dorsal homogomph falcate setae and ventral supra acicular heterogomph falcigerous setae and sub-acicular heterogomph falcigers and not more than two heterogomph setigerous bristles. The dorsal falcate bristles are never more than three in number and in the middle region of the body they are present with one or two homogomph setigerous bristles.

The tip of the appendix of both the heterogomph and homogomph falcate bristles is not obviously toothed and is only slightly curved. The curved edge is about half the length of the whole appendix and has hairs only on the lower half of its length. The setigerous setae are haired along the whole length of the appendix which is not extremely long and is approximately four times the length of the portion of the appendix articulating with the shaft. The shafts to the falcate setae are twice as thick as those of the setigerous setae.

Relations.—This form resembles very closely *Nereis coutieri* Gravier. The jaws are, however, dissimilar and there are in the latter heterogomph setigerous bristles ventrally in the anterior part of the body. Also in *N. coutieri* the dorsal lobe, as well as carrying on it the dorsal cirrus, has expanded into a round prominence dorsally and the different lobes of its parapodium are more widely separated than the form at present under discussion. The form of the parapodia resembles more closely *Nereis succinea* Leuckart but the dorsal cirrus of *N. succinea* is very much larger, resembling a third lobe.

The appearance of the paragnaths in closely set rows was very reminiscent at cursory examination of the rows of pectinato paragnaths characteristic of Platynereids, except for a relatively larger size. This suggests a possibility that Platynereids, by a fusion of the base of paragnaths are the result of specialisation of the jaw apparatus in the typical nereid form. Further fusion may result in the transverse ridges of Perinereids. McIntosh (1885), discussing *Platynereis tongatabuensis*, remarks that the "Continuous bars in group VII, VIII appeared, under higher magnification, to be separated minute points in compact series." This is also observed in the Platynereids of this collection, suggesting again the origin of pectinate paragnaths from entire and isolated conical teeth.

Nereis jacksoni Kinberg.

(Text Fig. 3 a–r)

Kinberg	1865	*Nereis jacksoni*
Augener	1913	*N. heirissonensis*
,,	1922	*N. jacksoni*
,,	1924	*N. jacksoni*

(*See* notes below on *Nereis jacksoni.*)

Atocous form.—Fifty specimens with *N. denhamensis* Aug. from Rottnest ; large numbers from Nornalup but no specimens of *N. denhamensis* taken from this area. Colour in alcohol pinkish white to deeper pink ; dark brown pigment patches on dorsum of prostomium and palps. Specimens from Rottnest, Point Peron 20–25 mm. long, 1 mm. broad, with about 60 segments. From Nornalup specimens 25–30 mm. long with 60–70 segments.

Prostomium, Palps, Tentacles, Eyes, as described by Augener (1913) for *N. heirissonensis.* Anterior margin of prostomium is not cleft. *Peristomial cirri* extend back to two-third perapodial segment.

Pharynx (text fig. 3 b) has typical small brown paragnaths which do not suggest a transparent or Ceratonereid condition (Augener, 1913). Arrangement of paragnaths is similar although there is a reduction in their numbers in larger Nornalup specimens as follows :—

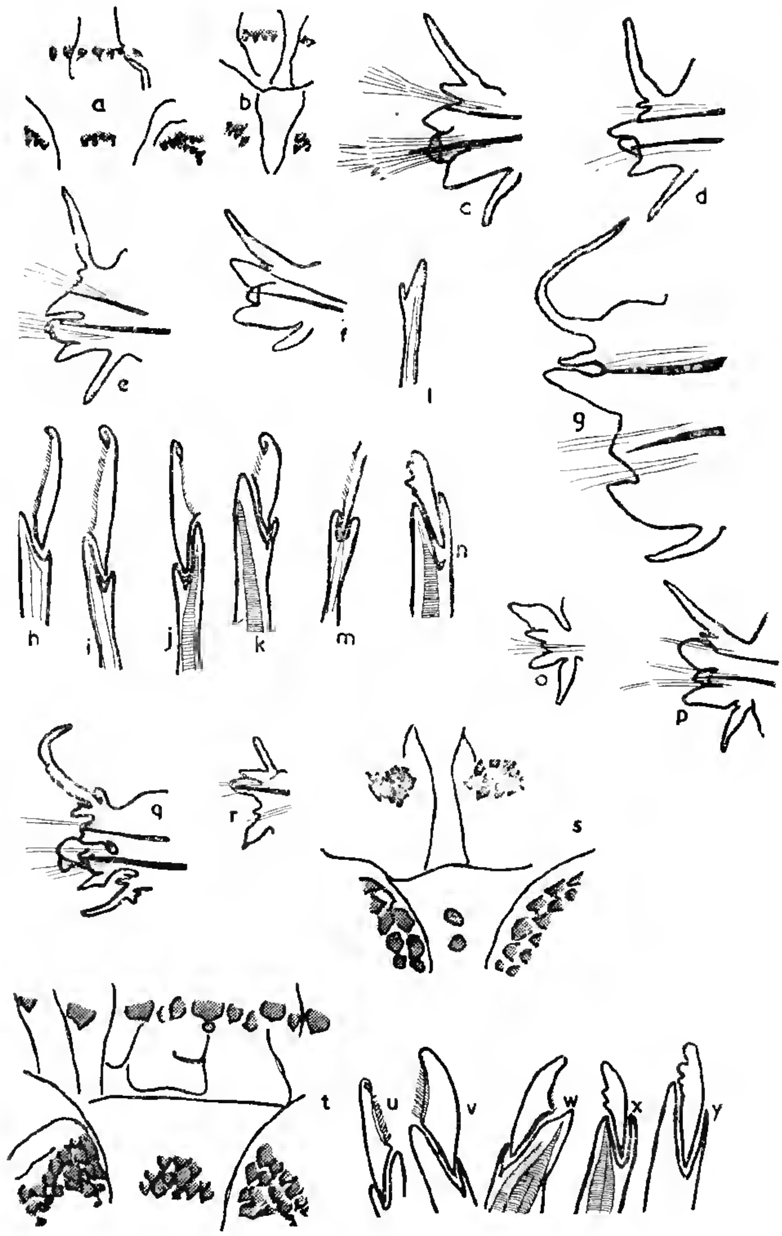
Point Peron-Rottnest :

I.	0
II.	Two oblique double rows of 4-2 paragnaths in each row.
III.	Transverse row of 5
IV.	Crescent of 9 anteriorly and 2-4 posteriorly
V.	0
VI.	Single transverse row of 4
VII., VIII.	Single row of 7 widely spaced.

Nornalup :

I.	0
II.	3 in oblique line
III.	0
IV.	2 curved rows, 3 in each
V.	0
VI.	1
VII., VIII.	A single row of 7 paragnaths

The paragnaths are all of much the same size. This latter condition is dentical with that given by Augener (1913).



Text Fig. 3.

Nereis jacksoni Kbg.

a—pharynx ventral; b—pharynx dorsal; c—4th parapodium; d—10th parapodium; e—12th parapodium; f—30th parodium; g—posterior, from Nornalup variety; h—anterior subacicular falcate seta; i—anterior supra-acicular falcate seta; j—posterior supra-acicular falcate seta; k—posterior sub-acicular falcate seta; l—hetero setose bristle shaft; m—homo setose bristle; n—dorsal falcate seta; o—1st epitocous parapodium; p—9th epitocous parapodium; q—15th epitocous parapodium; r—53rd cpitocous parapodium.

N. denhamensis Aug.

s, t—pharynx; u—anterior subacicular falcate seta; v—anterior supra-acicular falcate seta; w—posterior supra-acicular and subacicular falcate seta; x—anterior dorsal seta; **y**—posterior dorsal falcate seta.

Parapodia.—In first-third setigerous segments appendage lacks a dorsal lobe, the dorsal cirrus is one and a half times the length of the middle and ventral lobe and the ventral cirrus slightly shorter ; lobes round with parallel sides. At tenth parapodium the dorsal lobo attains maximum length of half the middle and ventral lobes, the dorsal cirrus twice the length of the latter two lobes and the ventral cirrus of equal length ; the lobes have become conical and pointed (text fig. 3d, e) more posteriorly the dorsal lobe gradually diminishes until it disappears entirely at about segment 35 in Rottnest and Point Peron specimens (text fig. 3f) but remains as a small projection half the length and thickness of the middle. This latter is the condition described by Augener (1933) for *N. heirissonensis* (text fig. 3g). *Setae.*—Anteriorly dorsal homogomph spinigerous bristles (text fig. 3m), ventral supracicular heterogomph falcigers (text fig. 3i) and subacicular heterogomph spingers (text fig. 3l). Posteriorly the spingerous bristles of the dorsal bundle are replaced by two, rarely three, homogomph falcigers with four teeth along their curved border ; the two proximal to the shaft are fine and hair-like. The ventral falcate setae are haired along the curved edge of the appendix, those of the supracicular longer than the subacicular and both types longer and narrower anteriorly. Setae are most plentiful anteriorly. Augener (1913) describes ventral acicular setae as outnumbering spinigerous bristles but this is not so in these specimens. Constant differences in the pharynx and parapodia of specimens from Point Peron, Rottnest and Nornalup show the latter forms as intermediate stage between *N. denhamensis* Aug. and *N. jacksoni* Kbg., as will be discussed below.

Epitocous form.—Two epitocous specimens of *N. jacksoni* were collected with the atocous forms and, as far as can be ascertained, are the first recorded epitokes of this form. They were both small, 15–20 mm. and 1 mm. in breadth. The prostomium was not markedly changed in any way, except for the eyes which were enlarged greatly though the eyes on either side of the head were not quite contiguous. The eyes were of a dark brown colour, almost black. The body was divided into three regions. The anterior atocous region reached to the fourth parapodial segment. The epitocous region extended thereafter for 36 segments and 44 segments respectively in the two specimens, and the posterior region was once again atocous. occupying 19 segments. The first parapodium (text fig. 3o) was identical with the same parapodium of the atocous form described above, except for enlargements in the dorsal and ventral cirri. These enlargements persisted in the first 34 parapodia but in the seventh parapodium the cirri had assumed a more slender and usual form and the whole parapodium entirely resembled that of the same region of the atocous form. The dorsal lobe first appears at the fourth parapodium. On the twelfth parapodium the middle and ventral lobes have become thicker and foliaceous and on the fourteenth segment the typical epitocous form has commenced. The epitocous appendages (text fig. 3r) are fundamentally constant throughout that region, changes taking place only in the size of the foliaceous outgrowths of the lobes, which increase posteriorly. The dorsal cirrus becomes very long, about four times the length of the dorsal lobe which reaches laterally as far as the setigerous and ventral lobes. The ventral cirrus is slightly longer than the ventral lobe. The middle lobe extends ventrally and laterally in a large fan-shaped outgrowth. The ventral setigerous lobe extends dorsally and laterally in a similar outgrowth which overlaps the former. The ventral lobe gives off ventrally an elongate finger-like process arising dorsally from its base and posteriorly becoming double, also a ventral arborescent outgrowth of two limbs. At the twenty-second parapodium, the dorsal cirrus has small and numerous sacculations along the ventral surface and single finger-like processes dorsally from dorsal lobe and dorsal cirrus respectively. The dorsal lobe progressively diminishes posteriorly. At the fiftieth segment the epitocous parapodia cease and the atocous form is resumed. There is here a total loss of the dorsal lobe and the middle lobe is considerably reduced. The dorsal cirrus is not as long as the atocous from this region of the body and has an enlargement similar to that of the first parapodium.

