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A GEOLOGICAL COMPARISON OF SOUTH AMERICA WITH SOUTH AFRICA

BY

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WITH A PALÆONTOLOGICAL CONTRIBUTION

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With twelve plates, one map, and seven text-figures

CHAPTER I

INTRODUCTION

With the passing of time and the growth of knowledge there has come about a fuller realization of the extremely prominent part played by the ancient continent of "Gondwanaland" in the past history of this earth. It does not detract from its importance that owing to lack of data the limits set to the land-masses during the various epochs are not always properly known, or, more correctly, the limits as seen in the relics preserved in the existing continental masses of the globe.

We are, on the other hand, still forced to speculate as to how these various sections, as we now find them, were bound together at the beginning of the Mesozoic and how they ultimately came to be parted by thousands of kilometers of ocean.

During the early part of the century and with the limited knowledge available, it sufficed to assume that the fragments, as we see them in South America, Africa, Madagascar, India, Australia, and Antarctica, were linked together at some periods in the late Palæozoic and in the Mesozoic by equally extensive land connections, or else by relatively narrow "land bridges," which at later stages became submerged by the ocean. Geological and geophysical researches within the past decade have, however, rather severely shaken our confidence in such orthodox views, which until then had commended themselves by their very simplicity. Astonishing similarities—stratigraphical, lithological, and palæontological—between regions now parted by ocean came to obtrude themselves, becoming all the more striking in that the fossil remains contained in these formations were not marine, but entirely terrestrial. Almost identical climatic vicissitudes and sequences could be deduced for the several sections—glacial to start with and arid toward the close—though impossible to explain under current theories, followed by volcanicity on a truly enormous scale. Major tectonic structures found their homologues across the wide intervening seas. Furthermore, the marine Tertiary deposits fringing the present continental masses not only indicated how different must have been the distribution of land and water during that late era, but hinted at an unexpectedly recent date for the origin of the existing oceanic basins.

The hypothesis of "continental disruption" or the "displacement hypothesis," brought forward independently by F. B. Taylor[1] and A. Wegener,[2] that the present continents have owed their posi-

[1] Taylor (1910). [2] Wegener (1912).

tions in great part to the breaking-up of much larger land-masses in the Cretaceo-Tertiary through the "drifting apart" of the crustal fragments, has on the contrary helped to bring numerous other irreconcilable facts into harmony and would almost seem to have provided us with the key to the riddle of the structure of the earth and more particularly of the history of "Gondwanaland."

In 1916,[3] though in ignorance of the details of Wegener's doctrine, the writer put forward an hypothesis somewhat different from those of Taylor and Wegener, the outcome of the study mainly of the glacial deposits of the Karroo system, supplemented by a personal acquaintance with their Australian equivalents. Later developments having seemingly rendered these ideas more and more worthy of serious consideration, it became one of his aims to visit South America in the hopes of being able, while gathering information about the Gondwana deposits of that continent, to discover any evidence favorable or adverse to the "displacement hypothesis."

Following the sympathetic representation by Dr. Fred. E. Wright, of the Geophysical Laboratory of the Carnegie Institution of Washington, and Dr. Reginald A. Daly, of Harvard University, the president (Dr. John C. Merriam) and trustees of the Carnegie Institution of Washington, appreciative of the scientific importance of such a mission, most generously offered a grant in aid, and, making use of my six months of leave from official duties, fortunately then available, I was enabled to cross the Atlantic and spend five months in Brazil, Uruguay, and Argentina. To the Carnegie Institution of Washington, in thus promoting research in the Southern Hemisphere, I am accordingly under the deepest of obligations, while I have further to thank them also for their generosity in publishing the results of these investigations, rather unfortunately delayed by reason of pressing official and other duties.

Taking into account the enormous size of the region traversed and the time necessarily consumed in traveling, the opportunities for original investigation were naturally limited, and it was often with keen regret that a particular line of research had to be dropped just as it was disclosing results of consequence. Nevertheless, the knowledge so acquired has permitted the copious scattered literature to be read with a certain amount of discrimination and has enabled a closer comparison of the Gondwana system of South America to be made with that of South Africa than has hitherto been possible. Papers in the English language on the geology of any part of South America are relatively few, while those in Spanish or Portuguese dealing comprehensively with any one of its republics are equally rare. Consequently, instead of limiting this account to the points investigated personally, the opportunity has been taken, although at

[3] Du Toit (1916).

the risk of undue length, of reviewing in addition the geology of South America in so far as it may have a bearing on the problem of Gondwanaland and of a former connection between Africa and the New World. The extraordinarily divergent conclusions reached on many vital questions by various eminent South American geologists is eloquent proof indeed as to the need of such a summary for the benefit of English-speaking persons. Furthermore, the notable advances made in recent years have rather impaired the value of that monumental work by Suess, The Face of the Earth, which even the French edition with its new maps and copious references to recent literature just fails to restore.

In this, the first comprehensive summary of the geology of the eastern part of South America, considerable liberty has been taken in the interpretation of the accounts of areas which naturally could not be visited, and doubtless there will be found not a few statements or conclusions to which the local geologists can and will take exception. It is nevertheless hoped that such differences in the presentation and interpretation may not be of too violent a character; for such the insufficiency of the data, even for the better known parts of this enormous territory, must in part be held responsible. Considerable difficulty was experienced in the preparation of the accompanying geological map; drastic alterations are required to Branner's map of Brazil,[4] while that by Leme,[5] though more up to date, is on a smaller scale and not sufficiently detailed; Walther's map of Uruguay[6] is valuable, but there is no general map of Argentina, while much of Paraguay, Bolivia, and the adjacent part of Brazil are geologically unexplored.

I found my South American confrères keenly interested in the problems herein discussed, though the size of their countries, the smallness of the staffs, the pressure of economic work, and the lack of coördinated effort between the geological surveys of the various republics and states have hindered the carrying out of any comprehensive scheme of work thereon. Furthermore, no one had any first-hand acquaintance with any of the other countries possessing Gondwana beds. I have reason to believe that interest in these problems has been appreciably stimulated as the consequence of this visit. While immediate results therefrom could hardly be expected, attention might be drawn to a paper by Professor Walther[7] on the Borings for Coal in Cerro Largo, Uruguay, and one by Señor E. T. Arocena[8] on the Glacials in the Department of Durazno as the outcome of certain observations made by the writer in that republic.

In order to aid comparisons with the African continent, a brief

[4] Branner (1919).
[5] Leme (1924).
[6] Walther (1919).
[7] Walther (1924).
[8] Arocena (1926).

account is given of the geological features of its western side, the literature thereon being rather scattered, with much uncertainty pertaining to the territories from Angola northward, while a summary of the geology of the important Falkland Islands has also been introduced for reasons that will appear in the sequel.

The schematic representation embodied in Figure 7 will assuredly be subjected to active and probably to hostile criticism on the score of the fantastic and apparently improbable character of the displacement theory, but a close and impartial study thereof is invited, so that the numerous congruences and "coincidences" in the stratigraphy, structure, etc., of the two great land-masses now parted by the South Atlantic may be duly scrutinized and pondered over, the weaknesses of the arguments advanced duly pointed out, and more reasonable alternatives suggested in explanation of the facts or their interpretation.

Leaving Cape Town on June 12, 1923, Río de Janeiro was reached a fortnight later, where the director of the Geological Service, Dr. Euzebio Paulo de Oliveira, with the permission of the Brazilian government, kindly detailed Dr. L. F. Moraes Rego to act as my guide and instructor, under whose able direction a tour was made of nearly six weeks' duration, the department obligingly providing rail transport. The program embraced a short visit to Ouro Preto, Bello Horizonte, and Diamantina to inspect the ancient formations of Minas and the Bôa Vista Diamond "pipe." The journey from São Paulo to Ityrapina and Baurú provided sections of the Triassic "traps" and the Cretaceous of the interior, while a trip through Ponta Grossa, Iratý, Roxo Roiz, Marechal Mallet, Río Claro, Porto União, and Río Negro to Curitýba enabled the Devonian as well as the full succession of the Gondwana system to be studied. Taking the steamer from Paranagua to Porto Alegre, Taquara, Cachoeira, Ferreira, Santa Maria, and Sant' Anna were visited, enabling good sections of the Triassic sediments and volcanics to be inspected.

In Uruguay the director of the Section of Geology and Water Boring, Señor E. Terra Arocena, generously placed his records at my disposal, while Dr. Karl Walther, professor of Geology at the Institute of Agronomy, Montevideo, kindly supplied me with valuable information. Fraile Muerto provided confirmation of the existence of Carboniferous glacial beds, originally reported therefrom by Guillemain, while Melo, Paso del Cerro, Santa Rosa, and Sauce were also visited.

In Buenos Aires, through the courtesy of the Minister for Mines, the director of the Geological Survey, Dr. J. M. Sobral, wholeheartedly detailed several of his staff to accompany me in turn on a tour of nearly two months, namely, Dr. Franco Pastoré, Dr. Augusto Tapia, and Dr. Juan J. Nágera, the government defraying the cost of rail transport. The route lay through Villa Dolores, Bajo de Velis, Córdoba, La Cumbre, Capilla del Monte, Marayes, San Juan, Mendoza, Cacheuta, Uspallata, Barreal, and across the Andes to Valparaiso in Chile and back to Buenos Aires; this enabled the various horizons in the Gondwana system to be inspected. Trips were made to Olavarría, Sierra de la Ventana, and La Plata to study the equivalents of the "Cape Fold ranges."

The return journey was made by Montevideo, Santos, São Paulo, Río de Janeiro, and Pernambuco. Through the kindness of Dr. Miguel A. de Lisboa, director of Irrigation, a rapid journey was made by rail to Campina Grande and thence to the irrigation dams under construction at Gargaleira and Parelhas in Río Grande do Norte, every facility being placed at my disposal by the Brazilian government through the agency of Doctor Netto. The voyage thereafter was made via Madeira, arriving at Cape Town on December 10, 1923.

Among the numerous other persons to whom I have been particularly indebted are Drs. T. H. Lee, Paulino F. de Carvalho, and Axel Löfgren, of the Brazilian Geological Service, Dr. Joviano A. Pacheco, head of the Geographical and Geological Commission of the State of São Paulo, Drs. Pablo Groeber, Roberto Beder, Juan Rassmuss, Anselmo Windhausen, Ricardo Wichmann, and Hausen, of the Geological Survey of Argentina, Dr. Juan Keidel, formerly director of that survey, Dr. H. Schiller, of the Museum of La Plata, Dr. C. Hosseus, of the University of Córdoba, and Mr. H. J. Hawley, geologist to the Standard Oil Company. To my former South African friends, Mr. Bernard W. Ritso, M.I.C.E., late director of the Section of Water Boring in Uruguay, Mr. David Draper, F.G.S., manager of the Bôa Vista Diamond Mine, to Mr. F. W. Scott, M.I.C.E., engineer-in-charge at Gargaleira, and Mr. B. H. Heatlie, of Buenos Aires, I am under great obligations. Furthermore, to Mr. L. S. Goldsmith, of the Geological Survey, Pretoria, is due the lettering on the Geological map.

My thanks are due to Dr. R. S. Bassler, of the United States National Museum, Washington, for his opinion on the invertebrate fossils collected in Brazil and Argentina, whilst, finally, I am excessively indebted to my friend Dr. F. R. Cowper Reed, of the Sedgwick Museum, Cambridge, England, for his labors on these collections, the results of which are embodied in the valuable Appendix to this report. His noteworthy discovery of the Triassic affinities of the Estrada Nova mollusca was, however, only made while this work was in the press, and it has been found impossible at this late stage to do full justice thereto and avoid some minor inconsistencies in the text.

CHAPTER II

GEOLOGICAL FRAMEWORK OF THE SOUTH ATLANTIC

SECTION A. THE WESTERN SIDE OF AFRICA

For convenience we may divide this region into *two portions:* (1) that from the extreme south of the Cape up to the Cunene River, of which the geology is now firmly established, while formations younger than the Triassic are scarcely represented, and (2) that from the Cunene River northward, for which reliable data are often wanting, while the coastal strip, just as in the opposed section of Brazil, is made up largely of marine Cretaceous and Tertiary deposits.