The setae of the atocous parapodia, particularly the sturdy falcate setae show a tendency to remain with the epitocous setae in the epitocous region of the body. There is at least one example of each seta usually to be found in each setigerous lobe, with the exception of heterogomph bristles in the ventral supracicular group where they are absent in the more posterior epitoke segments. (There is an absence of these setae in this group noted by Augener (1913) in describing *N. denhamensis*). The typical dorsal homogomph falcate bristles appear in segment 15. At the fiftieth segment the epicous bristlos are lost and the setae of the posterior segments of the atocous parapodia are left as described above.

The pharynx agrees in all groups, with that of the atocous form. There is noted, however, a tendency for reduction in some of the groups. Whether this is a change concurrent with the epitocous state or whether it is due to an early maturity or is merely an individual variation, cannot be ascertained with the small number of specimens available for examination. This reduction involves, in II, a single oblique row of three paragnaths in place of longer double rows ; in group III only three paragnaths in a transverse row. All other groups are identical with the previously described atocous form.

There are some specimens of this form which, although not epitocous, were filled with eggs. The epitocous form is not always developed with sexual maturity. The posterior atocous region of the epitocous specimen may possibly be due to regeneration but this cannot be ascertained until further specimens can be examined. However, this condition was constant in the two available epitokes and the parapodia of this region are well formed, with a definite decrease in the size of the epitocous segments posteriorly and a gradual change to atocous parapodia.

Nereis denhamensis Augener.

(Text figs. 3 s-y ; 4 l-q)

Augener 1913 *N. denhamensis*
Fauvel 1917 *N. denhamensis*
(*See* discussion below on *N. jacksoni*.)

Text Fig. 4.

Nereis callaona Grube.

a, b—pharynx; c—8th parapodium; d—52nd parapodium; e—56th parapodium; f—67th parapodium; g—dorsal falcate seta; h—anterior subacicular falcate seta; i—anterior supra acicular falcate seta; j—posterior sub acicular falcate seta; k—posterior supra acicular falcate seta.

N. denhamensis Aug.

l—1st parapodium; m—8th parapodium; n—34th parapodium; o—2nd epitocous parapodium; p—6th epitocous parapodium; q—34th epitocous parapodium.

Atocous form.—Sixty specimens from Point Peron and Rottnest. Length 15-60 mm., breadth 1.5-4 mm., with 70-80 segments. Colour in alcohol from white to dark pinkish brown with brown pigment spots on dorsum of prostomium and on the palps.

Prostomium, palps, tentacles as previously described. *Peristomial cirri* sometimes reach back to the 4th setigerous segment. *Pharynx* (text fig. 3 s.t.) differs from that of *N. jacksoni* Kbg. in greater number of paragnaths present in all groups and in the shape of groups III, IV, VI ; as described by Fauvel 1917.

Parapodia (text fig. 4 l-n) lobes generally more rounded than the corresponding lobes of former species, becoming pointed only at about the 20th parapodium. The middle lobe is slightly longer than the ventral lobe. The dorsal lobe is equal to the middle lobe at about setigerous segment 8 and at 34th segment is definitely longer, while posteriorly it is only slightly reduced. Dorsal cirrus is as long as that of *N. jacksoni* Kbt. but is not carried out along the dorsal lobe. The ventral cirrus reduced posteriorly to half the ventral lobe. *Setae* more numerous than preceding species and with a thicker shaft and appendix ; the latter much shorter (text fig 3 u-w). There is not a marked differentiation in the length of supra and sub-acicular falcate appendices although the former is thicker. Posteriorly both are similar. Four falcate bristles appear anteriorly in the dorsal bundle replacing spinigerous setae at about segment 30.

Epitocous form.—Two specimens measuring 20 and 28 mm. in length by 2 mm. in breadth. The prostomium and prostomial appendages show no change. The eyes are large but not contiguous and are coloured dark brown. The body consists of two regions only, anterior atocous and posterior epitocous regions. The epitocous segments begin at the 15th parapodial segment and continue to the end of the body, occupying 53 segments. The first parapodium is similar to that of the atocous form but dorsal and ventral cirrus are greatly enlarged and are almost oval shaped. In the second parapodium (text fig. 40) the ventral cirrus is smaller but the dorsal cirrus has increased to twice the length of the middle lobe, the enlargement is now localised to the basal half and is prominent dorsally. In the sixth parapodium (text fig. 4 p) the ventral cirrus has become slender, the dorsal cirrus twice the length of middle lobe with a sausage-like enlargement on its basal two-thirds. Here also the dorsal lobe (which appeared first on the third parapodium) has attained the length of the middle lobe. At the eight parapodium the enlargement on the dorsal cirrus has disappeared and the parapodia are typical of the atocous form with more rounded lobes than those of *N. jacksoni* ; on the fifteenth parapodium the change to epitocous form takes place. The epitocous parapodia undergo no changes (text fig. 4 q) in the rest of the body except for an increase in the size of lobes and their outgrowths until the fiftieth segment when foliaceous outgrowths begin to decrease in size. The dorsal cirrus of the epitocous parapodium is three times the length of the dorsal lobe. It has prominent sacculations along its ventral border and at the end of its basal two-thirds bears a prominent knob causing the remaining third of the cirrus to turn dorsally. From the base of the cirrus is a dorsal fan-shaped outgrowth which is absent in *N. heirissonensis*. The dorsal lobe is unchanged and maintains the same proportions throughout, reaching as far laterally as the middle lobe (as in the atocous form). The middle lobe bears a fan-shaped projection ventrally (as in the epitoke of *N. jacksoni*) overlapping the dorsal part of the large fan-shaped outgrowth around the end of the ventral setigerous lobe. This last named foliaceous outgrowth extends beyond the middle lobe and also ventrally while in *N. jacksoni* it extends laterally only as far as the middle lobe and does not extend ventrally. The ventral lobe bears no epitocous outgrowths ; thus the large foliaceous outgrowth of the more dorsal components of *N. denhamensis* epitoke cannot be accounted for by a consideration of this as a more mature condition than *N. jacksoni* since the latter bears a considerable outgrowth on the ventral lobe. The ventral cirrus extends beyond the ventral lobe and bears a dorsal finger-like process and a ventral fan-shaped process in place of the bilobod arborescent formation of *N. heirissonensis.* On the ventral cirrus of the thirty-fourth parapodium and a few succeeding parapodia there are sacculations similar to those found on the dorsal cirrus. Atocous setae are retained in all parapodia, though considerably reduced in number, in addition to the epitocous setae. The arrangement of paragnaths in the pharynx is similar to that in the atocous form with, however, fewer paragnaths and a total loss of paragnaths in group III. The differences betwcen the epitocous parapodia of this and *N. jacksoni* are as great or, in some cases, greater than the differences between the epitokes of other specific forms. So definitely, if species are to be defined by the characteristics now in use, *N. jacksoni* and *N. denhamensis* are not directly synonymous.

Notes on N. jacksoni *Kbg.*, N denhamensis *Aug. and* N. heirissonensis *Aug.*

N. denhamensis and *N. heirissonensis* were first described as such by Augener (1913). In 1922 he established their synonymy with *N. jacksoni,* basing his argument on the similarity of setae found in the three forms. There is no explanation of the fact that *N. heirissonensis* and *N. jacksoni* show marked contract to *N. dcnhamensis* in the form of the parapodial lobes and in the pharyngeal armature (*see* account of *N. denhamensis* above). Other species, differing only in characters generally recognised as more variable than these and yet with similar setae are regarded as separate species (*see N. kauderni, N. mortenseni*) ; therefore on the basis of this and above arguments, *N. jacksoni* and *N. denhamensis* are in the present work maintained as two distinct specios.

Nereis calloana Grube var. **peroniensis** n. var.

(Text fig. 4 a-k.)

Ehlers 1901 *N. callaona*

Three specimens with *N. jacksoni* from Point Peron. Colour in alcohol pinkish cream to dark brown. Length 30-50 mm., breadth 2-3 mm. Segments number 70-72.

Prostomium, palps, tcntacles, eyes of general form. *Persistomial cirri* extend to second parapodial segment.

Pharynx is similar to that of *N. jacksoni* (text fig. 4 a, b).

Parapodia (text fig. 4 c-f) differ from previous descriptions in length of dorsal cirrus and types of setae and justify a new variety. Dorsal lobe first appears in the second parapodium ; setae of the dorsal bundle appear in the third parapodium. At the eighth parapodium (text fig. 4 c) the dorsal cirrus is shorter than the dorsal lobe but after about four segments increases in length till at the thirty-first segment it is one and a half times the length of the dorsal lobe ; further posteriorly it is carried out along the dorsal lobe which itself has increased to twice the length of middle and ventral lobes. Also in the latter region the lobes are more narrow and finger-like (text fig. 4 e, f). The dorsal cirrus of *N. callaona* Grav. described by Ehlers (1901) is twice the length of the dorsal lobe all along the body. *Setae* (text fig. 4 g-k) dorsally are spinigerous homogomph setae replaced by homogomph falcigers posteriorly ; the latter are short, thick, with slight curve along which they are haired (differing from *N. trifasciata*, which has small denticle along this curved border). Supra acicular homogomph spinigerous setae, heterogomph falcigerous setae and subacicular heterogomph falcigers and spinigers. Setae of ventral bundles, anteriorly are long, slender and haired along their entire border except in the case of falcigers which are naked at the tip and slightly curved (falcigers of *N. Callaona* Grav. (Ehlers 1901) are haired basally only). Further posteriorly the hairs along the curved border of the falcigers have receded further from the tip (*N. trifasciata* Fauvel 1919 have the hook bent at right angles to the shaft).