(1) The *southern section,*[9] embracing part of the Cape Province and Territory of Southwest Africa (formerly German Southwest Africa), displays a great stretch of Archæan rocks from the Cunene River southward to Van Rhynsdorp, having a northeasterly strike in the Swakopmund-Windhoek region. Younger, though probably of Cambrian or pre-Cambrian age, is the Nama system, with a basal series of conglomerates and quartzites reposing unconformably on the crystallines, followed by limestones, dolomites, and shales, and these by red sandstones, red and green shales, and gray and red quartzites. Though nearly flat-lying inland, *e.g.*, at Kuibis, this formation, on approaching the coast, suddenly displays folding along axes following the ocean margin closely, from Lüderitz to the mouth of the Olifants River continued with a south-southeasterly to southeasterly strike through the Western Province of the Cape. These crumplings, which were accompanied by intrusions of granite, are of pre-Devonian age, but in the south a renewal of movement took place along them in late Carboniferous times.

Upon a worn-down surface of these rocks was deposited the triply-divided Cape system some 3,300 meters in thickness, widely distributed over the southern third of the Cape Province. The Lower Devonian Table Mountain sandstone at the base, some 1,600 meters thick, is composed of unfossiliferous, whitish, hard sandstones and grits characterized by tiny pebbles of white or gray vein-quartz and sometimes of red jasper, while current-bedding is conspicuous. An important feature is the occurrence of a fine glacial horizon some 700 meters above the base, the material having been derived from some locality lying out in the present Atlantic.

Then follows the Bokkeveld series of shales and sandstones, with its Lower-Middle Devonian "Austral" invertebrate fauna and above

[9] For fuller details see Du Toit (1926).

it the Witteberg series (upper Devonian-lower Carboniferous) of white quartzites, with some poorly preserved plant remains. The source of all these Palæozoic sediments lay in the north and northwest. In the neighborhood of the Olifants River mouth these beds are lying nearly flat, but on proceeding southward folding is discovered that follows the much older south-southeasterly directed crumplings, while near Ceres a second series of foldings appears with a general west-east trend continuing to the Indian Ocean; the mountainous belt thus formed is known as the "Cape Fold ranges."

South of latitude 33° the Witteberg passes up without a break into the upper Carboniferous glacials of the Dwyka series, which constitutes the lowest member of the Karroo system, and which, partaking in the above-mentioned foldings, possesses a thickness of over 400 meters and seems to have been largely deposited in standing water by ice-sheets originating in the north. North of the thirty-third parallel the tillite is found undisturbed, but transgresses across the Cape system and older groups to rest upon the Archæan, while the floor beneath it becomes uneven and in good exposures reveals typically striated *roches moutonnées*. The horizontal tillite is a true ground-moraine and can be traced through Calvinia and Bushmanland to appear again beyond the Orange River, whence it continues northward in Southwest Africa up the Fish River Valley to Mariental, but has not yet been recognized north of that point.

The succeeding beds, sometimes sharply defined, but often carrying small erratics, compose the upper Dwyka Shales and pass up into a zone of white-weathering carbonaceous and pyritic shales with occasional casts of the small reptile *Mesosaurus*, and, together with some dolomite and chert, constitute the horizon of the "White band," the thickness of these post-glacial beds being from 150 to 160 meters, approximately. These strata are recognizable from Robertson in the south to Mariental in the north, but fragments of *Mesosaurus* have been obtained from the Kaokoveld in latitude 20° 45′. All this is instructive when comparison is being made with the almost identical Iratý shales of Brazil with this similar zone fossil. No coals occur in the Dwyka shales, though the Brazilian seams appear to be on the corresponding horizon.

The White band passes up in the southern Karroo into the Ecca series, a thick group of greenish, bluish, and sometimes purplish shales and flagstones with calcareous nodules and dark-green or gray sandstones that have yielded silicified wood and the *Gangamopteris* flora, but to the northeast and to the north entirely different facies in the series have been developed. For instance, in Calvinia the group is composed almost entirely of dark-bluish, soft shales, while in the southern Kalahari and to the northeast of Keetmanshoop the strata are now largely red, the formation consisting of deep-red and green-blue shales with brown-weathering calcareous bands and soft yellowish and reddish sandstones, a facies closely comparable with the second and third stages of the Paganzo system of western Argentina and also somewhat like the Estrada Nova group in Uruguay. In the Transvaal, on the other hand, the overlap of the several subdivisions of the Dwyka and Ecca has taken place on to the thin glacial conglomerate or else on to the pre-Karroo rocks, while a fluviatile and thinner phase of the Ecca has led to the production of the Transvaal and Natal "Coal Measures," a group of pale grits, conglomerates, arkoses, and sandstones, with dark micaceous shales and seams of coal often from 2 to 8 meters in thickness. The flora is the "southern" one, allied to that of the Kárharbári of India or the Greta stage of New South Wales, but with some "northern" elements, a Lower Permian age being indicated.

The succeeding Beaufort series, well over 1,000 meters thick, in the southwest, is made of greenish mudstones and shales, often variegated and carrying calcareous concretions, together with yellowish felspathic sandstones, the beds being conspicuously red and maroon near the top. Small local depositional unconformities are common and the beds are decidedly of the "interior basin" type. A fairly abundant reptilian and amphibian fauna and a scanty flora allied to that of the Damuda of India and Newcastle of New South Wales, collectively indicate an age covering the upper Permian and lower Triassic. This formation is unrepresented to the northeast in the central Transvaal and to the northwest in Southwest Africa.

The Stormberg series embraces the plant- and coal-bearing Molteno group of grits, sandstones, and gray and blue shales, the striking deeply-colored group of the Red beds and massive contrasting cream or pink Cave sandstone and finally the Drakensberg volcanics, the whole assemblage representing the upper Triassic, Rhætic, and just possibly the Liassic. While conformable to the Beaufort in the south, this series transgresses across the Ecca or even the pre-Karroo rocks in the Transvaal, Southwest Africa, and Southern Rhodesia, so that the Red beds, Cave sandstone (and its equivalents, the Bushveld and Forest sandstone) and basalts come to cover wide tracts without the intervention of the Molteno or older groups, a feature paralleling the conditions to be found in South America in the case of the Trias-Rhætic beds. The series is well developed in the Kaokoveld, where it makes the coast-line for quite a considerable distance.

The Molteno flora with its characteristic genus *Thinnfeldia* is extremely like that of the "Rhætic" of western Argentina, though, the vertebrates (*saurischia* and *pseudosuchia*) of the Red beds and Cave sandstone confer an age not younger than Rhætic for these succeeding sediments. The Basaltic lavas cover broad areas and must have had a much wider extension formerly; they exceed 400 meters in depth in each of the main areas, the maximum thickness known being about 1,300 meters. Dolerite sills and dikes, closely related to the lavas, are most abundantly represented in the Karroo beds from Sutherland and Beaufort West in the south right up into Southwest Africa, a feature closely paralleled in the Paraná Basin in Brazil.

Cretaceous (Neocomian-Wealden) beds and Tertiaries (Eocene-Pliocene) are represented within the Coastal Belt of the south of the Cape, but no undoubted marine Cretaceous is known along the Atlantic shore south of the Cunene River nor directly opposite in South America.

(2) In the less known *northern area* Cretaceous and Tertiary beds, largely marine in origin, fringe the coast from Lobito Bay in Angola up to French Congo, widening out where traversed by the Cuanza and Congo Rivers, while in the former region the strata are actually flexed along axes concave towards the west and are also faulted. Dipping beneath them in places are the Dombe sandstones and in the Congo section the "Gres sublittoraux" of Fourmarier,[10] which have been regarded by Choffat as Lower Cretaceous, but by others as of Triassic age. The Albian of Benguella is of importance because of the presence of certain forms common or allied to the Sergipe Cretaceous of Brazil, as pointed out by Kossmatt, Newton, Gregory, and others.

The plateau to the east of Benguella, formed of crystallines and belts of ancient sediments, is crowned with the Bihé sandstone,[11] which is probably merely the fringe of the Lubilache series that covers such an enormous area within the Congo Basin, with its western boundary passing through Leopoldville northward to the borders of the Cameroons, a distance of over 1,500 km. This formation, several hundred meters thick, is composed of horizontal friable white, yellowish, or reddish sandstones, often displaying curious surface silicification. On the eastern side of this immense basin they repose upon, but quite possibly to some extent pass laterally into, the shales and sandstones of the Lualaba series. The age of these groups, as determined from some fish and crustacean remains, is Triassic or Rhætic and they correspond therefore with the Stormberg series farther to the south. In the west the Lubilache generally rests with unconformity upon the slightly folded strata ascribed to the Kundulungu series, a group of deep-red shales and micaceous flagstones alternating with gray or light-red sandstones and becoming more felspathic and coarser toward the summit. There are serious differences of opinion as to the age of this formation as seen in the Lower Congo or in French Congo, which can not be settled, owing

[10] Fourmarier (1924).

[11] Gregory (1916), p. 523.

to the absence of fossils, but a Permian or Carboniferous age is just possible, and if so, the group would correspond to the lithologically similar Estancia beds of Bahía and Sergipe.

The Kundulungu in turn rests disconformably upon the system "Schisto-calcaire," a group unconformable to the pre-Cambrian complex, having a basal conglomerate stated by Delhaye and Sluys [12] to be largely of glacial origin, followed by over 1,000 meters of limestones and dolomites, occasionally oölitic, but as yet not proved fossiliferous. They either correspond with the Otavi dolomite (Nama) of Southwest Africa—probably Proterozoic—or are of early Palæozoic age and hence possibly comparable with the Bambuhy series of eastern Brazil. These beds display strong foldings directed nearly north-northwest, crossed by a set at right angles thereto, along the latter of which a renewal of movement occurred probably in the Permian as well as in still later times.

From Cameroons the coast of Africa turns abruptly westward and a region[13] is reached displaying many points of similarity with the Pernambuco-Maranhão territory of Brazil. Along the low-lying coast, extending from Cameroons to Accra, with a tongue reaching into northern Nigeria, is a curving belt of marine Tertiaries, in which zones so far back as the Eocene are to be found, resting upon either Cretaceous or ancient formations and passing beneath younger deposits. Bituminous shales and lignites are known from the earlier tertiaries in several areas and can be compared with the Eocene bituminous shales with fish remains in Alagoas and perhaps Maranhão. Much of the western part of Africa was inundated by the Cretaceous ocean, and wide tracts of the hinterland are covered by marine beds belonging to various stages of that epoch, just as is so marked a feature of Ceará, Piauhý, and Maranhão. On both sides of the Atlantic these strata have locally been affected by post-Cretaceous movements.

Among the older formations might be mentioned the Buem series on the eastern side of the Volta River in Togoland, composed of conglomerates, arkoses, quartzites, and shales, of which certain conglomerates have been regarded as of morainic origin by Koert and hence of Permo-Carboniferous age; Lemoine classes them, however, in the Devonian. Conspicuous is the tectonic line of the Atacora Range south of the Niger in Dahomey—the "Saharides" of Suess—in which a belt of folded quartzites and schists, flanked by crystallines, ascribed to the Silurian, but probably older, strikes north-northeastward from the Gold Coast and thence at intervals into the Sahara, where the folds now trend more nearly northward; associated is the Tarkwa series in Gold Coast Colony with northeastward strike and certainly pre-Palæozoic.

[12] Delhaye and Sluys (1921).

[13] Lemoine (1913).

This brings us to the consideration of the undoubted Palæozoic rocks of western Africa and central Sahara. On the borders of Sierra Leone and French Guinea, resting unconformably on schistose rocks, is an undulating sandstone formation carrying Silurian (Wenlock) graptolites,[14] apparently the beginning of the huge area of horizontal sandstones on the upper Niger building up the plateau of Homboi ("Bandiagara sandstone") and south of the great bend of the Niger, but which have not as yet been proved fossiliferous. To the northeast the Silurian of Tuareg and Aïr is folded and overlain by gently dipping Lower Devonian possessing a fauna including in addition to European forms, not only some from North America, but certain from the Bokkeveld as determined by Haug.[15] Future work will doubtless add largely to the known area of Palæozoics in this part of Africa. Of great importance too is the occurrence of the Middle Devonian in a small down-faulted block at Accra on the Gold Coast, with a "Hamilton" fauna,[16] while slates, provisionally placed in the Lower Carboniferous because of certain poorly preserved mollusca—but possibly Devonian—are known at Sekondi to the west of Accra.

Undoubted pre-Mesozoic marine beds have not yet been found to the southeast in Cameroons, and the presence of this wide, though interrupted belt extending from Sierra Leone into the Sahara, in which marine Palæozoic beds have been developed, is of immense importance, inasmuch as it shows correspondence with the broad, shallow syncline of marine Silurian, Devonian, and Carboniferous strata within the lower Amazon Valley in which similar faunal elements are actually present.