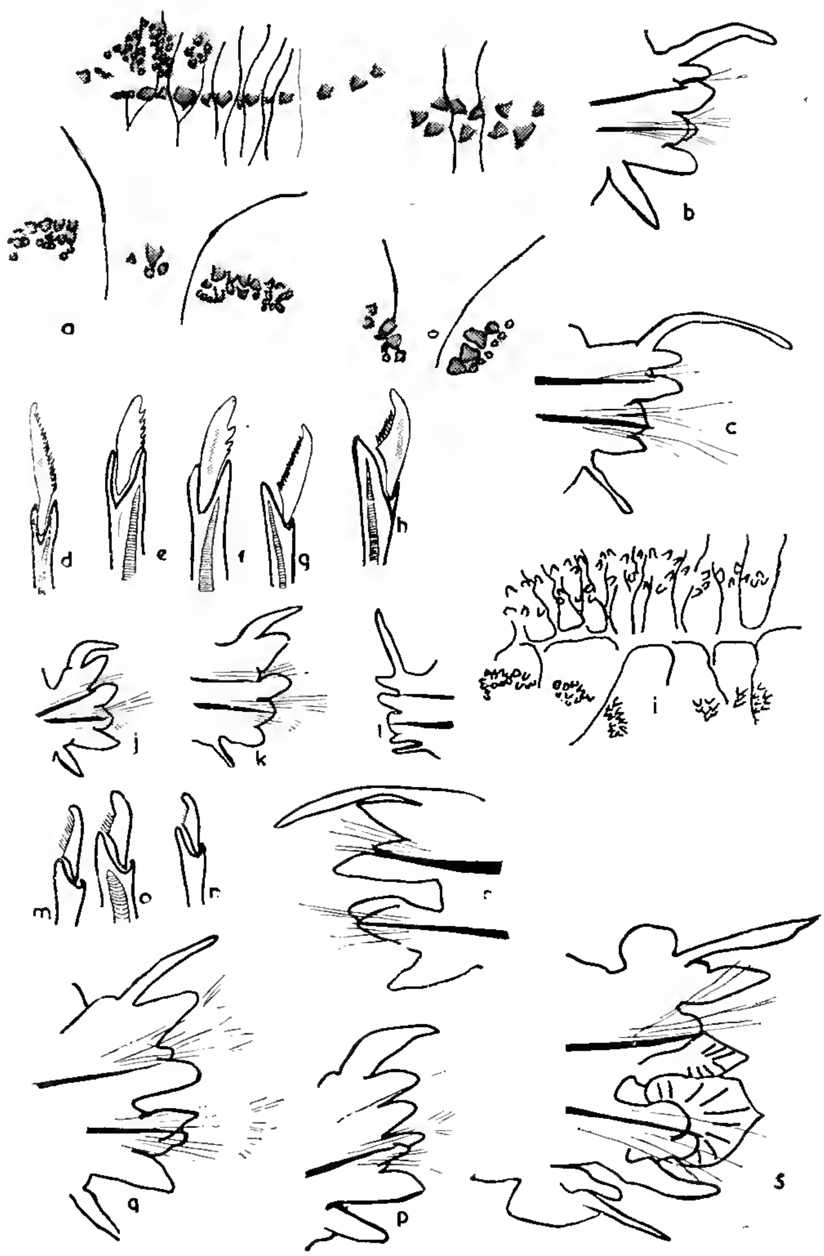
Sub-Genus NEANTHES.

KEY TO SPECIES.

1.	Eyes present	2
	No eyes	*N. abyssicola* Horst (Horst 1924)
2.	With falcate setae	3
	Without falcate setae	*N. oxypoda* Marenz. (Monro 1938)
3.	No heterogomph setose setae	*N. cricognatha* Ehl. (Augener 1927)
	Has heterogomph setose setae	4
4.	No hetero falcate setae in ventral supra acicular bundle	*N. latipalpa* Willey (Willey 1904)
	Has hetero falcate setae in ventral supra acicular bundle	5
5.	No heterogomph setose setae in ventral acicular bundle	6
	Has heterogomph setose setae in ventral acicular bundle	*N. vancauria* Ehl. (Ehl.)
6.	Enlargement of dorsal lobe posteriorly with dorsal cirrus at extremity of lobe	*N. succinea* L. (Monro 1933)
	Dorsal cirrus never at extremity of lobe	7
7.	Dorsal cirrus never longer than dorsal lobe	*N. operta* St. (Day 1934)
	Dorsal cirrus always longer than dorsal lobe	8
8.	Dorsal cirrus never twice as long as dorsal lobe ; anterior lobes rounded, post lobes conical	*N. capensis* Willey (Willey 1904)
	Dorsal cirrus at least twice as long as dorsal lobe	9
	Dorsal lobe triangular, others finger-like	*N. thompsoni* n. sp.
9	With dorsal homogomph falcate setae	*N. albanyensis* Aug. (Fauvel 1917)
	Without dorsal homogomph falcate setae	*N. vaali* Kbg. (Aug. 1927)

Nereis (Neanthes) thompsoni n. sp.

(Text fig. 5 a-h.)



Text Fig. 5.

Neanthes thompsoni n.sp.

a—pharynx; b—anterior parapodium; c—posterior parapodium; d—anterior dorsal falcate bristle; e—middle dorsal falcate bristle; f—posterior dorsal falcate bristle; g—posterior subacicular falcate bristle; h—posterior supra acicular falcate bristle.

Nereis albanyensis Aug.

i—pharynx; j—4th parapodium; k—10th parapodium; l—50th parapodium; m—anterior supra acicular falcate seta; n—posterior sub acicular falcate seta; o—posterior supra acicular falcate seta.

Ceratonereis costae Grube.

p—1st epitocous parapodium; q—12th atocous parapodium; r—posterior atocous parapodium; s—epitocous parapodium.

Forty-seven specimens were collected from Rottnest, Point Peron and from Aldritch's Cove, Nornalup. Size of specimens collected varies from 10-30 mm. in length and are 3-1 mm. broad. Segments number 65-70. The colour of the preserved specimens varies from pinkish brown to a pale whitish yellow.

Prostomium, with palps and tentacles bears similar relationships to those found in *N. jacksoni*. *Peristomial cirri* reach back to the fourth to fifth parapodial segments.

Pharynx (text fig. 5 a) is diagnostic for the species. There is great variability in the size of teeth of a single individual. All groups of paragnaths except those mentioned below resemble those of *N. albanyensis* Aug. Group VII and VIII, however, consist of a very wide girdle of paragnaths of varying size, and Group III contains only four paragnaths arranged in the shape of a cross. Below is a summary of pharyngeal armature.

Group I.	1 or 2 paragnaths, one behind the other.
Group II.	2 oblique parallel rows diverging posteriorly in the everted pharynx. Paragnaths of the more lateral row at least half the size of those in the medium rows.
Group III.	4 arranged in a cross with 3 small paragnaths anteriorly and one posteriorly.
Group V.	Fairly large paragnaths arranged in a triangle, apex directed anteriorly.
Group VI.	4 paragnaths of the same size as those of Group V., arranged at the four corners of a square.
Group VII., VIII.	A continuous girdle of small irregularly arranged paragnaths about 6 deep with a well defined single row of alternating large and small paragnaths anteriorly.

The pharynx of this species corresponds in some parts to that of *N. zonata-persica*. Marked differences, however, are observed in areas V, VI and III. The pharynx of *Nereis pelagica* is also similar but differs in areas V, III, IV.

The anterior parapodia (text fig. 5 b) exhibits a dorsal cirrus, a little more than twice the length of the dorsal lobe. The dorsal lobe is finger-like, half the thickness of and reaches as far laterally as the middle lobe. The middle lobe is slightly thicker than the ventral lobe which extends laterally slightly further than the former. The ventral cirrus is not as long as the ventral lobe. More posteriorly (text fig. 5 e) the dorsal surface of the parapodium has increased in length and the dorsal cirrus is carried out along the dorsal lobe. The lobes are narrower than anteriorly with more pointed tips, although they remain finger-shaped. The middle lobe maintains its length laterally but has decreased its thickness to equal that of the dorsal lobe. The ventral setigerous lobe and the ventral lobe now extend only half the distance laterally as the middle lobe. The ventral cirrus is slender and as long or perhaps longer than the ventral lobe. The dorsal cirrus here is three or four times the length of the dorsal lobe. In this character the forms of the parapodia deviate from those of *N. denhamensis*, which in other ways are very similar.

Setae (text fig. 5 d-h) are not very distinctive. They are similar to those found in *N. denhamensis*, *N. jacksoni*, etc. and show a gradation along the body from one to other types ; and so are, in this species of particular interest in determining the relationships of other species. Their distribution is as follows :

In the anterior parapodia there are dorsal homogomph spinigerous bristles, ventral supra and sub-acicular heterogomph falcate bristles and supra acicular homogomph spinigers and sub-acicular heterogomph spinigers. The ventral heterogomph falcate bristles are of the general form already recorded for *N. jacksoni* with longer appendages anteriorly and in the supra acicular group ; becoming shorter and thicker in the sub-acicular bundle and more so posteriorly. They are haired almost to their obtusely bent tip. In the dorsal bundle more posteriorly there appears heterogomph falcate setae, haired in the basal two-thirds with an obtusely bent tip. The form is similar though slightly more exaggerated than the posterior ventral falcate setae. In the middle of the body the haired region of the dorsal falcate seta has become dentate. The denticles number about five and illustrate a gradual condensation of the hairs into hooks towards the posterior end of the body ; especially since more posteriorly the denticles become thicker and fewer in number until the falcate appendix resembles closely or is identical with that of *N. jacksoni* or *N. mortenseni* and bears three denticles. In view of the striking resemblance in these posterior dorsal falcate setae and the fact that the paragnaths are similar, it is comparatively simple to interpret these forms as a stage previous to the differentiation of *N. denhamensis* by loss of some paragnaths in V, VII, VIII and a reduction of the dorsal cirrus ; from which *N. jacksoni*, by the reduction of the dorsal lobes, may have been derived.

Fauvel (1917) mentioned the similarity between *N. zonata* and *N. jacksoni*, the main difference occurring in the pharynx. In *N. thompsoni*, the pharynx bears a closer relationship to *N. zonata*. These arguments lead to the conclusion that there is close relationship between *N. jacksoni*, *N. denhamensis*, *N. zonata* and *N. thompsoni*.

There were no epitokes amongst the collection but a number of mature forms filled with eggs.

Amongst the collection is one specimen of average size, incomplete posteriorly and bearing, in place of the paired prostomial tentacles, a single median tentacle.

Following is a table comparing described sub-species of *N. zonata* with *N. pelagica*, *N. thompsoni* and *N. denhamensis*.

N. thompsoni.	*N. zonata-procera.*	*N. zonata-persica.*	*N. pelagica.*	*N. denhamensis.*
		PHARYNX.		
1 = 1 or 2 V = 3 in triangle VI = 4 large teeth in square VII, VIII = wide band	1 = 2 or 1 V = O VI = oval of 6 to 10 small paragnaths VII, VIII = wide band	I = 1 or 2 V = 0 VI = oval of 6 to I0 small paragnaths VII, VIII = wide band	1 = several V = 0 VI = 4 large in square VII, VIII = wide band	I = 1 or 2 V = 0 VI = triangle of large paragnaths VII, VIII = single row
		SETAE.		
Dorsal falcate, seta dentate with hairs anteriorly denticles posteriorly	Dorsal falcate, seta dentate with stiff pointed hair-like denticles	Dorsal falcate, seta with denticles and sometimes hair-like denticle basally	Dorsal falcate, seta smooth	Dorsal falcate, seta dentate with dentate setae

Nereis (Neanthes) albanyensis Aug.

(Text fig. 5 i-o.)

Fauvel 1917 *N. albanyensis* Aug.

Sixty specimens from sand, rock and weed at Point Peron. Size generally small, length 10–20 mm. ; maximum breadth at anterior segments 2 mm., 50–56 segments. Colour of preserved specimens brownish white or pink with increased intensity of colour anteriorly on the prostomium.

Prostomium twice as long as the buccal segment and twice as long as broad. *Eyes* vary from large brown circles with prominent lenses to small black spots without obvious lenses. *Peristomial* cirri reach to about fourth segment (as Fauvel 1917, not Augener 1913).