SECTION B. THE FALKLAND ISLANDS

These remarkable islands, of which a brief geological sketch cannot be omitted, constitute a most striking link between South Africa and South America, despite the fact that they are situated only a few degrees from Patagonia and well down below the fiftieth parallel. Our knowledge concerning them has been enormously extended through the work of Andersson[17] and after him Halle,[18] with H. A. Baker[19] just recently, while the Devonian molluscan fauna has been discussed by J. M. Clarke[20] and the Gondwana flora described by Halle, Seward and Walton.[21]

The dominant Devono-Triassic succession has been affected by two main tectonic structures. The more important of these, marked by strong folding and some faulting, traverses the northern part of East Island, trending west to west-northwest and curving more to the

[14] Dixey (1925), p. 213; Lecointre and Lemoine (1925).
[15] Haug (1905).
[16] Kitson and Morley Davies (1925).
[17] Andersson (1907).
[18] Halle (1912).
[19] Baker (1923).
[20] Clarke (1913), p. 55, p. 326.
[21] Seward and Walton (1923).

northwest through the northern side of West Island, with some parallel subsidiary flexuring in the center of that land; the other structure crosses nearly at right angles, striking southwestward along both shores of Falkland Sound. In the southern side of East Island and the southwestern side of West Island the beds, on the contrary, undulate slightly or are flat.

The lower Devonian sandstones are restricted to the southwestern side of West Island, resting unconformably upon crystallines at Cape Meredith and having a thickness of many hundred meters. The series is extraordinarily like the Table Mountain sandstones of the Cape Province, consisting of a group of unfossiliferous, pale, false-bedded sandstones and quartzitic sandstones with some red micaceous shales at the very base, while small pebbles of white vein-quartz are common, making in places conglomerates. It passes beneath a group of slaty rocks, shales, flagstones, and sandstones that has yielded a typical "austral" Devonian fauna, overlain by similar beds with lepidodendroid plant remains and thus like the Bokkeveld series of the Cape. Of the mollusca, some 20 species are common to the latter and some 25 to the equivalent Devonian of South America, including in each case several trilobites, besides other closely allied forms. This group is succeeded by quartzites and quartzitic sandstones and interlaminated shales that correspond with the Witteberg series. Baker has pointed out these surprising resemblances with the Cape system, not only lithologically, but in regard to thickness as well, so far as such can be made out in the folded ranges of East Island.

The Gondwana beds are referred to as the Lafonian system, having a thickness of possibly over 3,000 meters and occupy the southern half of East Island, but are brought down by folding in a few localities in West Island. At the base are glacial boulder-beds about 650 meters thick, identical in their characters with those of the Dwyka tillite, usually folded and cleaved, with striated erratics often traversed by regular jointing; underneath them Baker has discovered some quartzite surfaces with striations running from north to south, presumably glaciated floors. Some passage beds with small inclusions lead up into the Lafonian sandstone, and this in turn into "banded siltstones," apparently seasonally banded "varve" rocks representing glacial material deposited in fresh water.

Next comes a huge group of alternating brown, yellow, gray, and green mudstones, shales and similarly colored sandstones and hard greenish sandstones in which occur members of the *Glossopteris* flora. The form identified by Halle as *Gangamopteris* is regarded by Seward and Walton[22] as more probably a *Glossopteris*, with which occur *G. browniana*, *G. indica*, *Voltzia*, and several species of

[22] Seward and Walton (1923), p. 324.

Phyllotheca and *Dadoxylon*, evidently an Ecca-Beaufort flora. The highest beds, exposed on the eastern side of Falkland Sound, have yielded *Neocalamites carrerei* (Zeill.), suggestive of a Triassic age.

Dolerites, just like those injected into the Karroo system at the close of the Rhætic, pierce the strata at a number of places, significantly avoiding the northern folded belt, but frequently possessing a northeast-southwest trend. Not improbably the westerly to northwesterly directed foldings correspond in age with those striking nearly east-west in the Cape, which we know were initiated at the very close of the Palæozoic, but were renewed in mid-Cretaceous times, and from which dolerite is absent. The Western Province of the Cape displays in addition another set of foldings trending southwest or west-southwest.

The precise place of the Falkland Islands, stratigraphically, lithologically, and structurally, with reference to the Cape and to Argentina, will be discussed at a later stage (Chapter VI), when it will be shown that they display characters consistently intermediate between those of the two countries, though somewhat more closely allied with the former.

SECTION C. SOUTH AMERICA[23]

Commencing in the north, the outstanding feature is the great syncline of Lower Palæozoics, much covered by Tertiary and Quaternary deposits, in the Amazon Valley, trending eastward from Manaos to Pará, in which direction its axis deviates towards east-northeast. In this trough marine strata of Silurian, Devonian, and Carboniferous ages are all involved, resting upon the Archæan, which bounds the structure for immense widths, both to north and south.

Eastward in Maranhão, Piauhý, Ceará, Parnahyba, and Pernambuco there is a wide fringe of Tertiaries, and no Palæozoics are known to occur, if we ignore the rather doubtful series of Serra Grande, while inland in the first two States Permian and Triassic Gondwana sediments spread over a wide area, reposing mainly on crystallines. In Alagoas, Sergipe, and the adjoining part of Bahía undoubted Permian and possibly upper Carboniferous form belts rest on the (probably) pre-Devonian basement and display a certain amount of folding. Save for them and the similar patch in the southern end of Bahía, Gondwana beds do not reach the coast of Brazil, except in the neighborhood of Torres.

Inland from Bahía is an extensive trough of folded lower Palæozoic beds—mainly slates and limestones, probably Ordovician—as well as much older formations, striking southwestward from near the great bend in the Río São Francisco, following up the valley of that river almost to the boundary of Minas, which feature is continued

[23] See Branner (1915) (1919).

beyond with similar trend through São Paulo and Paraná in the more closely folded and altered condition to reappear in Uruguay. This lengthy tectonic structure, running approximately parallel to the Atlantic coast, has been termed the "Brasilides" by Keidel.

Occupying the whole of the Upper Paraná drainage area is the great but shallow "Paraná Basin," made of Gondwana beds, called the Santa Catherina system, deposited upon a platform of crystallines and folded Ordovician, but in parts of Paraná and Matto Grosso upon nearly horizontal lower Devonian strata like those of the Cape; its boundaries have been determined by erosion on all sides except to the west of the Paraguay and Lower Paraná Rivers, where the beds disappear beneath the geologically recent Neogene formations. A large part of east-central Brazil is, furthermore, covered by horizontal Cretaceous and perhaps Tertiary sandstones of continental type, in places concealing the Santa Catherina beds.

Passing over the wide stretch in Eastern Argentina, beneath which these Gondwana strata have been proved by deep borings, those beds reappear in the west at intervals within a huge region from Bolivia southward to Córdoba and Mendoza, where they, together with Palæozoics beneath and Cretaceo-Tertiaries above, have been involved in the Andine movements, with general strike either north or a little east of north; here they are known as the Paganzo system. Farther to the south similar strata, from Devonian to Permian in age, build the ranges between Buenos Aires and Bahía Blanca with southeasterly trend, structures termed the "Gondwanides" by Keidel[24] and regarded by him as the continuation of the Southern Fold ranges of the Cape, involving as they do precisely similar and equivalent formations.

The equivalent systems of Santa Catherina and Paganzo generally begin with a glacial formation, which corresponds with the Dwyka tillite of South Africa and is followed by plant- and often coal-bearing lower Permian beds with the "*Glossopteris* flora" and by higher Triassic and Rhætic rocks, but an important intraformational break exists, extending perhaps over most of the region. At the top come the enormously widespread basaltic effusions of Paraná, though not restricted to that region, being also represented in Maranhão and in certain of the remnants in the pre-Cordillera as well as in Patagonia, where, however, the bulk of the volcanics appear to be of acid composition, largely overlain by nearly flat lying Cretaceous and Tertiary beds.

The western limits of Gondwanaland are not exactly known, as the Andine belt is largely composed of Mesozoic marine beds and volcanics, all intensely folded and injected with igneous matter.

[24] Keidel (1916 and 1922).

SECTION D. GENERALIZED COMPARISONS BETWEEN THE TWO CONTINENTS

Confining attention in each case to a strip some 45 degrees in length by 10 in breadth, we shall now proceed to compare the two stretches, namely, the tract extending from Sierra Leone to Cape Town on the one side with that from Pará to Bahía Blanca on the other; furthermore, whenever the direction of any structural feature has to be mentioned, such will be given with reference not to the meridian, but to the coast-line near at hand.

In *each continent:*

(1) The foundation rocks consist of crystallines of pre-Cambrian age and certain belts of infolded pre-Devonian sediments of various though mostly undetermined ages, but generally corresponding lithological characters,

(2) In the extreme north, marine Silurian and Devonian beds, only slightly disturbed, rest unconformably upon this complex, occupying a broad syncline trending *obliquely* to the coast-line, namely, between Sierra Leone and Gold Coast and underlying the estuary of the Amazon.

(3) Farther to the south, belts of Proterozoic and early Palæozoic strata, mainly quartzites, slates, and limestones, strike nearly parallel to the coast, being gently flexed in the north, but becoming more disturbed toward the south, where they are invaded by granitic masses, for example, in the region between Lüderitz and Cape Town and that between the Río São Francisco and Río La Plata.

(4) Corresponding to the nearly flat-lying Devonian of Clanwilliam is its all but identical counterpart in Paraná and Matto Grosso.

(5) More to the south we find the Devono-Carboniferous of the southern Cape paralleled by the terrain appearing a little to the north of Bahía Blanca, passing up conformably into the Carboniferous glacials and Permian sediments, both successions having been intensely crumpled under Permo-Triassic and Cretaceous movements that display similar orientations.

(6) Traced northward, the tillites in each case become horizontal and transgress across the Devonian to rest upon a glaciated peneplain formed by these and by older rocks; farther to the north they fail.

(7) The glacials are in each case overlain by continental Permian and Triassic strata with the "*Glossopteris* flora," covering enormous areas, followed by vast outpourings of basalts and penetrated on an extensive scale by dolerites of presumed Liassic age.

(8) These Gondwana beds extend northward from the Southern Karroo to the Kaokoveld and from Uruguay to Minas Geraes.

(9) Further great detached areas occur in the north, in each case

some distance inland, in the Angola-Congo and the Piauhý-Maranhão regions.

(10) An intraformational break is widespread, though commonly there is no angular unconformity between late Triassic and early Permian beds. In certain areas, however, the former may rest with visible discordance on tilted Permian or pre-Permian formations.

(11) Tilted Cretaceous beds occur on the coast only in the Benguella-Lower Congo and Bahía-Sergipe areas.

(12) Horizontal Cretaceo-Tertiary, both marine and continental, cover great extents between Cameroons and Togoland and in Ceará, Maranhão, and also more to the south, while the extensive deposits of the Kalahari can roughly be paralleled with the Neogene and the Quaternary Pampean of Argentina.

(13) In setting down this generalized summary, the important link constituted by the Falkland Islands must not be overlooked. Their folded Devono-Carboniferous succession is all but indistinguishable from that of the Cape, while the Lafonian closely parallels the Karroo system. *Stratigraphically and structurally the Falklands have their place with the southwest of the Cape and not with Patagonia* (Chapter VI).

(14) From the palæontological viewpoint, attention should be focussed on: (*a*) the "austral facies" of the Devonian of the Cape, Falklands, Argentina, Bolivia, and Southern Brazil, in contrast to the "boreal facies" of northern Brazil and central Sahara; (*b*) that unique reptilian genus *Mesosaurus* from the Dwyka shales of the Cape and Iratý shales of Brazil, Uruguay, and Paraguay; (*c*) the *Gangamopteris-Glossopteris* flora, with a small admixture of northern forms within the Lower Gondwana beds in the south of each country; (*d*) the *Thinnfeldia* flora of the Upper Gondwana of the Cape and Argentina; (*e*) the Neocomian (Uitenhage) fauna in the south of the Cape and northwest of Neuquén in Argentina; (*f*) the Northern or Mediterranean facies of the Cretaceous and Tertiary faunas north of the Tropic of Capricorn; and (*g*) the South Atlantic-Antarctic facies of the Eocene (San Jorge formation) of Patagonia.

(15) The geographical outlines of Africa and South America are amazingly similar, not only in the main, but even as to detail; moreover, excepting in the north, the fringe of Tertiaries is of small width and the presence of those beds of little moment therefore.

On following the various groups embraced between the Devonian and the Rhætic of the two continents in a direction away from the Atlantic shores an amazing generalization shows itself, namely, that the *variation in facies* of these several formations commonly discloses greater divergences within distances of say from 5 to 15 degrees of arc than those actually noticed on comparing the developments

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European equivalents	Cape Province			Falkland Islands		Sierra de la Ventana	
Liassic.	Karroo system	Stormberg	Basalts.				Paganzo system
Rhætic.			Cave sandstone.				
			Red beds.				
Triassic.			Molteno beds.				
			Beaufort.				
Permian.				Lafonian system	Sandstones and shales.	Pillahuincó beds.	
			Ecca.		Shales, clay-stones, etc.		
Upper Carboniferous.		Dwyka	White band.				
			Upper shales.		Shales, sand-stones, etc.	Shales.	
			Glacials.		Glacials.	Glacials.	
			Lower shales.				
Middle and lower Carboniferous and middle Devonian.	Cape system		Witteberg quartzites and shales.		Quartzites, sand-stones, and shales.	Greywackés.	
Lower Devonian and uppermost Silurian.			Bokkeveld beds (fossil-iferous).		Fossiliferous shales and sandstones.	Fossiliferous slates.	
			Table Mountain sand-stones.		Barren sandstones.	Sierra de la Ventana quartzites.	

Table I.—*Stratigraphical Table Showing the Devono-Lias Succession in South America and South Africa*

(The wavy line indicates an unconformity.)

European equivalents	Cape Province	Falkland Islands	Sierra de la Ventana	San Juan—La Rioja	Barreal	Northern Argentina and Southern Bolivia	Paraná Basin	Maranhão	Southwest Africa		Transvaal
									North	South	
Liassic. Rhætic.	Karroo system: Stormberg: Basalts. Cave sandstone.			Paganzo system: V. Red conglomerate, etc.	V. Red conglomerate.	Marls. Limestone and Dolomite.	Santa Catherina system: São Bento: Serra Geral volcanics. Botucatú sandstone.	Mearim: Basalts. Red sandstones.	Stormberg: Basalts. Kaoko beds.	Stormberg: Basalts.	Karroo system: Stormberg: Basalts. Bushveld sandstone.
Triassic.	Red beds. Molteno beds. Beaufort.			IV. "Rhætic."	IV. "Rhætic."	Bermejo: Upper sandstones (Machareti). Mandiyuti. Oquita.	Río do Rasto. Passa Dois: Estrada Nova. (upper part)	(?)			Bushveld marls.
Permian.	Ecca.	Lafonian system: Sandstones and shales. Shales, claystones, etc.	Pillahuincó beds.	III. Stage. II. Stage.		Materal.	Estrada Nova. (lower part)	Parnahyba: Shales and sandstones with *Psaronius*.			
Upper Carboniferous.	Dwyka: White band. Upper shales. Glacials. Lower shales.	Shales, sandstones, etc. Glacials.	Shales. Glacials.	I. Shales, etc. Glacials. *Cardiopteris* beds. Glacials.	Tontal series: Marine beds with *Productus* and *Spirifer*. Glacials.	*Spirifer* and *Productus* beds.	Iratý. Itararé Tuberão: Palermo. Bonito. Glacials.			Ecca. Dwyka: White band. Upper shales. Glacials.	Ecca: Coal measures. Dwyka: Glacials.
Middle and lower Carboniferous and middle Devonian.	Cape system: Witteberg quartzites and shales.	Quartzites, sandstones, and shales.	Greywackés.			*Sica-sica* beds.					
Lower Devonian and uppermost Silurian.	Bokkeveld beds (fossiliferous). Table Mountain sandstones.	Fossiliferous shales and sandstones. Barren sandstones.	Fossiliferous slates. Sierra de la Ventana quartzites.	Slates, greywackés, and sandstones.		Huamampampa sandstones. *Conularia* and *Crinoid* beds. Icla sandstones.	Ponta Grossa shales. Furnas sandstone.				

nearest the two opposed shores, although the ocean between is no less than from 40 to 70 degrees in breadth. This observed arrangement is considered to constitute the most telling argument in favor of the conception that the *two continental masses were in the past geographically closer to each other*, which is actually the keynote of the Displacement or Disruption Hypothesis. Evidence for this momentous assertion will be found in the following pages and the problem reviewed in Chapter VII.

For convenience, the accompanying correlation table has been introduced at this stage to indicate the stratigraphical succession in the type areas to be dealt with in detail below.

CHAPTER III

ARGENTINA AND BOLIVIA

SECTION E. THE SIERRAS OF THE DISTRICT OF BUENOS AIRES

Rising out of the plain of Pampean deposits (late Tertiary to Quaternary), here close upon 200 meters above sea-level, are the two well-known chains of ancient rocks lying to the south and southwest respectively of Buenos Aires.

(1) The Sierra de Tandil[25]

The first of these stretches from Mar del Plata on the Atlantic coast in a direction a little to the west of northwest past Tandil to Olavarría—a distance of over 300 km. with a mean breadth of about 50 km.—being composed of a series of small chains and isolated hills with frequent interruptions and nowhere exceeding an altitude of 450 meters. The features displayed are those of a buried and partially exhumed mountain chain, and along its margins the belt is bordered by inliers of the hard rocks projecting through the soft mantle of the plain.

The formation consists largely of pre-Palæozoic granite, on which rests unconformably a basal quartzitic member followed by dolomite, quartzite, slate, white limestone, etc., to a thickness of fully 150 meters. In contrast to the distinctly younger beds of the Sierra de la Ventana, the strata in the Sierra de Tandil are but gently flexed, and are often lying nearly flat, the harder members producing table-topped hills; on the coast the nearly horizontal quartzites have determined Cape Corrientes. This flexuring follows two directions mainly, namely, west-northwest to east-southeast and one almost at right angles thereto, *i.e.*, north-northeast to south-southwest. The latter represents the mid-Palæozoic "Brasilides," as Keidel has called them, which have been crossed and modified here by the first-mentioned set of the Permo-Triassic "Gondwanides," so finely displayed in the belt to the southwest, which foldings, although of considerable intensity in that quarter, seem to have faded out to the northeast before reaching Uruguay.

Where seen by me in one of the outliers of the Dos Hermanos ("The Two Brothers"), near Olavarría, the quartzites, resting on a pedestal of red granite, are white, hard, and fine-grained, though somewhat coarser at their base and not unlike the Kuibis quartzites of the Nama system of Southwest Africa, that are also followed by slates and limestones. They are, however, presumed to be of Silurian

[25] Aguirre (1879); Hauthal (1896, 1901); Valentín (1894); and Nágera (1919), who gives a bibliography.

or more probably of Ordovician age, because of impressions referred to *Arthrophycus harlani* Hall, in certain of the quartzites at Balcarce[26] while Siemiradski reported finding *Stromatopora* and *Atrypa* in the dolomitic group,[27] though such does not appear to have been confirmed.

It should be observed that this belt stands wholly isolated in the Pampean formation, that it is over 400 km. distant from the possibly equivalent strata in Uruguay and 150 km. from the Palæozoics of the Sierra de la Ventana and Pillahuincó, and that the few bore-holes that have penetrated the Pampean covering have only proved granite; for example, that at Buenos Aires and at Telén in the district of La Pampa to the west.

(2) The Sierra de la Ventana

The Fold-ranges, among which is embraced this most important of the sierras, lie not far to the north of Bahía Blanca and occupy a tract some 180 km. long by 50 km. at its widest. They include the Sierra de Puán, Sierra del Chaco, and Sierra de la Ventana proper in the southwest and west, and the Sierra de Bravard, Sierra de las Tunas, and Sierra de Pillahuincó on the northeast, and make a sweeping double curve with general strike from southeast to northwest, bending to the west in the latter direction. In the heart of the ranges the Río Sauce Grande courses along a strike valley that generally follows the Tillite zone. As with the Sierra de Tandil, the Pampean formation laps around the base of the rising ground and enters many of the valleys.

The geology has been described by Aguirre, Hauthal, and Schiller,[28] and more particularly by Keidel,[29] who has not only given the most detailed and accurate account, but by the discovery of the Carboniferous tillite was first able to point to the wonderful similarity with South Africa and show that the ranges, structurally as well as geologically, appeared to form the continuation across the Atlantic of the Fold-ranges of the Cape Western Province. The writer's researches bear out the value of Keidel's work and perception, for in only one essential does his interpretation differ from that of this Argentine geologist, namely, in the stratigraphical position of the Pillahuincó beds. To the visitor from South Africa the resemblances with that country are simply astounding, such being the case not only with the major elements, but in so many minor respects, as well as in lithological details regarding the tillite and in the presence and attitude of the Tertiary "high-level gravels."

The cross-section from southwest to northeast passing through

[26] Nágera (1919*a*), p. 7.
[27] Siemiradski (1893).
[28] Aguirre (1891); Hauthal (1892, 1896, 1901, 1904); Schiller (1907).
[29] Keidel (1916), also (1922).

the railway station of Sierra de la Ventana (formerly called Río Sauce Grande) would show (Fig. 1) on the southwest a closely folded and inverted succession of Palæozoic strata in which the softer beds display a strong cleavage that is dipping at a high angle to the southwest (shown by broken lines in the diagram).

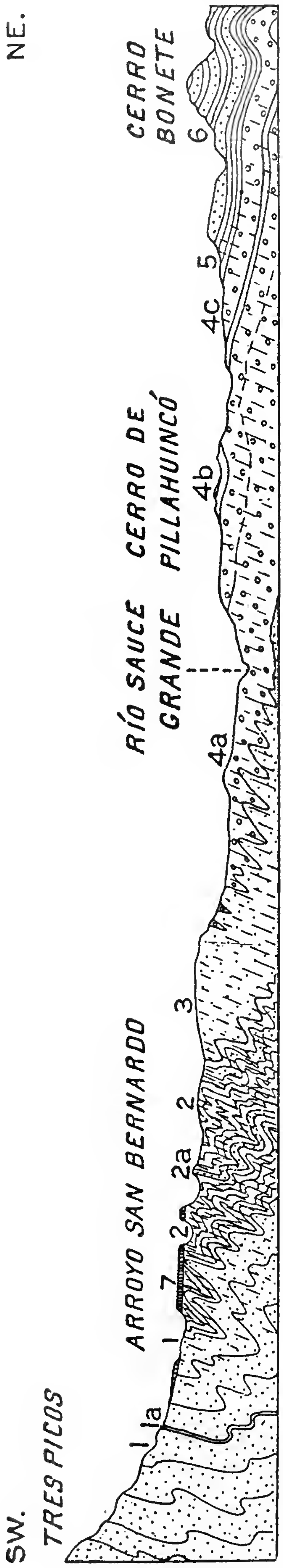

Fig. 1—Succession on the northeastern side of the Sierra de la Ventana. Distance about 20 km.; vertical scale exaggerated. The highly inclined broken lines indicate the cleavage.

The *lowest member*—a thick, whitish, quartzitic sandstone formation, the equivalent of the Table Mountain sandstone of the Cape—builds the main range, which in its various aspects strongly recalls the chains of the Langebergen, Outeniqua, and other coastal barriers of the Cape, and which culminates in the Cerro de los Tres Picos (1,280 meters); farther along the crest is the peak pierced by the famous "ventana" or window, from which the range takes its name. On its southwestern foot the basement granite is reported to crop out near Tornquist and Aguas Blancas, the contact being an inverted one apparently. The sloping ground to the northeast, for a distance of some 5 or 6 km. down to the valley of the Río Sauce Grande, is made by the *second member*, a series of cleaved slates and greywackés, corresponding to the Bokkeveld and Witteberg series of the Cape, in which the folding can at times be made out, while the valley floor, together with the rising ground just beyond, is composed of a cleaved greenish tillite, the representative of the Dwyka glacials.

The stratigraphical position of the strata to the northeast has hitherto been in doubt, the folded quartzites and slaty beds of the Sierra de Pillahuincó having been regarded by Schiller as the equivalent of those in the ranges to the southwest, a view satisfactorily disposed of by Keidel, who has nevertheless considered them as probably of pre-Devonian age. My observations, however, have shown an upward passage into them from the tillite, which goes to indicate that these beds are the equivalent of the folded Ecca series of the southwestern part of the Cape Karroo and of the Lafonian of the Falkland Islands, as will be discussed in the sequel. While the entire succession is thus extraordinarily similar to those in the Cape and Falklands, its resemblances to the equivalent beds represented in the pre-Cordillera of San Juan to the northwest are, it should be noted, by no means so clearly marked.

(*a*) *The Infra-tillite Succession*—To the excellent account given by Keidel[30] there is little to add. The basal group may possibly be close on 1,000 meters in thickness, but the intense crumpling in this section would prevent any exact measurements being made. In the splendid exposures at the head of the Arroyo San Bernardino the quartzites (Fig. 1, *1*) are isoclinally folded in a rather regular fashion, the succession being of course an inverted one, the pressure, just as in South Africa, having come from a southerly direction. Owing to a mishap to a negative, I am unable to give a photograph of these fine contortions, but one of Beder's views, published by Keidel, taken further to the west along the same range, is reproduced, which will serve to bring out this feature very clearly (Plate I).