Pharynx (text fig. 5i) agrees with description by Augener (1913) but differs from descriptions of Fauvel (1917) in Group II in which the latter's specimens had a triangular arrangement.

Parapodia (text fig. 5j-l). Anterior dorsal cirrus slightly longer than other lobes ; ventral cirrus half the length of the ventral lobe. At the eighteenth segment the dorsal cirrus is one and a half times the length of the dorsal lobe, which extends laterally beyond the middle and ventral lobe. Further posteriorly the dorsal cirrus is carried out along the dorsal lobe and is one and a half times as long as the latter. Ventral cirrus is equal to the length of the ventral lobe. The lobes change little in shape, becoming slightly more pointed and thinner posteriorly ; they have gland cells in their tips, and these are sometimes present in the base of the parapodia also, becoming more marked posteriorly. *Setae* (text fig. 5m-o). Homogomph spinigerous setae in dorsal and ventral supracicular bundles, heterogomph spinigers in ventral sub-acicular bundle and heterogomph falcigerous setae in both ventral bundles ; smallest falcigers in the sub-acicular bundles and falcigers from both bundles become shorter and thicker posteriorly with the hairs on the curved border gradually receding to the base (Fauvel 1917). Augener (1913) described falcate setae similar to those found anteriorly but appears to have ignored those found posteriorly. This is supported by the fact that Augener describes only the condition of ventral cirrus found in these specimens anteriorly.

Nereis (Neanthes) cricognatha Ehl.

Augener 1927 *N. crigognatha.*

Seven specimens were collected from Point Peron.

Segments number from 50–60 in animals of 20 mm. length. The body measures 1 mm. in breadth and each parapodium equals in breadth the anterior segments. Posteriorly the parapodia increases relative to the width of the segmonts. The peristomial cirri reach to the eighth and ninth segment. The form of the parapodia and the arrangement and form of seate agree with the account given by Augener (1913) as does also the arrangement of the paragnaths in the pharynx. There were no epitocous forms collected.

Sub-Genus **CERATONEREIS.**

Nereis (Ceratonereis) costae Grube.

(Text fig. 5 p-s; 6 j-l.)

Augener 1913 *C. lapinigensis* Grube

Two specimens—one epitocous, one atocous, from Rottnest in association with *N. albanyensis* Aug. Size 30 mm. long, 3 mm. broad.

Atocous form.

Prostomium, palps, eyes, pharynx described by Augener (1913). *Setae* of similar form as those of *N. albanyensis* (text fig. 6j-l).

Epitocous form.

Eyes enlarged.

Parapodia.—The first 14 setigerous segments are atocous but the dorsal cirrus of the first six parapodia (text fig. 5 p-s) show elongate enlargements in the basal two-thirds. Epitocous parapodia are as follows :—

A large outgrowth appears dorsally at the base of the ventral cirrus. A thickening forms along the dorsal cirrus. A large fan-shaped vascular outgrowth develops from the end of the middle lobe and from the anterior lip of the ventral setigerous lobe. From the base of the ventral cirrus ventrally is a fan-shaped outgrowth, while dorsally a finger-shaped process forms (text fig. 5p, s).

The *Pharynx* of the epitocous form agrees with descriptions given by Augener (1913) and Fauvel (1923) and bears also a single paragnath in group I. This latter paragnath was recorded by Grube (1869) for the synonym *N. fasciata* but Fauvel (1919) considers it to be exceptional. I could find no differences between this form and *N. lapinigensis* Grube as remarked by Fauval (1919).

Nereis (Ceratonereis) tentaculata Kbg.

(Text fig. 6 m-p.)

Day 1934 *N. (Ceratonereis) mirabilis.*
Augener 1913 *N. (Ceratonereis) tentaculata.*

Three specimens from Rottnest Island in damaged condition. Size approximately 30 mm. in length, 2–3 mm. broad, 62 segments. Colour in alcohol a whitish yellow.

Description of prostomium, prostomial appendages, peristomial cirri and parapodia given by Augener (1913) agrees entirely with these specimens.

Pharynx (text fig. 6 m, n, o).

Setae (text fig. 6 p) differ slightly from Augener's descriptions. Dorsally homogomph spinigers. Ventrally homogomph spinigers and heterogomph falcigers in the supra acicular bundle; in the sub-acicular bundle heterogomph falcigers and about three heterogomph spinigers. Posteriorly the dorsal bundle supports homogomph faligers as well as spinigers. Form of the setae constant throughout. See Ehlers (1887) but not as described by Horst (1924) for this species ; falcate setae are similar whether from anterior, posterior, dorsal or ventral bundles ; appendages are long, parallel sides, the falcate curved edge haired almost to tho terminal strongly-curved tip (*N. cricognatha* Ehl.).

Nereis (Ceratonereis) erythraensis Fauvel.

Monro 1938 *N. (Ceratonereis) erythraensis.*

There is one specimen collected in weed from Point Peron. The preserved specimen is a whitish yellow colour with brown pigment dorsally. The specimen measures 30 mm. long, has 70 segments.

The longest peristomial cirrus reaches back to the sixth parapodial segment. The buccal segment is large and forms a large bay about the mouth. Falcate setae are absent in the first few anterior segments, appear at the tenth segment in the supra-acicular ventral bundle and at the thirtieth segment are plentiful in both ventral bundles. The acicular setae are not dentate.

Full description agreeing with this specimen has been given by Fauvel (1919). Monro (1938) discusses the synonymy of this form with *N. aequisetis* Aug. At present, since it seems hardly possible that Augener could have overlooked what are very obvious components of the parapodial armature, the two forms have been regarded as different species.

Genus **PLATYNEREIS.**

More synonymy exists perhaps in this group than in any other genus of Nereidae. This makes the formation of keys a particularly confusing work. There follows a summary, giving the arguments of past workers for the lumping together of certain species originally described as distinct.

Synonymy of *Pl. australis.*

Pl. eatoni McI. and *N. magalhaensis* Kbg. were established as synonyms by Ehlers (1901). Willey (1904) recognises *Pl. striata* Schm. and *Mastigonereis striata* Schm. as identical. Augener (1913) describes *M. striata* and *M. quadridenta* Schm. as synonymous with *Pl. australis* Schm. In 1909, Benham established a case for the synonymy of *Pl. australis* and *Pl. eatoni.* Thus the above-named species may be considered as synonymous and members of the one species.

Synonymy of *Pl. dumerili.*

Later there is furthor synonymy suggested by the relations of *Pl. dumerili* Aud. and Ed., Izuka (1912) and Marenzeller (1879) believe that *Pl. agassizi* Ehl. and *Pl. dumerili* Aud. and Ed. are synonymous and Izuka also adds *Pl. kobiensis* McI. to this synonymy. Augener (1927), however, maintains *Pl. agassizi* Ehl. is distinct from the two former. Monro (1933) reiterates previously-stated synonymy of *Pl. agassizi* and *Pl. dumerili* (he does not, howevor, give as reference Izuka 1912, Augener 1927, or Ramsay 1914). It seems, therefore, possible that since Izuka's and Marenzeller's specimen of

Pl. dumerili had the falcate appendix fused to the shaft, that their specimens were actually *Pl. agassizi* so great is the similarity in other respects. Then it follows that *Pl. agassizi* is a synonym of *Pl. kobiensis* McI., characterised by the presence of simple falcate setae in the dorsal bundle. *Pl. dumerili* is distinct in the presence of an articulated dorsal falcate bristle. Ramsay (1914) has summed up the position thus :—

> " *Pl. dumerili, Pl. kobiensis, Pl. agassizi* in the Pacific all have fused falcigers in the upper bundle, and the sole feature distinguishing them from *N. dumerili* of Atlantic coasts. No author has given any distinguishing features between Pacific forms. Isuka figures them all but gives no distinctions. It seems, therefore, that *Pl. agassizi* and *Pl. kobiensis* are merely geographic sub-species of *dumerili,* in which the falcate dorsal setae has become fused to a simple seta. Since Marenzeller figures a dorsal compound forsed seta of a young Japanese specimen of *Pl. dumerili,* it seems that the species are definitely homologous and the fused seta only a modification to be found in the Pacific."

Therefore in the compilation of the following key *Pl. agassizi* and *Pl. dumerili* are considered distinct forms.

Fauvel (1911) establishes a definite synonymy between *Pl. dumerili* and *Pl. insolita* Grav. and *Pl. pulchella* Grav.

Pl. bengalensis Kbg. is likened to *Pl. insolita* (Ehl. 1905). In his description of *Pl. bengalensis,* however, Willey states that it differs from *Pl. insolita* by the presence of a dorsal prominence on the dorsal falcate bristle. This throws a doubt on the synonymy of *Pl. dumerili* and *Pl. insolita* and suggests the identity if *Pl. bengalensis* with *Pl. dumerili.* This is supported by the comparison of parapodia of Willey's specimens of *Pl. bengalensis* with some of *Pl. dumerili* (Fauvel). The two are, however, distinguished by their pharynx.

Fauvel (1916) and Monro (1930), basing their argument on epitocous forms of the *Pl. dumerili* and *Pl. magalhaensis,* state that since the only difference in epitokes of the two species is a variation in the segments on which the epitocous parapodia commence, then the two forms are not to be separated. No explanation, however, is made of the absence of the dorsal falcate setae in the *Pl. magalhaensis.* Therefore, in compilation of the following key *Pl. australis* and *Pl. dumerili* with their synonyms have been retained as distinct forms. Day's species is probably *Pl. dumerili* Aud. and Ed. var. *australis* Day, but is not a synouym of *Pl. australis.*

Pl. abnormis Horst lacks paragnaths in Group III and has thom in II, so Fauvel's (1932) key character for *Platynereis* must be modified since he distinguishes these species by the absence of paragnaths in Groups I, II and V. It seems advisable to distinguish the genera of family Nereidao by the form of paragnaths rather than by their arrangement.

PLATYNEREIS.

KEY TO SPECIES.

1.	Without dorsal falcate setae	2
	With dorsal falcate setae	4
2.	Prostomium not notched anteriorly....	3
	Prostomium notched anteriorly	*Pl. arafurensis* McI. (McI. 1885)

Platynereis—*continued.*

3.	Paragnaths in areas I., II.	*Pl. polyscalma* Chamberlin (Fauvel 1932)
	Paragnaths not in areas I., II.	5
4.	Setose bristles in subacicular bundle	*Pl. australis* Schm. (Horst 1924)
	No setose bristles in subacicular bundle	*Pl. cristatus* Horst (Horst 1924)
5.	Some simple dorsal falcigerous bristles	*Pl. agassizi* Ehl. (Aug. 1927)
	Without simple dorsal falcigerous bristles	6
6.	Dorsal heterogomph falcate bristles	*Pl. tongatabuensis* McI. (McI. 1885)
	Dorsal falcate bristles homogomph	7
7.	Dorsal falcate bristles with dorsal prominence	8
	Dorsal falcate bristles without dorsal prominence	9
8.	Conical tentacles	*Pl. pulchella* Grav. (Monro 1936)
	Cirriform tentacles	*Pl. insolita* Grav. (Fauvel 1911)
9.	Dorsal falcate setae exceed number of setose setae posteriorly	*Pl. hewitti* Day (Day 1934)
	Dorsal falcate setae always less than dorsal setigerous bristles	10
10.	Long cirrus in 7th parapodial segment	*Pl. abnormis* Horst (Fauvel 1932)
	No long cirrus in 7th parapodial segment....	11
11.	Paragnaths in area IV. only	*Pl. bengalensis* Kbg. (Horst 1924)
	Paragnaths in area IV. and other areas	*Pl. dumerili* Aud. & Edl. (Monro 1933)

Platynereis dumerili Aud. and Ed.