Most of the beds are hard, white, fine-grained quartzite, but there are darker and faintly greenish varieties and a number of thin, greenish-gray schistose quartzites and slaty kinds in thinner layers. One conspicuous shale bed (Plate II, *A*, and Fig. 1, *1a*) perhaps a few hundred meters from the top of the series, is 8 meters thick, a dark-green, silvery slate, with base well defined, which invites comparison with the well-known "shale band" of the Table Mountain sandstone, but no glaciated pebbles were seen in it or just below it. The uppermost hundred meters of strata are distinctly darker than those composing the range proper, approaching a greywacké in some respects, the rock being schistose, showing some false-bedding and including a little grit with quartz fragments and pebbles, which was the only coarse material seen. The schistose and darker character tends to obscure the upward passage into the slate group, which, as Keidel has pointed out, is rapid, though not obvious. That the quartzites underlie the slates can be shown by a study of their folded junction.

To sum up, the quartzites have marked similarities to the Table Mountain series of the Cape; not to that in the Ceres or Clanwilliam districts, but to the facies in the south, *i.e.*, Mossel Bay, George, or Knysna, where it is finer-grained, where quartz pebbles are rarer and smaller, and where thin layers of dark slates are not unusual.

In the overlying, seemingly thick, group—called the "esquistos" by Aguirre, the folding can now and again be made out, despite the strong cleavage. The lowest beds are fine slates, with some bands of greywacké appearing higher up, while the topmost beds consist

[30] Keidel (1916), pp. 11–12; 21–22; 28–29.

not of quartzites, as in the Cape and Falklands, but of highly cleaved greywackés, mostly brownish in color and full of feldspar, finer alternating with coarser varieties, the latter becoming in places quite gritty, while a few pebbles of dark bluish quartzite were observed. The marked cleavage obscures both the dip and the folding, but the topmost bed, in contact with the tillite, is a hard, brown, uncleaved grit.

These strata are manifestly the equivalent of the middle and upper divisions of the Cape system, much distorted Devonian fossils having indeed been obtained in several places in the slaty basal portion of the assemblage, while a specimen inclosed in a sandy rock approaching a greywacké, which is exhibited in the La Plata Museum, was derived from this locality. The greywacké, marked (*2a*) in the section (Fig. 1), is evidently the same bed as is shown on Keidel's map of the territory lying a short distance farther to the northwest along the same strike, and recalls the first or fossiliferous sandstone of the Bokkeveld series and the Tibagý sandstone of Paraná. The uppermost group of greywackés and occasional slates, which has so far yielded neither molluscan nor plant remains, is wholly different from the white, fine-grained quartzites with green slaty intercalations of the Witteberg series or those occupying a similar horizon in the Falklands, and in this very important respect the succession here differs from those in South Africa and the Falkland Islands.

It is uncertain whether the phyllites and greywackés known from the Sierra Pintada in the southeastern part of the Mendoza district are of Devonian age, but, as will be set forth later on (Chapter VI), the strata in Jachal to the north referred to this epoch and containing the typical "austral fauna" in their upper part, are in their basal section no longer white quartzites, but shaly sandstones and sandy shales with bands of soft, dark sandstone and of a friable nature. This marked difference in lithology of the basal portion of the Devonian within the distance of less than 1,000 km. toward the northwest, as compared with the slight change noted in the distance of almost 6,000 km. from the Cape or 2,000 km. from the Falklands can not be overemphasized and will be discussed in Chapter VII.

(*b*) *The Tillite*—In the neighborhood of Sierra de la Ventana station the lower part of the glacial beds (*4a*) is but poorly exposed over the gently undulating ground, but practically continuous outcrops can be seen in the higher country to the east of the railway bridge spanning the Río Sauce Grande, while excellent artificial sections are disclosed in the railway cuttings between kilometer posts 529 and 536. The total breadth of the belt is about 9 km. The prevailing strong cleavage (Plate II, *B*), directed southwestward at an average angle of about 65°, coupled with the unsatisfied character of the deposit, obscures the true behavior of the formation, which accounts for the erroneous interpretations of the section by Hauthal and others, but a careful study of the attitude of certain shaly or else quartzitic layers goes to indicate that the formation, though seemingly dipping southwestward beneath the greywackés in that direction, is actually resting upon the latter and as a whole is dipping northeastward below the strata of the Sierra de Pillahuincó. On the southwest the folds are isoclinal with axial planes dipping southwestward at nearly 45°, but along the Río Sauce Grande flattening has occurred and thereafter the glacials are but slightly flexed, to pass ultimately at quite a low angle northeastward beneath the sediments of the Cerro Bonete. I agree with Coleman[31] that Keidel[32] has overestimated the degree of folding that is present in the railway section, since, except for one important reversal of dip, the mass is inclined regularly northeastward, though signs of strong compression are nevertheless clear. The thickness is difficult to estimate here, because of the uncertainty as regards that of the lower part of the formation, but it is undoubtedly well in excess of the figure given by Keidel, namely, 60 meters; it would seem to be at the least 200 meters, perhaps more.

The *base* was studied on the left side of the Arroyo San Bernardino, a few kilometers west of the station, the nearest point where the junction with the hard top of the greywacké group (*3*) is exposed. A careful examination showed the tillite to be dipping at 45° beneath the greywacké, but within the latter are what were taken to be two narrow infolds of the base of the glacials, certain marginal and other characters indicating that they were merely the repetition of one and the same zone. As a rule, the change from greywacké to dark-blue, fine-grained tillite with small inclusions takes place within a distance of a few centimeters, while some small pebbles occasionally occur just within the greywacké itself. At one place a wedge of soft schistose strata appears just within the latter, including some isolated pebbles like those in the tillite, all of which makes it practically assured that there is a *perfectly conformable transition* from the arenaceous into the glacial formation. This conclusion, therefore, confirms the opinions arrived at by both Hauthal and Keidel.

The condition thus parallels that in the south of the Cape (south of latitude 33°) where no discordance has been detected, though the change from the one formation to the other is often quite abrupt, but differs from those in the Tanqua Karroo or in the Falklands, where the tillite rests upon a slightly striated surface of the underlying Carboniferous quartzites.

Of the glacial origin of the formation, a discovery first made by Keidel and since confirmed by Coleman, there can not be the slightest doubt. All the phenomena displayed duplicate down to minutest

[31] Coleman (1918), p. 319.
[32] Keidel (1916), p. 25.

detail those characterizing the Dwyka tillite in the south of the Karroo. The rock is a hard greenish unstratified material, having scattered irregularly and sometimes rather sparsely through it inclusions that rarely exceed 0.5 meter in length. Among the host of rock types represented, Keidel discovered a lump of fossiliferous limestone, while noteworthy are certain quartzites and greywackés indistinguishable from those of the Sierra de la Ventana, but it is important to observe in the *uncleaved* condition. Keidel also mentions erratics of material like the beds in the Sierra de Pillahuincó, but I could find nothing that could with any confidence be ascribed to those formations exposed to the northeast. Well-striated and often faceted boulders, such as are typical of glacial tills, can be obtained without difficulty, such as have been figured by Keidel and Coleman.

Like the Dwyka along the south of the Karroo, the Río Sauce Grande conglomerate is not one uninterrupted, single body of morainic matter, for there are several surfaces of discontinuity, which evidently mark the cessation and subsequent renewal of glacial activity. At kilometer 535 in a railway cutting is exposed the sharply defined top to a tillite body with a thin, splintery shale resting upon the plane or break and passing up in turn into a normal tillite. A little higher up there appears a "gravelly" band of the kind of material termed in South Africa "gravel Dwyka," charged with small angular and sub-angular stones, while next in turn comes an instance of a "boulder pavement" in which the inclusions within the top of the lower body of morainic material have all been pressed down to one level and striated in a direction, so far as can be made out, north 65° west (true); this is overlain by normal tillite. The way in which the top of each of these pebbles just rises above the surface of discontinuity, and other features, show that the phenomena are due to the overriding of the moraine by the ice itself and are not due to subsequent tectonic movements. Boulder pavements of identical character have been recorded in the Dwyka and in the Carboniferous glacials of Cape Wynyard in Tasmania. Furthermore, there is a very important intercalated zone of quartzitic rocks (Fig. 1, *4b*), probably lenticular in habit, with a maximum thickness of 40 meters, which splits the tillite mass, occurring on a horizon about 70 meters from the top of the glacials building up the outlying peak of the Cerro de Pillahuincó immediately to the west of the 534 km. post and seen again on the railway at 533.50 and 533 and running in a belt 1 km. to the east on the left side of the Arroyo Negro, where it can be seen to pass below the upper tillite (*4c*). At 531.2 km. the base is found to be an intensely hard, gray, small-pebble conglomerate, crammed with inclusions—some certainly striated—resting through the medium of a greenish, thin, and variable quartzite on the lower tillite, a break occurring at this level. This is the band whence most of the specimens in museum collections labeled "tillite" come from, though it is decidedly not representative.

The zone itself consists of this hard conglomerate, followed by brownish to greenish quartzites and greywackés possessing feeble or irregular bedding, with some softer bands allied to tillite. The zone recalls some of the quartzite bands and lenses in the southern Dwyka, for example, some near Matjesfontein station in the Southern Karroo, being in the nature of interglacial sands, while at kilometer 531.75 are some of those curious quartzitic "pseudo-boulders," such as have been recorded from the Cape and Natal, representing masses of sandy material picked up by the ice and "balled up" during the progress of the glacier.

The upper part of the glacial series is best seen along the road from Sierra de la Ventana to Peralta, at a point nearly midway between the Cerro de Pillahuincó and the Cerro Bonete. Here the tillite (*4c*) becomes finer grained and more cleaved, inclusions get isolated, smaller, and at length fail entirely, and the rock passes up without a break into a zone (*5*) about 100 meters thick, of hard, cleaved slates of blue-gray color characterized by little ocherous concretions due to the oxidation of pyrite or marcasite, and these in turn into the group of sandstones, greywackés, flagstones, and quartzites (*6*) building the Cerro Bonete and the hills to the northeast and north, which can for convenience be termed the "Pillahuincó beds."

(*c*) *The Strata of the Sierra de Pillahuincó*—This is the only point in this neighborhood where I found the exposures sufficiently good to show the passage between the glacials and the group building the Sierra de Pillahuincó, the age of which has hitherto been in doubt. It is true that Keidel recorded the superposition of the latter upon the tillite at one point, which, however, he took to be due to thrusting, as is not at all unlikely, for in the range lying a few kilometers to the northwest from kilometer post 529 the arenaceous zone near the base of the Pillahuincó beds seems to be thrown against the tillite by faulting.

The strata that were studied between the Cerro Bonete and Peralta station consist of hard gray-green sandstones and quartzites, pale in the coarser and generally darker in the finer-grained varieties; there are also schistose greywackés and some thinner shaly and flaggy bands still displaying cleavage, but the strata as a whole are very different from the Devono-Carboniferous succession to the southwest. To the east of the railway, Keidel has recorded red and green slaty beds, often blotchy, and beds of clayey limestone and marl similar to those observed by Schiller on the northern edge of the Sierra de Pillahuincó, north of Peralta, intercalated with the quartzites—probably higher zones within the series.

The folding in the Cerro Bonete is gentle, but, followed northeastward, it becomes more intense. While asymmetrical there, as is also the case just northwest of the railway, on proceeding northward the folds, as Keidel has remarked, become overturned to the southwest, though it is important to observe that the crumpling afterwards decreases and that opposite Stegmann Station (507 km.) the beds are now practically flat. The fact that the pre-Devonian strata of the Sierra de Tandil are so little disturbed indicates that the "Gondwanides" must be fading out towards the northeast.

The parallel is extraordinarily good with the Ecca series of the southwestern Cape, say between Laingsburg and Prince Albert, where the foldings die out in a northerly direction within a relatively short distance. The southern Ecca, moreover, contains thick groups of hard grayish and dark greenish sandstones, almost a quartzite in places, and much flagstone in addition to hard green and purple mudstones and shales and sometimes impure limestones. The unfossiliferous nature of the Cape beds is another parallel, for in the brief search possible near Peralta only worm castings were seen and some poor impressions that might be parts of plants. A further examination of these beds is hence extremely desirable. In the corresponding portion of the Lafonian system of the Falklands, Baker has also recorded fine-grained and intensely hard greenish sandstones, and sometimes typical slates. It should be noted that the carbonaceous shales of the Dwyka or of the Iratý series do not appear to be represented, but they are certainly missing in the Falklands and probably too in the district of San Juan to the northwest.

(*d*) *The High-Level Gravels*—To my mind the most striking parallel with the Cape is formed by the consolidated gravels and breccias resting on benches or terraces cut along the inner side of the quartzite chain of the Sierra de la Ventana (Plate III, *A*). Indeed, viewed even at short range, I had great difficulty in realizing that this was another continent and not some portion of one of the southern districts in the Cape, say Caledon, Oudtshoorn, or Uniondale. Taken in conjunction with the other resemblances already mentioned, the parallelism is so wonderfully close that one can not escape from the conclusion that the geological histories of these two countries must have been all but identical from mid-Palæozoic down to early Tertiary.

As Keidel[33] has so well described, and exactly as in the Cape, the highest terrace is merely a shelf incised in the quartzites beneath the crest of the range, running at a level of close on 800 meters above the ocean. The second has an altitude varying between 450 and 550 meters, cut at about the junction of the quartzites and the younger slates, and evidently had a wide distribution formerly, since the spurs of slates and greywackés between the valleys leading down to

[33] Keidel (1916), pp. 37–42.

the Río Sauce Grande show all the characters of a dissected peneplain transecting the highly tilted Palæozoics and sloping from the range gently toward the northeast. In places this terrace still bears cappings of hard, bright-red conglomerates and breccias, as, for example, at the head of the Arroyo San Bernardino below the Tres Picos (Fig. 1, 7) where the deposit is composed chiefly of subrounded to angular lumps of quartzite coarsely stratified and set in a hard arenaceous cement colored with oxides of iron. The material resembles exactly in its character and habit the so-called "high-level gravels" or "ferricretes" of the southern Cape; comparison might be made between Keidel's Plates IX and X and Plates XXIII and XXIV in Rogers and Du Toit's Geology of Cape Colony.

Obviously these are terrestrial scree and gravel deposits, which, from analogy with South Africa, were formed on a peneplain carved out during the early part of the Tertiary, and which in similar fashion have since been dissected to a depth of from 100 to 200 meters, as marked by accumulations of boulders or by patches of younger gravels at various levels in the valleys. This in the Cape was due to the elevation of the interior of the continent in about the Miocene or Pliocene. In Argentina, however, this broken country subsequently became in great part buried beneath the mantle of Pampean loess.

Attention might be drawn to the fact that in the neighborhood of Bahía Blanca borings have disclosed at a depth of about 600 meters beneath marine (probably lower) Tertiary a group of red clays and grey and white marls sloping gently to the southeast, which, although unfossiliferous, are regarded as upper Cretaceous from their resemblance to strata of that age developed in Patagonia.[34]

SECTION F. THE SOUTHERN PRE-CORDILLERAN REGION

As Windhausen[35] has pointed out, the fold-belt of the area just described is doubtless prolonged to the northwest beneath the Pampean formation, curving somewhat toward the north in that direction, for Gondwana beds appear from below Pleistocene basalts and Triassic volcanics in the Sierra Pintada near San Rafael on the Río Atuel, where they exhibit a north-northwesterly strike.

Unfortunately, very little is known about this rather important inlier, though Windhausen has mentioned the presence of a tillite and also an unconformity at the base of the Gondwana beds, but the intensity of the erosion that followed the late Permian foldings is indicated by the unconformity between these and the succeeding Triassic quartz-porphyries and tuffs.[36]

It would appear that the "Gondwanides"—the "Hercynian folds" of Groeber—extend northward into Mendoza and San Juan;

[34] Wichmann (1918).
[35] Windhausen (1918), p. 35.
[36] Windhausen, p. 35; Groeber (1918), p. 53.

but in that direction the strata have subsequently become involved in the younger Andine movements with a north-south strike and are much affected by overturning and thrusting, whereby slices of different formations down to the Tertiary have repeatedly been brought into abnormal relationships with one another and the continuity of the relatively narrow belts of Gondwana frequently interrupted. The earlier north-northwesterly directed flexures can nevertheless still be made out in parts of San Juan and Jachal. Throughout this region the Gondwana, known as the "Paganzo," rests *unconformably* upon the Devonian or upon older formations.

(1) The Glacial Beds of San Juan and Jachal

At the foot of the Sierra Chica de Zonda, to the south of the town of San Juan, various strata have, through the labors of Stappenbeck, Bodenbender, and Keidel,[37] long been known to crop out, containing examples not only of Carboniferous plants, but of the *Glossopteris* flora, and also glacial beds. It becomes important, therefore, to consider the precise relationships of the formations involved, in view particularly of the opinion expressed by Keidel that there are *two distinct* plant-bearing groups, the one pre-Gondwana with European Carboniferous forms, the other overlying the glacials and considered as of "Permian" age. It will accordingly be instructive to describe in some detail the certain sections that I visited at the foot of this great range some 25 km. to the south of San Juan, where the relationship of the plant-bearing zone to the glacials is beyond all question. The area examined is a few kilometers long, extending from a point a little to the Río Grande down to the Río de la Mina, as shown in the sketch map (Fig. 2).

The Sierra consists of a lofty barrier of gray-weathering Ordovician limestones and along its eastern base extends a group of highly tilted green slates and greywackés, with some thin fossiliferous limestones, presumably of Silurian age. The Gondwana beds are exposed in the foothills and in a number of small ravines, but on leaving the slopes their outcrops soon become hidden beneath deposits of boulders and gravels. Good exposures are found of the basal beds, but the outcrops of the higher groups are limited and sometimes isolated. Piecing together the various sections, which can be done without much uncertainty, there is discovered a thickness of about 360 meters of the Gondwana, or, as they have customarily been termed, "Paganzo" beds, resting unconformably upon the Lower Palæozoic and dipping eastward below a covering of tilted Calchaqueños (Tertiary) and nearly horizontal Quaternary gravels.

The Gondwana embraces *three distinct glacial horizons*, one of which forms the very base of the system, while the intercalated sedi-

[37] Stappenbeck (1910); Keidel (1922).

ments between that and the second horizon yielded plant remains, among which were the Carboniferous genera *Cardiopteris* and *Rha-*

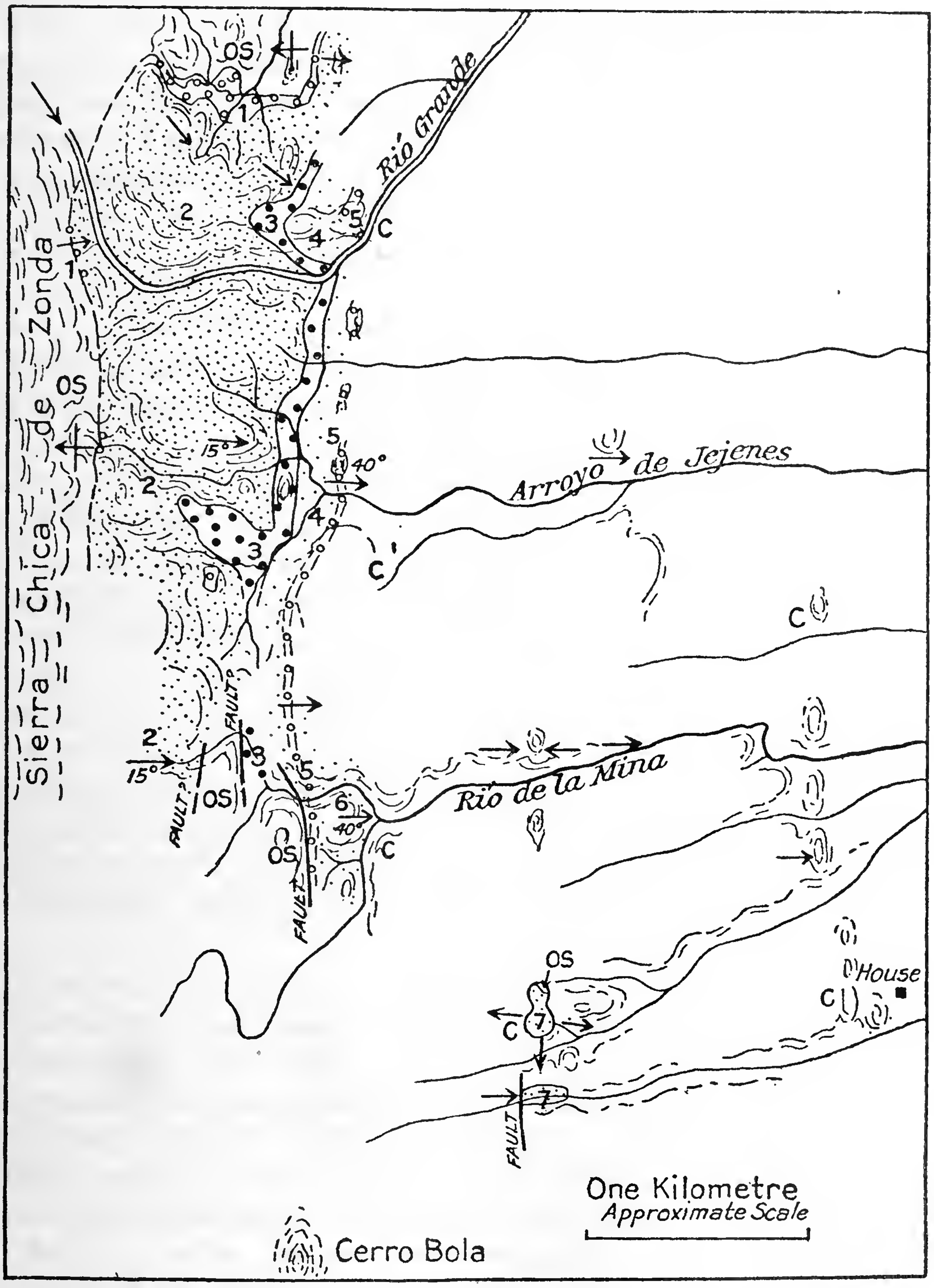

FIG. 2—Geological sketch-map of a small area along the eastern base of the Sierra Chica de Zonda to the south of San Juan. *OS*, Ordovician and Silurian limestones and shales. 1–7 Paganzo system: 1, first glacial zone; 2, plant-bearing shales and sandstones; 3, second glacial zone; 4, sandstones; 5, third glacial zone; 6, shales with some sandstones; 7, red and dark shales. C, Calchaqueños and Quaternary gravels.

copteris, but no marine fossils. The discovery of these forms, taken in conjunction with the other plants found in this locality by previous workers, tends to invalidate Keidel's argument for the existence of two distinct formations, one with Carboniferous plants older than the Paganzo, the other having glacials and containing the *Glossopteris* flora. For this reason it does not become necessary to make use of the two-fold division made by him into the "Jejenes" and the "Zonda" series, nor need the supposed relationship of these series be argued. In only this respect do the very valuable observations and conclusions of Keidel need to be modified, though unfortunately it will affect his criticisms of the writings of Bodenbender, Hausen, Penck, and others.