Monro 1933 *Pl. dumerili.*

Several hundred specimens, all small, obtained from submarine light hauls, from weed washings at Rottnest and Point Peron. Some from Jurien Bay, Nornalup and the Abrolhos.

They are identical in all ways with already published descriptions of *Pl. dumerili* except for the following feature—the dorsal homogomph falcate bristle is haired along its concave border. This has not before been recorded. Fauvel (1923) illustrates only denticles in this region.

Platynereis australis Schm.

Augener (1913) *Pl. australis.*

Fewer specimens than *Dumerili* and larger. As described by Augener and others.

Genus **PERINEREIS**

KEY TO SPECIES

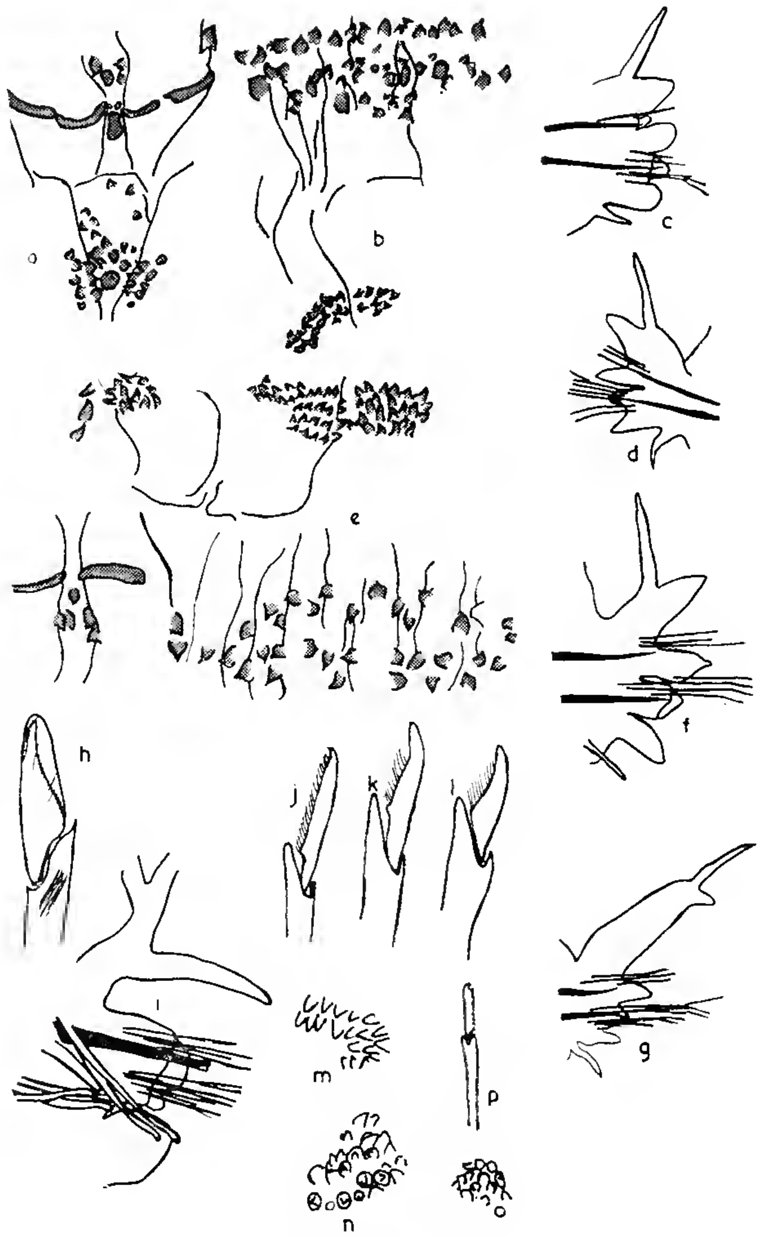
Fauvel (1919) and Horst (1924) have published Keys simplifying the identification of certain groups of Perinereid, in particular the indentification of the sub-species of several variable species. (*P. cultrifera, P. nuntia*). The classification of this group is based largely on the pharynx, which is most variable. It has already been pointed out that the pharynx is an independable character for classification. Since other factors, parapodia, setae, are constant in numbers of species, the pharynx is at present the only group on which a key can be based. It should, however, be borne in mind that a single transverse ridge on VI may very easily be broken up into two or more paragnaths (*e.g.*, *P. oliveirae*, *see* Fauvel, 1923). In such cases the species has been placed in the key in the group to which it usually conforms.

1.	Groups VII., VIII. without paragnaths	*P. saluana* Horst (Fauvel 1932)
	Groups VII., VIII. with paragnaths....	2
2.	A transverse row of many denticles in VI.	3
	One or two large flattened denticles in VI.	7
3.	Groups I. and II. absent	*P. neo-calendonica* Pruvot (Fauvel 1932)
	Groups I. and II. present	4
4.	1-2 paragnaths in I. in a longitudinal row	5
	5 paragnaths in I. in a round group	*P. rumphii* Horst (Horst 1924)
5.	V. absent	*P. binongkae* Horst (Horst 1924)
	V. present	6
6.	Dorsal cirrus twice as long as dorsal lobe	*P. ponuiensis* Aug. (Augener 1924)
	Dorsal cirrus never as long as dorsal lobe	*P. nuntia* Savigny (Fauvel 1919)
7.	2 transverse paragnaths in VI.	8
	1 transverse paragnath in VI.	12
8.	Single paragnath in V.	*P. singaporiensis* Grube (Fauvel 1932)
	More than a single paragnath in V.	9
9.	2 rows of 3 in each row in V.	*P. variodentata* Aug. (Aug. 1913)
	Triangular patch of 3 in V.	10
10.	Paragnaths of VI. conical	*P. aibuhitensis* Grube (Aug. 1913)
	Paragnaths of VI. broad, flattened	11
11.	Dorsal cirrus equals dorsal lobe	*P. vancaurica* Ehl. (Fauvel 1932)
	Dorsal cirrus twice the length of dorsal lobe	*P. camiguinoides* Aug. (Aug. 1924)
12.	V. missing	*P. cavifrons* Ehl. (Fauvel 1932)
	V. present	13
13.	V.—transverse group of 5	*P. amblyodonta* Schm. (Aug. 1913)
	V.—triangular patch of 3 or 1	14
14.	Posterior feet enlarged	16
	Posterior feet not enlarged	15
15.	Middle lobe as long as dorsal lobe	*P. cultrifera* Grube (Fauvel 1932)
	Middle lobe only two-thirds as long as dorsal lobe	*P. obfuscata* Grube (Horst 1924)
16.	Oval mass of small black points in 1	*P. falklandica* Ramsay (Ramsay 1920)
	Triangular group in 1	17
	1–7 in a cluster in 1	*P. nigropunctata* Horst (Horst 1924)
17.	Peristomial cirri reach back beyond 7th segment	*P. bairdii* Webster (Monro 1933)
	Peristomial cirri does not reach back beyond 5th segment	*P. oliveirae* Horst (Fauvel 1923)

Of *P. dongalae* Horst (1924) there was insufficient information for inclusion in this key.

Perinereis variodentata Augener.
(Text fig. 6 a-g.)

Augener 1913 *P. variodentata.*



Text Fig. 6.

Perinereis variodentata Aug.
a, b—pharynx; c—anterior parapodium; d—posterior parapodium.

P. amblyodonta Schm.
e—pharynx; f—anterior parapodium; g—posterior parapodium.

Eunice denticulata Webster.
h—anterior compound seta; i—55th parapodium.

Ceratonereis costae Grube.
j—anterior supra acicular falcate seta; k—middle supra acicular falcate seta; l—posterior supra acicular falcate seta.

C. tentaculata Kgl.
m—Group II of pharynx; n—Group III of pharynx; o—Group IV of pharynx; p—dorsal falcate seta.

Two specimens from Point Peron, five from Nornalup. Size.—20-25 mm. long, 2 mm. broad ; approximately 70 segments. Colour in alcohol a whitish pink.

Prostomium and its appendages as described by Augener (1913).

Pharynx agrees in general with Augener's description but certain frequent variations in tho few available specimons have been observed (text fig. 6 a, b).

I. Frequently richly supplied with paragnaths of varying sizes and irregularly arranged, covering the whole of Area I, or fewer paragnaths of regular size, sometimes arranged asymmetrically but in one specimen there are three paragnaths arranged in a triangle with the apex anteriorly directed.

III. Three in a T.S. line.

V. In ono specimen there are the two curved rows as described by Augener but in three other specimens two lateral paragnaths of the posterior row were missing. Frequently the median paragnath of this row was greatly elongated longitudinally (*see* Pl. VIII, fig. 1).

Parapodia (text fig. 6 c, d) as described by Augener.

Setae differs slightly from Augener's descriptions :

These specimens contain homogomph and heterogomph spinigerous seta in the supra and sub-acicular bundles respectively of the ventral division in all segments with the exception of the first few anterior segments, where the ventral spinigerous seta is missing.

I could find no supra acicular homogomph falcigerous seta recorded by Augener (1913) for this species.

Perinereis amblyodonta Schm.

(Text fig. 6 e-g.)

Augener 1913 *P. amblyodonta* Schm.

Six specimens from Point Peron. Sizo 25-35 mm., four mm. broad.

Prostomium, prostomial appendage, peristomial cirri as described by Augener.

Pharynx (text fig. 6 e) with narrow, elongate and pointed paragnaths in the maxillary ring and shorter, fewer paragnaths in the oral ring.

Parapodia (text fig. 6 f, g) with markod glandular patches in all lobes on the parapodia. *Setae.*—Falcate setae curved, haired basally (*see* those in ventral bundle of *N. callaona*). The appendix of spinigerous bristles three times the length of the falcate appendix and former is haired all along its length. There are no falcate bristles in dorsal bundle and heterogomph falcigers only in the sub acicular bundle.

Fam. **EUNICIDAE.**

Genus **EUNICE.**

The classification of this genus is, as is the case with other groups of Nereidiforma, confused by the variability of features used. As with other genera, the most dependable characters were the seta. The value of gill arrangement and numbers in classification is doubtful, due to the wide variation which these organs undergo within a species ; and due to the fact that in some younger forms the gills in some parts of the body have not yet appeared. Within certain limits, however, the gills do give an indication of the groups to which any species belongs (Crossland 1924) and with other morphological details (*e.g.*, setae) are useful characters for identification. The key which follows has been modified mainly from Fauvel (1932) to include a wider number of species recorded.

The groupings of Crosslands key (1904) were not used since the divisions were most arbitrary, and based on extremely variable and overlapping characters, such as the length of tentacles and assymetry of the jaws.

KEY TO SPECIES.

1.	Gills commence beyond 10th parapodial segment	2
	Gills commence before 10th parapodial segment	14
2.	No acicular or pectinate setae	3
	Pectinate or acicular setae present	4
3.	Mandibles enormously developed	*E. cariboea* Grube (Treadwell 1921)
	Mandible of average size	*E. siciliensis* Grube (Monro 1933)
4.	Gills continue to anal segments	5
	Gills cease posteriorly	12
5.	More than 4 filaments in gills	7
	Not more than 4 filaments in gills	6
6.	Gills commence beyond 80th segment	*E. tenuis* Tread. (Treadwell 1921)
	Gills commence between 60th and 70th segment....	*E. schizobranchia* Clap. (Fauvel 1923)
	Gills commence between 15th and 20th segments	*E. afra* Peters (Monro 1933)
7.	Gills commence at segment 80	*E. gracilis* Crossland (Fauvel 1932)
	Gills commence before segment 40	8
8.	Gills of one filament	*E. guanica* T. (Treadwell 1921)
	Gills of more than one filament	9
9.	Filaments increase in number posterior	10
	Filaments reduced to one posterior	*E. denticulata* Webster (Treadwell 1921)
10.	Gills commence segment 20	*E. bucciensis* Treadwell (Treadwell 1921)
	Gills commence segment 27-30	11
11.	Gills increase to 3 filaments posterior	*E. spongicola* T. (Treadwell 1921)
	Gills increase to 2 filaments posterior	*E. filamentosa* Grube (Monro 1933)
12.	Gills commence beyond segment 20	*E. cariboa* Grube (Monro 1933)
	Gills commence before segment 20	13

13.	Maximum of 3 filaments developed in middle body	*E. notata* T. (Treadwell 1921)
	Maximum of 2 filaments developed posteriorly in body	*E. prognatha* (McI. 1885)
14.	Gills continue to anal segments	15
	Gills cease before anal segments	26
15.	Not more than 4 filamentous gills	16
	Not less than 4 filamentous gills	19
16.	Constant number of gill filaments	17
	Number of gill filaments increases	18
17.	Gills arise from base of trunk; not bifid	*E. tribranchiata* McI. (McI. 1885)
	Gills do not arise from base of trunk; are bifid	*E. equibranchiata* McI. (McI. 1885)
18.	In middle body dorsal cirrus not longer than gills	*E. mutilata* Webster (Treadwell 1921)
	In middle body dorsal cirrus is longer than gills	*E. mindanavensis* McI. (McI. 1885)
19.	Palps bilobed; prostomium quadripartite	20
	Palps not bilobed; prostomium bilobed	24
20.	Gills commence 3rd-7th feet	21
	Gills commence 8th-10th feet	23
21.	Tentacular cirru articulate	*E. tentaculata* Aug. (Monro 1933)
	Tentacular cirri smooth	22
22.	Compound setae with terminal piece sword-shaped anteriorly, sichel-shaped	*E. tubifex* Crossland (Fauvel 1932)
	Compound setae with all terminal pieces sichel-shaped	*E. floridana* Pourtale (Fauvel 1932)
23.	Maximum 15 filaments	*E. longisetis* Webster (Treadwell 1921)
	Maximum 30 filaments	*E. aphroditois* Pallas (Monro 1933)
24.	Acicular setae tridentate posteriorly	*E. antennata* Savigny (Monro 1936)
	Acicular setae not tridentate posteriorly	25
25.	Maximum of 8 filaments	*E. grubei* Gravier (Fauvel 1932)
	Maximum of 12 filaments	*E. magellanica* McI. (McI. 1885)
26.	Prostomium lobed	27
	Prostomium not lobed	*E. vittata* Delle Chiaj (Monro 1933)
27.	Branchia commence 3rd-4th feet	28
28.	Prostomium bilobed	29
	Prostomium quadripartite	33
29.	Head as broad as body	30
	Head not as broad as broadest part of body	31
30.	Tentacles annulated	*E. australis* Qfgs. (Fauvel 1932)
	Tentacles not annulated	*E. tridentata* Ehl. (Monro 1933)
31.	Acicular setae tridentate	32
	Acicular setae bidentate	*E. indica* Kbg. (Monro 1933)
32.	Tentacles articulate	*E. savignyi* Grube (Fauvel 1932)
	Tentacles not articulate	*E. longicirrata* Webster (Monro 1933)

33.	Peristomium narrow	*E. kobiensis* McI. (McI. 1885)
	Peristomium as broad as following segment	34
34.	Compound setae bidentate	*E. pennata* Muller (Fauvel 1923)
	Compound setae not dentate	*E. fucata* Ehl. (Treadwell 1921)

The species, purely European, *E. harassi*, *E. oerstedii*, *E. torquata*, included in key published by Fauvel (1923) have been omitted from this key.

Eunice antennata Savigny.

Monro 1936 *E. antennata.*

Approximately 200 specimens from all stations. Size 10-65 mm. long, 1-5 mm. broad, 70-110 segments. Living specimens green with dorsally a white spotted band on the first setigerous segment (Augener 1913). On the buccal segment dorsally there is a spotted white triangle and similar round patches of white spots extend along the mid-dorsal line in each segment. These latter mid-dorsal white circular areas are indistinct in the first three segments but become more distinct posteriorly. In some specimens white areas are replaced by brown pigment. There is a brown band around the intersegmented contriction of segmented appendages. Specimens in alcohol are pinkish white to brownish pink and retain the white areas.

Prostomium notched to half its length anteriorly. *Palps* grooved ventrally presenting two marginal lobes. *Prostomial tentacles* jointed moniliform. In one specimen jointing only evident basally, nuchal segment bears two moniliform cirri extending slightly beyond the ridge of the buccal segment. *Eyes* round, black, at base of outer paired tentacles.

Pharynx sometimes white calcareous incrustations on edge of jaws. Number of teeth show much variation as :—

8 — 8 : 6 + 5 — 8
6 — 6 : 7 + 9 — 8
7 — 5 : 7 + 6 — 7

Parapodia.—Dorsal cirrus is jointed, anteriorly 5-6 segments, 3-4 posteriorly ; in anterior segments half as long as gill filaments ; posteriorly the same length as the gills. Ventral cirrus on first seven segments is pyriform. In the following 20 segments the base is elongate, sausage-like ; its base is applied to the body wall ; further posteriorly it is finger-like. Gills commence invariably at segment 5 with 1-3 filaments. Maximum development of 6-12 filaments at about segment 20. Number and length of filaments thereafter reduced to 1-3 filaments until in the posterior body third is a slight increase in number (but not in length) to 2-4 filaments respectively. Longest gills anteriorly reach the mid-dorsal line. Gills absent in last three segments. Longest filaments arise mostly proximally from common stalk. *Setae.*—Two aciculae either side of a group of simple pectinate and spinigerous setae. Ventrally are compound bidentate setae sometimes with a third tooth posteriorly, and bidentate acicular seta, tridentate posteriorly and sometimes absent anteriorly. The aciculae (Crossland 1904) sometimes bidentate. Anal cirri.—6-8 segments.

Young forms.—Joints of moniliform appendages indistinct, no increase in length of gills posteriorly and palps viewed dorsally appear to be fused medially. There is a tendency to assymetry in commencement of gills on different segments either side ; bifid or trifid gills and occasionally bifid dorsal cirri.

Eunice denticulata Webster.

(Text fig. 6 h, i.)

Treadwell 1921 *E. denticulata.*

Five large specimens were taken from Rottnest and Point Peron. Some specimens were taken in tubes (Treadwell 1921). Colour of the preserved specimens varied from greyish white to pinkish white.

One relatively small specimen only was complete, and measures 80 x 5 mm. There are two large samples consisting of the hind end only, measuring 160 x 10 mm. and 90 x 10 mm. and two similar specimens represented by the anterior end of the body only.

Prostomium, as represented by a pair of palps, projects anteriorly only as far as half the length of the peristomium and is cleft deeply to the anterior border of the peristomium. There is no ventral groove visible on the palps. The origin of the prostomial tentacles is hidden by the overlapping peristomium. They are short, the median tentacle slightly longer than the peristomium and the inner and outer pair progressively shorter. The inner pair of tentacles arise in line with the origin of the median, the outer pair arise more posteriorly with a round black eye with a lens at their base and lateral to the base of the inner pair of tentacles. The tentacles are smooth, show no trace of annulation or jointing ; similarly the nuchal and dorsal cirri.

The body segments of the anterior and broadest part of the body are about eight times as broad as their length.

Parapodia are as described by Treadwell for *Eunice denticulata* (1921). The *gills,* commencing constantly from segment 23, are in the region of their greatest development at least three times the length of the dorsal cirrus. Posteriorly in the smaller and complete specimen, the single gill filament may be reduced to the length of the dorsal cirrus, unlike the condition in the larger incomplete hinder fragments where the single gill filament posteriorly becomes shorter than the dorsal cirrus as described by Treadwell (1921). The smaller specimen has throughout relatively larger gills than the large samples. In the specimens of this collection the number of filaments may be up to four. *Setae* posteriorly are also similar to those described by Treadwell ; anterior compound setae (text fig. 6 h) with a longer appendix, less prominently dentate and without the basal tooth of the posterior setae. The aciculae and acicular setae are distinctive and more numerous than those previously described (text fig. 6 i). Anteriorly there are two aciculae, one dark brown, the other reddish brown. Dorsal to these are the simple winged setose setae and pectinate setae and ventrally are the compound setae. Both the simple and compound setae are a pale yellow colour. At about the 20th segment the reddish brown aciculum has become deeply embedded in the muscle of the parapodium and ventral to the remaining protruding seta there appears, also of reddish brown colour, and embedded in the parapodium, another aciculum. The three aciculae are thick. At about the thirty-fifth parapodium two ventral bidentate hooded acicular setae have been added, as described from the posterior parapodia by Treadwell, and the ventral aciculum has become bifid terminally. At the fiftieth parapodium (text fig. 6 i) three more bidentate acicular setae have been added. Further posteriorly the setigerous lobes contain compound falcigerous bristles, simple setose and pectinate bristles, one acicular seta and one black aciculum which has acquired a curved tip and dentate guard (*see* Treadwell 1921, fig. 49).

Pharynx.—The jaws are black ; the mandible with minute denticulations along the terminal edge ; forceps strongly curved.

Formula for teeth on maxillary plates as follows :— 4 —3 : 4 + 2 — 6, which is identical with Treadwell's description of the pharyngeal armature of *E. denticulata* Webster.

Eunice siciliensis Grube.

Monro 1933 *E. siciliensis.*

One specimen collected from Rottnest. It is 100 mm. in length and 5 mm. broad, inclusive of the parapodia. The colour of the preserved specimen is whitish grey speckled all over with white, particularly in the anterior region.

Prostomium is cleft only ventrally, is speckled with brown and carries two round black eyes which are not hidden by the overlapping peristomium. The tentacles are jointed, not quite moniliform and are slightly longer than the peristomium. The peristomium and nuchal segments are of equal length, slightly longer than the other body segments. The body segments are twelve times as broad as their length.

Parapodia are situated more or less ventrally. The gills, beginning on segment 100, are of a single filament throughout.