In the small ravine 0.5 km. north of the Río Grande the base of the Gondwana is excellently exposed, the *first glacial* zone (Plate III, *B*) from 8 to 20 meters thick, resting upon an uneven surface of highly tilted slates (*A*) and limestones (*B*) (Fig. 3). At the point *X* the floor is actually vertical, and in the pocket below it lies true ground

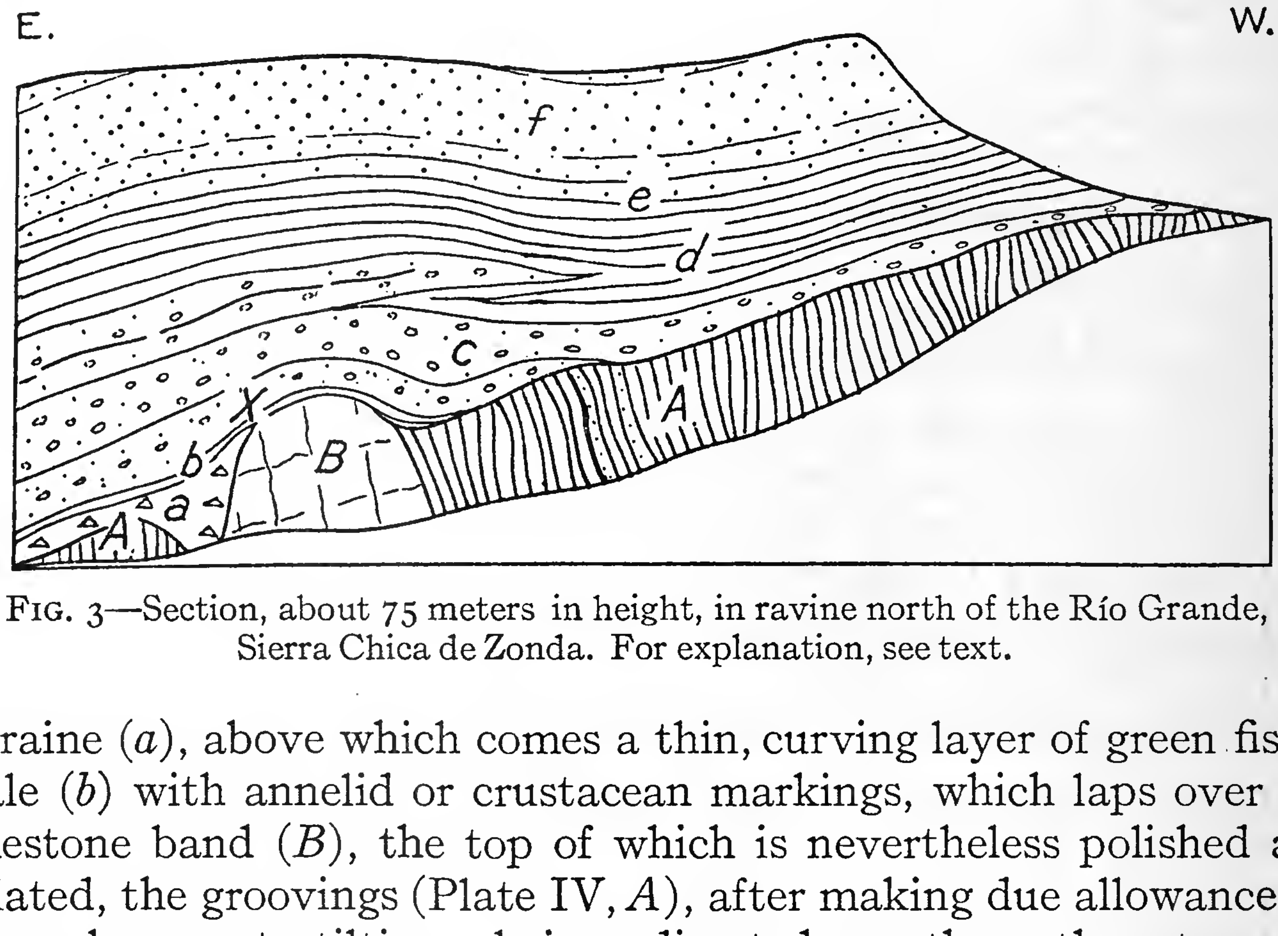

FIG. 3—Section, about 75 meters in height, in ravine north of the Río Grande, Sierra Chica de Zonda. For explanation, see text.

moraine (*a*), above which comes a thin, curving layer of green fissile shale (*b*) with annelid or crustacean markings, which laps over the limestone band (*B*), the top of which is nevertheless polished and striated, the groovings (Plate IV, *A*), after making due allowance for the subsequent tilting, being directed north-northwest–south-southeast. The overlying glacials (*c*) range from a true, unbedded tillite of normal character to a stratified fluvio-glacial conglomerate having the inclusions lying with their longer axes parallel to the stratification, though striated boulders are common. They pass up into, or to some extent are even interlaminated with, dark carbonaceous shales and micaceous flagstones and thin sandstones with occasional plant remains (*d*), grading up into a group of flagstones (*e*) and yellowish-gray sandstones (*f*), sometimes micaceous, getting coarser toward the summit, the succession being clearly shown in Plate IV, *B*.

At a height of about 165 meters above the base the *second glacial* zone makes its appearance (Plate V, *A*). In the neighboring Río de

Jejenes, on the southern side of the ravine (Plate V, *B*), its base is sharp, the band incloses lenses of sandy stuff as shown in the nearby view (Plate VI), and the inclusions are as a rule small and of hard rock, though one of them, composed of gneiss and resting directly upon the sandstone, constituting the floor, is nearly 3 meters in diameter. The succession, it might be remarked, is a perfectly conformable one. In the lower ground to the east, where this zone is proceeding to disappear beneath higher beds, it is nearly 50 meters thick, composed of a lower group of fluvio-glacial sandstones and tills and a thin bed of shale above, passing up through boulder-shale into tillite (Plate VII, *A*); finely striated erratics can readily be picked up. An example has been figured by Coleman and it is hence unnecessary to give any additional illustrations.

The top passes through pebbly grit and sandstone into greenish shaly beds, in which at 50 meters there appears boulder-shale, and next the *third glacial* zone, about 12 meters thick, overlain by more hard, greenish shales, and these, as seen to the south in the channel of the Río de la Mina, by alternations of sandstone and shale, with a thin zone of soft black carbonaceous shales constituting the highest strata visible. Although so thin, this upper tillite carries some exceptionally large inclusions, mainly of Ordovician limestone, one slab of which, a couple of meters in length, contained several large coiled cephalopods. The conspicuous green coloring in some of the beds, absent in the region to the northeast, serves to link this formation with the equivalent Pillahuincó beds of the Sierra de la Ventana.

In this terrain, crossing the Río Grande and the Agua de Jejenes, the beds are dipping regularly eastward and are not dislocated, there can not be the slightest doubt that the sequence is a normal upward one which is resting unconformably upon the Silurian and is embracing Paganzo beds only. Great weight, therefore, must be attached to this section, since it provides us with the key to the Permo-Carboniferous stratigraphy of a very wide region in the pre-Cordillera, as will be discussed later on.

Proceeding southward in the direction of the Río de la Mina, irregularities make their appearance, due partly to the fact that the floor beneath the system seems to have been highly diversified, and partly to subsequent tectonic movements, by which anticlinal cores of Ordovician limestone have been driven through the younger formation. By such movements, what from their lithological peculiarities must be regarded as slightly higher zones of the Paganzo, appear in two fine continuous domes (Plate VII, *B*), from beneath the folded unconformable Calchaquenos formation a little to the southwest of the lime-kilns of Carpintería not far from the Cerro Bolá, a group of carbonaceous and micaceous shales with nodules carrying plant remains, soft micaceous sandstones, and reddish mudstones resting seemingly through the medium of a thrust-plane upon a core of Ordovician limestone; this has been figured very roughly by Stappenbeck (1910, p. 36, Fig. 1).

The overshadowing feature of the sections just described is the direct evidence that they furnish upon the position of the plant-bearing horizons in relation to the glacials, at the same time proving the close association of European Carboniferous plant forms with members of the *Glossopteris* flora, thereby bringing the succession into harmony with the sequences observed more to the north and northeast in the Sierra Umango, Sierra Villa Unión, Sierra de los Llanos, etc., namely, near the base of the Paganzo system, as will be discussed later.

Seemingly the glacials are represented at intervals along the base or flanks of this range, as, for example, in the Cuesta de Pedernal farther to the south, where Stappenbeck[38] reported thick conglomerates overlain by beds with a "Culm flora" resting upon the Silurian; but this and other cases require to be reëxamined in the light of the sections described from near Río Grande.

Working southward from this "type" region, mention has to be made of the fine section on the northwestern side of the Cerro Pelado between Mendoza and Uspallata, where, according to Stappenbeck[39] the Paganzo, thrown down against Ordovician limestones and dipping southeastward at a pretty high angle, has a development of basal conglomerate, stated by Keidel to be glacial in its nature, resting on presumed Devonian and followed by conglomerates, arkoses, sandstones, shales, bituminous shales, and impure coals from which *Sigillaria*, *Annularia*, and *Gangamopteris* have been collected. This section is of further interest in that here and also at Villa Vicenze toward the north these beds, according to Keidel,[40] are overlain with *strong unconformity* by the sediments and volcanics of the upper Triassic.

The mention by Windhausen[41] of the "Permian" glacial conglomerate resting unconformably on older beds near San Rafael to the south in the curious Sierra Pintada with its northwest-southeast trend is important, as such would indicate a link between the glacials of the Sierra de la Ventana and those of the Mendoza district.

In the museum of the Geological Survey at Buenos Aires stands a photograph of an exposure of a tillite labeled "Arroyo del Chiquero, High Cordillera, Mendoza," which apparently refers to outcrops at the base of the Sierra de Tigre, some 40 km. to the northwest of Uspallata. This helps to connect with the important occurrence recorded by Keidel at Leoncito Encima in the same valley further to the north, 25 km. distant from Barreal and with that at the Quebrada

[38] Stappenbeck (1910), p. 36.
[39] Stappenbeck (1910), p. 51 and Fig. 2.
[40] Verbal communication.
[41] Windhausen (1918), p. 35.

del Salto immediately to the east of the latter village, referred to by Stappenbeck,[42] though he did not then realize the glacial character of the basement conglomerate. Compared with the succession in the Sierra Chica de Zonda these two occurrences are outstanding, because the presence of marine fossils in them indicates that within a length of 45 km., though appreciably greater distance when the effect of folding has been allowed for, the formation has changed in character from *continental to marine*; it has now been termed the Tontal series.

In the Arroyo de Cabeceras, about 3 km. above the homestead of Leoncito Encima, I discovered the tillite folded in with the pre-

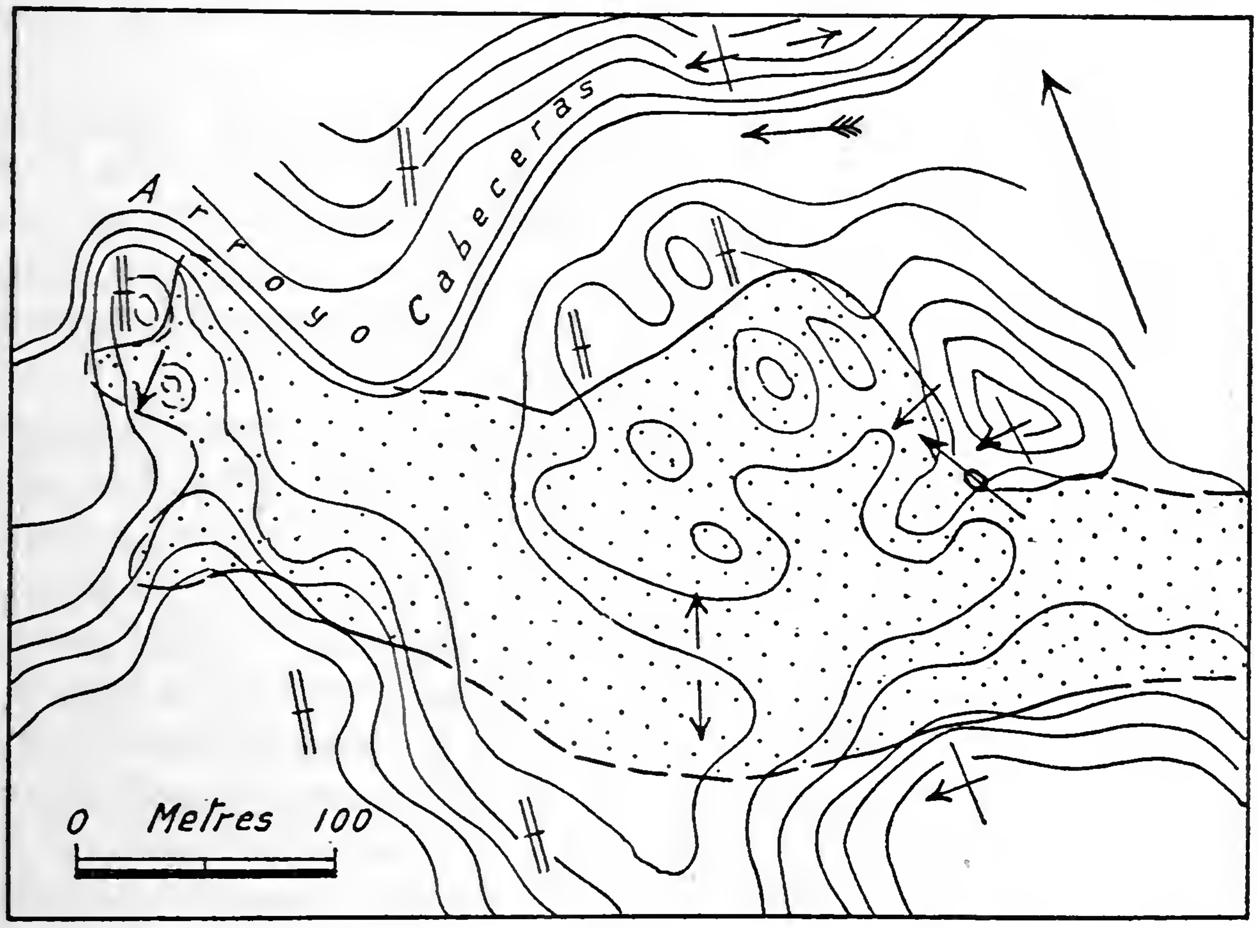

FIG. 4—An infolded patch (stippled) of tillite in Palæozoic beds close to Leoncito Encima, Barreal.

sumed Devonian slates and greywackés in an extraordinary fashion, as shown in Figure 4, a feature due to the superposition of the prevailing north-south crumplings of the pre-Cordillera upon a presumably older northwest-southeast folding. The base of the tillite transgresses across the strike of the supporting Palæozoics and the unconformable contact can clearly be made out at several points, where the surface below, when visible, is polished and shows striæ directed north-northwest–south-southeast (making allowance for the considerable subsequent tilting of the floor) and which are not strictly parallel, as in slickensided faces, but cross one another at a very acute angle in the manner characteristic of glacial pavements. The tillite is dark green, fine-grained, with small inclusions, rarely more than 15 cm. in diameter, many of them being finely striated;

[42] Stappenbeck (1910), p. 46.

a rude bedding is present in places, brought out by some banded and more quartzitic layers. The thickness preserved in this narrow ravine would not be more than about 30 meters.