Genus **MARPHYSA.**

Treadwell (1922) has described a new species of *Marphysa* with a specific name "*simplex*" preoccupied by Crossland (1903). Treadwell's specimen had tentacles twice the length of the prostomium ; no compound setae ; simple setose setae, long and tapering with marginal denticulations ; anterior pectinate setae ; ventral acicular setae with terminal and subterminal teeth and a hood. I could find no distinction in the description of Treadwell's *M. simplex* and *M. mossambica* Peters.

It is hard to understand how Treadwell could have overlooked *M. simplex* Crossland since Treadwell refers to *M. macintoshi* first described by Crossland in the same publication as he recorded *M. simplex*.

KEY TO SPECIES.

Other keys published by Crossland (1903) and Fauvel (1932)—

1.	Prostomium undivided	2
	Prostomium bifid	6
2.	Gills large, confined to a few anterior segments	3
	Gills extend over most of body length	5
3.	No spinigerous setae present	*M. adenensis* Grav. (Day 1934)
	Spinigerous setae present	4
4.	Only spinigerous setae anteriorly	*M. strangulum* Grube (Fauvel 1932)
	Both spinigerous and falcigerous setae anteriorly	*M. bellii* Aud. & Ed. (Treadwell 1921)
5.	Compound setae knife-shaped	*M.* Macintoshi Crossland (Day 1934)
	Compound setae hooked	*M. bifurcata* n. sp.
6.	No compound setae present	*M. mossambica* Peters (Day 1934) Syn. *M. simplex* Tread.
	Compound setae present	7
7.	Compound setae absent in anterior and posterior parts of body	*M. gravelyi* Southern (Fauvel 1932)
	Compound setae present throughout body	8
8.	Compound setae spinigerous or knife-like only	9
	Compound setae falcigerous only	16
	Compound setae both spinigerous and falcigerous	20
9.	Tentacles shorter than the prostomium	*M. brevitentaculata* (Treadwell 1921)
	Tentacles longer than the prostomium	10
10.	Tentacles less than twice length prostomium	11
	Tentacles at least twice length prostomium	14
11.	Acicula setae not dentate	12
	Acicula setae dentate	13
12.	Gills maximum of 3 filaments	*M. simplex* Crossland (Crossland 1903)
	Gills maximum of 5-6 filaments	*M. parishii* Baird (Treadwell 1921)
13.	Gills begin about segment 20	*M. californica* Moore (Treadwell 1921)
	Gills begin about segment 30	*M. nobilis* T. (Treadwell 1921)
14.	Ventral acicula setae dentate	*M. viridis* T. (Treadwell 1921)
	Ventral acicula setae not dentate	15

15.	Gills commence before segment 20	*M. sanguinea* Montague (Day 1934)
	Gills commence after segment 20	*M. durbanensis* Day (Day 1934)
16.	Tentacles greater than twice prostomium	*M. goodsiri* McI. (McI. 1885)
	Tentacles less than twice prostomium	17
17.	Gills of one or 2 filaments only	18
	Gills of more than 1 or 2 filaments only	19
18.	....	*M. capensis* Schm. (Day 1934) *M. saxicola* Langerhans (Crossland 1903)
19.	Toothed acicular seta	*M. corallina* Kbg. (Day 1934)
	Acicular seta not toothed	*M. regalis* Verril (Treadwell 1921)
20.	Gills commence beyond segment 30	21
	Gills commence before segment 30	22
21.	Gills commence at about 60th segment	*M. languida* Treadwell (Treadwell 1921)
	Gills commence at about 40th segment	*M. depressa* Schm. (Aug. 1924)
22.	Prostomium only a shallow cleft	*M. fallax Marion* (Fauvel 1923)
	Prostomium deeply emarginated	*M. chevalensis* Willey (Aug. 1924)

Marphysa sanguinea Montagu.

Day 1934 *M. sanguinea.*

Three specimens only collected from some rock washings at Point Peron. The largest specimen measures 110 mm. in length and is 5 mm. broad. Two other specimens small and incomplete posteriorly are 1–2 mm. broad.

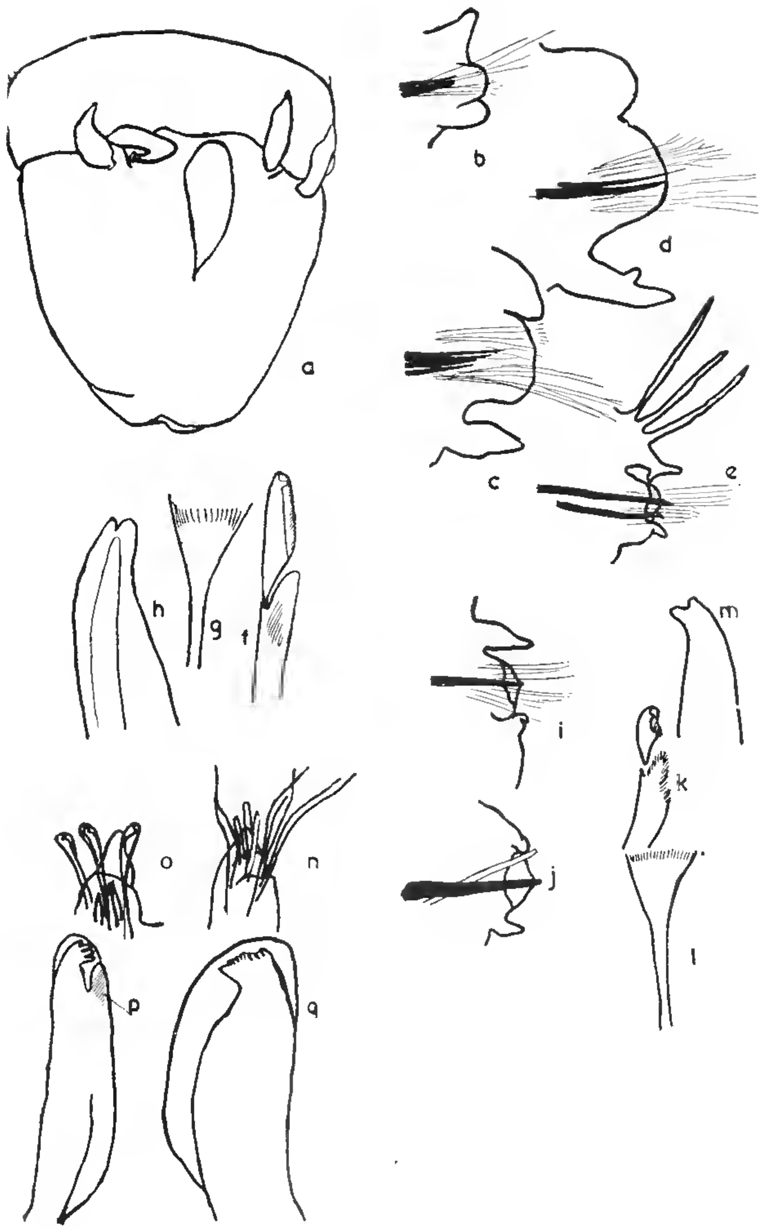
They are brownish pink in colour, convex slightly ventrally and almost flat dorsally, with the greater distance between the parapodia of the two sides on ventral surface. The gills commence on segment 18 and attain a maximum of four filaments. The prostomium and tentacles are similar to those described by Crossland (1903). The median tentacle, however, in the specimens under discussion, is longer and is about twice the length of the prostomium. The parapodia and setae are identical with Crossland's specimens from East Africa, with dimorphour pectinate setae posteriorly exhibiting the typical comb lime form.

The mandibles are black and tipped with white ; the forceps strongly curved. Teeth on the maxillary plates are fewer than has previously been recorded as follows :—

$$3 - 4 : 4 + 3 - 4$$

Marphysa bifurcata n. sp.

(Text fig. 7a-h.)



Text Fig 7.

Marphysa bifurcata n. sp.

a—head; b—1st parapodium; c—6th parapodium; d—17th parapodium; e—posterior parapodium; f—compound seta; g—pectinate seta; h—acicular seta.

Lysidice collaris Grube.

i—anterior parapodium; j—posterior parapodium; k—compound seta; l—anterior pectinate seta; m—acicular seta.

Lumbriconereis jacksoni Kbg.

n—anterior parapodium; o—posterior parapodium; p—anterior acicular seta; q—posterior acicular seta.

One specimen collected from the sheltered north reef at Point Peron. Colour of the preserved specimen is brownish grey with iridescent cuticle. Size 60 mm. in length, 3 mm. broad, and contains 130 segments. A small portion of the posterior end, however, is missing. The body anteriorly is cylindrical, but becomes flattened dorsally and convex ventrally as in *M. sanguinea* Montagu.

Prostomium (text fig. 7 a) bears no trace of idontation but is more pointed than that figured by Crossland for *M. macintoshi* although this effect may be partly due to shrinking of tissues in the preserving fluid. The prostomial tentacles are very small, the median the longest and the inner and outer pair progrossively smaller, but they all reach forward to one-third the length of the prostomium since they are arranged in an arc with concavity directed anteriorly. They are smooth and neither jointed nor annulated. Lateral to the base of the inner pair of tentacles and set obliquely between these and the outer pair is a line of brown pigment, in the position where the eyes are usually found. The *buccal segment* is about half the length of the prostomium and as wide as the following few anterior segments of which it is twice as long. This anterior part of the body has a cylindrical cross section, apparently maintained by the pharynx, but it soon acquires the flattened dorsal surface.

The *gills* commenco on sogment 22 with a single filament half the length of the dorsal cirrus. The number of filaments and their length increase until segment 27, where there are three filaments as long as tho dorsal cirrus. There is a maximum of five slender filaments in the region of the 50th segment, where the filaments are also longer and reach to the mid-lino dorsally. Further posteriorly the body width has been reduced, but the gill filaments retain their maximum development and so reach well over the mid dorsal line from oither side. The terminal segments of this sample show no reduction in length or number of filaments. The gill filaments arise along the baso of the dorsal cirrus independently of one another (text fig. 7 e). The dorsal cirrus is also distinctive.

Parapodia.—The first parapodium (text fig. 7 b) bears a conical dorsal cirrus slightly longer than and widely separated from the setigerous lobe and ventral cirrus, which is as long as the setigerous lobe. At the sixth parapodium (text fig. 7 c) the setigerous lobe and ventral cirrus are wider and moro rounded and the dorsal cirrus finger-like. At the seventeenth parapodium (text fig. 7 d) the slight prominence which is seen on the inner side of the dorsal cirrus starts to increase in length. This continues, and the dorsal cirrus from about the twentieth parapodium to the end of the body is bifurcate (text fig. 7 c). Tho ventral cirrus becomes longer and thinner but still arises from a broad base. The ventral cirrus is at all stages practically confluent with the setigerous lobe, and in tho posterior segments is particularly hard to distinguish from the setigerous lobe. *Setae* (text fig. 7 f-h). The simple capillary setae found dorsally are long, very slightly curved, with a thin wing either side and tapering gradually to a long point. The simple setae in the ventral part of the group are very much shorter. About tho middle of the body pectinate setae of general type were added to this group. Ventrally the compound setae are bidentate throughout and protoctod by a striated hood. The supporting aciculae are black anteriorly and number four in the sixth parapodium. At the twentieth their number has been reduced to two and they are coloured a lighter brown. There is later added a ventral bidentate acicular seta of the same thickness as the aciculae. At the posterior end of the body there is only one aciculum and one acicular seta.

Pharynx.—The jaws a dark brown colour. The mandibles are similar to those of *M. macintoshi* Crossland. The teeth on maxillary plates are as follows :— 3 — 4 : 5 + 4 — 6.

Genus **LYSIDICE.**

KEY TO SPECIES.

As far as I can ascertain there have been no other keys to this species published.

1.	Tentacles shorter than prostomium	2
	Tentacles as long or longer than prostomium	3
2.	With black aciculum and acicular setae	*L. capensis* Grube (Ehlers 1908)
	With yellowish aciculum and acicular setae	*L. brevicornis* Kbg. (Augener 1927)
3.	Only one aciculum in the parapodia and no acicular setae present	4
	Dentate acicular setae present	5
4.	Prostomium equals the length of peristomium	*L. parva* T. (Treadwell 1922)
	Prostomium three times the length of peristomium	*L. torgugae* T. (Treadwell 1921)
5.	Prostomium with a deep cleft	6
	Prostomium with a shallow cleft	7
6.	Tentacles jointed	*L. trimera* Ehl. (Ehlers 1901)
	Tentacles not jointed	*L. fusca* T. (Treadwell 1922)
7.	Mid tentacle arises behind others	*L. notata* Ehl. (Treadwell 1921)
	Mid tentacle arises in front of others	*L. collaris* Grube (Monro 1936)

Lysidice calloris Grube.

(Text fig. 7 i-m.)

Monro 1936 *L. collaris.*

Thirty specimens were collected from rock and weed washings at Point Peron, Rottnest and Pelsart Group, Abrolhos. Colour in alcohol pinkish brown to white ; some are covered with a white fleck. Size from 30–40 mm. in length and about 2 mm. broad. Smaller specimens are 15–20 mm. long.

Prostomium, buccal segment, and *anterior body segments* are of equal length and breadth in specimens with invaginated proboscis. Where the pharynx is partly evaginated the buccal segment is narrower than the prostomium and anterior parapodia. The prostomial tentacles are slightly longer than the prostomium which has a shallow cleft anteriorly extending back along the ventral surface. The median tentacle varies in length ; usually it is only slightly longer than the outer paired tentacles but in one specimen it is considerably longer and in several other specimens, all with the pharynx partly extruded, the median tentacle is about half the length of the prostomium. The tentacles are jointed and flattened, dorso-ventrally. The eyes are of characteristic semi-lunar shape (Augener 1913) and are borne at the base of the outer pair of tentacles.

Parapodia and *setae* typical of the species.

Setae.—Pectinate setae posteriorly are more plentiful and exhibit longer teeth. The setae and aciculae are a yellow colour.

Pharynx.—The jaws are brown with a white calcareous coat, especially thick on the mandibles. The teeth of the distal paired plates are very small denticulations and not very easily observed. The number of teeth on the dental plates is fairly constant in the specimens examined :—

$$4 — 4 : 2 + 3 — 4 \text{ or } 5.$$

Genus **LUMBRICONEREIS.**

KEY TO SPECIES.

Fauvel (1923, 1932) and Crossland (1924) have published keys to this genus, from which the following has been adopted.

1.	With compound setae	2
	Without compound setae	12
2.	With globular or rounded head	3
	With conical head	7
3.	With very few setae and a median ventral furrow on the prostomium	*L. macquariensis* Benham (Benham 1921)
	Average number of setae and without a median ventral furrow	4
4.	Dorsal surface of parapodial lobes horizontal	5
	Ventral surface of parapodial lobes horizontal	6
5.	....	*L. floridana* Ehl. (Treadwell 1921) *L. coccinea* Ehl. (Willey 1904)
6.	Prostomium longer than broad	*L. sphaerocephala* Schm. (Monro 1933)
	Prostomium broader than long	*L. albifrons* C. (Crossland 1924)
7.	Enlarged posterior setigerous lobe conical	8
	Enlarged posterior setigerous lobe cylindrical	11
8.	Anterior and posterior setigerous lobes conical	*L. gracilis* Ehl. (Fauvel 1923)
	Posterior setigerous lobe conical, anterior lobe rounded	9
9.	No aciculae anteriorly, aciculae present throughout	*L. nuchalis* T. (Treadwell 1921)
	Aciculae present throughout	10

10.	Small serrations on compound setae	*L. magalhaensis* Kbg. (Benham 1921)
	Larger serrations on compound setae	*L. latreilli* Aud. & Ed. (Monro 1933)
11.	....	*L. paucidentata* T. (Treadwell 1921)
		L. bidens Ehl. (Ehlers 1887)
12.	No hooked setae present	*L. pseudobifilaris* Fauvel (Fauvel 1932)
	Hooked setae present	13
13.	With gills	*L. branchiata* T. (Treadwell 1921)
	Without gills	14
14.	With rounded globular prostomium	15
	With conical or oval prostomium	19
	With accentuated prostomium	*L. acutifrons* McI. (McI. 1910)
15.	Anterior and posterior lobes either side of setigerous lobe	*L. cingulata* T. (Treadwell 1921)
	Only posterior and setigerous lobes	16
16.	Posterior lobe flattened posteriorly	*L. heteropoda* Marenz (Crossland 1924)
	Posterior lobe not flattened posteriorly	17
17.	Mandibles very long	*L. mando* Cross. (Crossland 1924)
	Mandibles not very long	18
18.	About 10 teeth on hooked seta	*L. mirabilis* Kbg. (Augener 1922)
	About 4 teeth on hooked seta	*L. jacksoni* Kbg. (Augener 1922)
19.	Posterior lobes not produced into long, finger-like processes	*L. abyssorum* McI. (McI. 1885)
	Posterior lobes produced into finger-like processes	20
20.	Anterior and posterior lobes produced to equal extent posteriorly	*L. bifurcata* McI. (McI. 1885)
	Posterior lobe produced to greatest extent posteriorly	21
21.	Elongate posterior lobe double	22
	Elongate posterior lobe single	23
22.	Both posterior lobes tapering	*L. bifilaris* Ehl. (Fauvel 1932)
	One posterior lobe papilliform	*L. papillifera* Fauvel (Fauvel 1919)
23.	Hooks and capillary setae continue to posterior end	*L. punctata* McI. (McI. 1885)
	Hooks only continue posteriorly	24
24.	No hooks anteriorly before the 30th parapodium	25
	Hooks and capillaries anteriorly in about 1st-5th parapodium	27
25.	Acutely pointed prostomium	26
	Rounded prostomium	*L. guilielmi* Benham (Benham 1915)
26.	No black in aciculae	*L. tetraurus* Schm. (McI. 1903)
	Black in aciculae	*L. fragilis* Muller (Fauvel 1923)

27.	Head acutely pointed	*L. neo-zealandica* McI. (McI. 1885)
	Head bluntly conical	28
28.	Feet increase in length posteriorly	29
	Feet shorter posteriorly	*L. debilis* Grube (Crossland 1924)
29.	With hood on more than half protruding part of setae	*L. maculata* T. (Treadwell 1921)
	Hoods on only terminal part of setae	30
30.	Hooks of anterior feet narrowest	*L. impatiens* Clap. (Fauvel 1923)
	Hooks of anterior feet not narrowest	*L. brevicirra* Schm. (Monro 1933)

There has been some question of synonymy between *L. jacksoni* Kbg. and *L. brevicirra* Schm. Augener (1913) has described specimens as *L. brevicirra*. Later, in 1922, he figures a hooked seta of *L. jacksoni* from S.W. Australia, remarking that it was previously identified as *L. brevicirra* although he does not mention that this was the form he described in 1913 as *L. brevicirra*. Benham 1927, believes they are synonymous. I find, however, on comparison of descriptions of these two forms, that there are certain differences ; the anterior setigerous lobe of *L. brevicirra* is pointed while that of *L. jacksoni* is rounded ; the prostomium of *L. jacksoni* is rounded while that of *L. brevicirra* is conical ; *L. brevicirra* as described by Ehlers (1904) has nuchal organs, which are absent in *L. jacksoni* ; and in *L. brevicirra* the two peristomial segments are not clearly divided (Crossland 1924).

Lumbriconereis jacksoni Kbg.

(Text fig. 7 n-q.)

Augener 1913	*L. brevicirra.*
Benham 1927	*L. brevicirra.*
Augener 1922	*L. jacksoni.*

Four specimens were collected from Rottnest, all of about 90 mm. in length and 3 mm. wide. Preserved specimens are a brownish white colour. They are as described by Augener (1913) for *L. brevicirra*. Prostomium is well rounded, as wide as its length without the nuchal organs described by Ehlers. The first and second peristomium segments are well separated and do not show the faint division mentioned by Crossland (1924) as typical of *L. brevicirra*.

Genus **STAURONEREIS.**

KEY TO SPECIES.

Crossland (1924) has published a key for identification of some of these species which has been incorporated into this key.

1.	No Eyes	*S. atlanticus* McI. (McI. 1885)
	Eyes	2
2.	Has nuchal cirri	3
	Has no nuchal cirri	8
3.	Palps equal tentacles	4
	Palps greater than tentacles	6

4.	Shafts of compound setae denticulate	*S. crassa* Chamberlin (Chamberlin 1919)
	Shafts of compound setae not denticulate....	5
5.	No terminal piece on dorsal cirrus	*S. gardineri* Cross. (Crossland 1924)
	Has terminal piece on dorsal cirrus	*S. cerasina* Ehl. (Ehl. 1901)
6.	Shafts compound setae denticulate	7
	Shafts compound setac not denticulate	*S. australiensis* McI. (Fauvel 1917)
7.	End piece of dorsal cirrus indistinctly separated	*S. rubra* Grube (Treadwell 1921)
	End piece of dorsal cirrus a conical style	*S. moniloceras* Moore (Crossland 1924)
8.	Forked setae present	9
	No forked setae present	13
9.	4 eyes	10
	2 eyes	11
10.	Tentacles shorter than palps	*S. longicornis* Ehl. (Ehlers 1901)
	Tentacles almost twice as long as palps	*S. australis* Hasw. (Augener 1913) *S. loveni* Kbg. (Augener 1922)
11.	Tentacles longer than palps	*S. pallidus* Langerhans (McI. 1910)
	Tentacles length of palps at most	12
12.	Forked bristle with arms of equal lengths	*S. kefersteni* McI. (McI. 1910)
	Forked bristle with arms of unequal length	*S. ciliatus* McI. (McI. 1910)
13.	More than one joint in dorsal cirrus	*S. melanops* Verrill (Treadwell 1921)
	Only one terminal joint in dorsal cirrus	*S. vittata* Grube (Treadwell 1921) *S. similis* Cross. (Crossland 1924) *S. angolana* Aug. (Monro 1933)

S. rubrovilattus is distinguished by the presence of a nuchal papilla and peculiar brush-like jaws.

Stauronereis australiensis McI.

Augener 1913 *S. australiensis.*

One specimen was collected from Rottnest. It is 3 mm. broad, excluding the parapodia, and 35 mm. long. It agrees in all details with Augener's description (1913).

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