About 150 meters distant from the homestead of Leoncito Encima is the outlier mentioned by Keidel.[43] Lack of time unfortunately prevented any detailed examination of either the base or the topmost beds, but some sandstones and thin shales were observed overlain by tillite, and the latter in turn by gritty sandstone with pebbles, followed by fluvio-glacial conglomerates. Important was the presence of some particularly fine "boulder pavements" of the kind recorded in the Sierra de la Ventana, with erratics exposed on the curving, ploughed-up surfaces, showing good striæ directed north-northwest and therefore in full agreement with the evidence obtained higher up the valley, as well as in the Sierra Chica de Zonda. Fossils were collected here by Keidel either as casts or in nodules of clayey limestone, principally of brachiopods such as *Spirifer*, *Dielasma*, etc., but not specifically determined by him, though he has noted forms resembling *Spirifer alatus* and *S. rugulatus*, suggestive of the Permian;[44] *Productus* was absent. Whether these beds at Leoncito Encima are really Permian, as supposed by Keidel, or Carboniferous like those at Barreal, to be described below, can only be decided by the working out of these fossils.

I was unable to trace the glacials continuously northward, but feel fairly confident that it must be the same formation that is laid bare immediately to the east of Barreal, in the Quebrada del Salto, the beds being finely sectioned by a small ravine a kilometer to the south of the latter, this dry watercourse rising in an anticlinal valley scooped out of shales overlying the tillite and hemmed in by a ring of hard gray and speckled quartzitic sandstones, thin-bedded red flagstones, gray and bluish siliceous shales, and some soft dark shales (Plate VIII, *A*). The tillite is greenish and homogeneous, passing by degrees through sandy mudstones into olive shales with occasional small pebbles, and from these into olive sandy shales without inclusions. Not more than 25 meters of glacial material was exposed at this spot, with the base not visible, though not improbably a search to the south would disclose its floor.

Fossils occur not only in the overlying shales in profusion, but less abundantly in the mudstones with erratics, though absent from the tillite proper. *Spirifer*, *Productus*, *Pseudamusium*, and *Spiriferina* are common, while *Polypora* and *Fenestella* are conspicuous low down in the mudstones, thus duplicating the features seen in the lower marine series of the Hunter River region of New South Wales, with its glacial erratics and abundant polyzoa.

Some 150 to 200 meters above this fossiliferous zone, exposed

[43] Keidel (1922), p. 256.

[44] *Loc. cit.*, p. 334.

close by and just to the north in the Quebrada del Salto, is another horizon of dark, reddish weathering, sandy shales from which numerous mollusca were collected; this must be the locality discovered by Stappenbeck,[45] from which he obtained a fauna with *Spirifer supramosquensis* Nik., etc, correctly regarded by him as of upper Carboniferous age. Some higher beds of hard sandstones and shales follow, covered up by Calchaqueños to the north, while on the east the succession ends by faulting against "Rhætic" beds.

The forms collected from these two horizons are fully discussed by Dr. Cowper Reed in the Appendix, and it will suffice therefore to quote his important decision that these Barreal faunas can without hesitation be ascribed to the Carboniferous and probably to the base of the upper Carboniferous. The tillite should belong, then, to about the border-line between the Moscovian and the Uralian, that is to say, between the Westphalian and the Stephanian, wherefore it has to be concluded that this succession near Barreal must be the *marine equivalent* of the glacials with their plant-bearing zone of the Paganzo system of the Sierra Chica de Zonda. Phases transitional between them will now have to be sought for in the intermediate belts of Paganzo mapped by Stappenbeck[46] in the Sierra Alta de Zonda and on the western side of the Paramillo de Tontal, where, as recorded by him, conglomerates, arkose, green and reddish slates, and sandstones rest on "Devonian" greywackés.

Further to the north towards Jachal, illuminating sections have been recorded by Stappenbeck and in more detail by Keidel.[47] For example, fluvio-glacial beds are mentioned by the latter as resting with slight discordance upon a thick group of unfossiliferous though post-Devonian greywackés in the Quebrada de Talacasto (lat. 31°). In the Lomas de los Piojos, a little to the south of Jachal, reposing unconformably on the lower Devonian with *Leptocœlia flabellites* or on upper Silurian beds, is a tillite passing up into fluvio-glacial conglomerates and these into sandstones with occasional boulders, the whole possessing a thickness of from 50 to 60 meters. At one spot Keidel[48] found the morainic matter resting upon a well-striated pavement of fossiliferous Devonian sandstones with the groovings directed northwest-southeast (see his Plate VII, Fig. 2).

Evidence of glacial deposits is forthcoming from the Cerro Fuerte, to the east of Jachal, and also from farther north, near Guandacol, similar strata cropping out around the southern end of the Cerro Villa Unión and the Sierra de Umango, being well seen, for example, on the western side of the Cerro Guandacol, as described by Bodenbender and Hausen,[49] the latter recording a coarse, tillite-like con-

[45] Stappenbeck (1910), p. 37.
[46] *Ibid.*, p. 43.
[47] Keidel (1921).
[48] *Ibid.*, p. 59.
[49] Hausen (1921), p. 70.

glomerate at the base, followed, but overlapped, by sandstones and shales and by much younger stages of the Paganzo, including beds of Rhætic age. More detailed reference to these last and to their equivalents in the ranges more to the east, *e.g.*, the Sierra de Sañogasta, Sierra del Valle Fertil, and Nevada de Famatina, will be made later. Undoubted glacials have not yet been recorded to the east and north-east of the last named, barring Penck's assertion of an unbedded tillite-like formation close to Angulos on the eastern side of the chain. Instructive is his discovery in the Puna de Atacama of *Cardiopteris polymorpha* in coaly shales resting on the conglomeratic sandstones of the lowest division of the Paganzo, as in San Juan, while intercalated basaltic flows are also present.

(2) The Plant-bearing Beds and Their Age

Though this discussion might more appropriately follow the succeeding account of the Paganzo system, it is most conveniently introduced here in order to demonstrate the close relation of the fossiliferous bands to the glacial horizons of the Sierra Chica de Zonda.

In the course of a brief search in the Río Grande I obtained from the carbonaceous shales (*d*, Fig. 3) between the first and second glacial horizon and about 50 meters above the base of the system, specimens of *Cardiopteris polymorpha* and *Rhacopteris szajnochai*, while Bodenbender[50] collected (almost certainly from this band, which is to be found cropping out again in the next ravine nearby, that of the Arroyo de Jejenes) *Rhacopteris szajnochai*, and in addition *Gangamopteris cyclopteroides*, *Glossopteris browniana*, *Cordaites*, species of *Sphenopteris*, and fragments of a fish, *Rhadinichthys argentinus* Tornq. So far as I can make out, just a little to the north of the Río Grande and west of Paradero kilometer 489 is Rinconada, whence Bodenbender gathered *Cardiopteris polymorpha*, *Adiantites antiquus*, *Neuropteridium validum*, and species of *Sphenopteris*. Some 5 km. south of Jejenes and to the west of Carpintería he also discovered *Glossopteris ampla*, presumably in the same beds as *Bergiopteris insignis*, *Lepidodendron* cf. *australe*, and *Asterocalamites scrobiculatus*, while beyond at Retamito, in the Quebrada del Agua, in beds overlying thick conglomerates—not improbably glacials—resting upon the Silurian, Bodenbender found *Rhacopteris* sp., *Botrychiopsis weissiana*, *Asterocalamites scrobiculatus*, *Lepidodendron pedroanum*, *L. australe*, *L.* cf. *nothum*, and *Cordaites* sp. Kurtz[51] has described several other forms from these several localities, such as *Rhacopteris inequilatera*, var. *ovata*, *Archæopteris argentinæ*, and *Cardiopteris elegans*.

[50] Bodenbender (1902), p. 203, (1911), p. 86; Stappenbeck (1910), p. 40.
[51] Kurtz (1921–22).

More to the south, in bituminous shales above the glacials of the Cerro Pelado, *Gangamopteris* is associated with *Sigillaria* and *Asterocalamites*. Traveling northward, one finds at Trapiche,[52] between Jachal and Guandacol, *Cardiopteris polymorpha*, with *Lepidodendron* (*Lepidophloios*) *laricinus*, *Cordaites hislopi*, and *Neuropteridium validum*, the latter also at Cerro Bolá, a little to the east, and at Sañogasta, while in the Cuesta Colorada (Escala de Famatina) *Rhacopteris inequilatera* has been gathered. Penck[53] has reported the finding in the Puerta de Guanchin in the Puna de Atacama, of *Cardiopteris polymorpha*, *Botrychiopsis weissiana*, *Phyllotheca australis*, and *Gingkophyllum grasseti* in clay shales and thin impure coals overlying the basal conglomerate, here 22 meters thick. In the Sierra de Vilgo at the Cuesta de la Torre, *Lepidodendron aculeatum* occurs low down in stage I of the Paganzo. At Saladillo,[54] near the southern end of the Sierra del Velasco, black shales have yielded *Lepidodendron selaginoides* and *L. veltheimianum*. On the other hand, proceeding southeastward into the Sierra de los Llanos, we have recorded from the Arroyo Totoral and elsewhere *Neuropteridium validum*, *Cordaites hislopi*, *Glossopteris retifera*, *G. indica*, *Phyllotheca deliquescens*, and other forms, while at Bajo de Velis,[55] in the Sierra de San Luis farther to the south, has been obtained the well-known assemblage including *Neuropteridium validum*, *Gangamopteris cyclopteroides*, *Cordaites hislopi*, *Noeggerathiopsis whittiana*, *Rhipidopsis densinervis*, *R. ginkgoides*, etc.

Keidel[56] has been to great pains in order to prove that there are actually *two distinct series* resting unconformably upon the older Palæozoics, one with a flora including lower and upper Carboniferous forms and hence of Carboniferous age, overlain by the second formed of the glacials and the sediments with the *Glossopteris* flora, belonging to the Gondwana system and of "Permian" age.

It must candidly be admitted that the evidence as to the precise horizons from which these several identified collections were made is not beyond criticism, and unfortunately my limited opportunity for collecting did not enable me to dispel such doubts, though the question could very readily be settled. It can nevertheless be affirmed that along both the Río Grande and the Arroyo de Jejenes the carbonaceous shales (*d*, Fig. 3) constitute a zone such as would naturally be searched by the collector, although not the only fossiliferous horizon present, since the upper part of the sandstone group, *f*, also yielded some poorly striated stems. No plants were observed in the sandstones between the second and third glacial zones and, suggestively, no strata higher than the latter are represented in those two

[52] Bodenbender (1911), pp. 82–83.
[53] Penck (1920), p. 146.
[54] Bodenbender (1911), p. 81.
[55] Kurtz (1895).
[56] Keidel (1922).

localities. To the south, however, along the Río de la Mina, plant fragments were noticed in shaly sandstones between 30 and 40 meters above the third glacial zone.

It would consequently seem most likely that Bodenbender's specimens mentioned above from the Arroyo de Jejenes came from the strata lying between the first and second glacial zones. Bodenbender, Kurtz, and others nowhere remark that the plants collected by them in any one locality near the base of the Sierra Chica de Zonda were actually derived from distinct horizons, wherefore, until more careful collecting has been carried out, we can only assume that each lot was obtained from some stratigraphical unit rather than from several horizons a good distance apart.

In analyzing these various collections, we observe further that in one locality or another some typical member of the "northern flora" is in apparent association with some member of the "southern," and this in so many ways that we have difficulty in escaping from the conclusion that all these various plants must probably have occurred intermingled on horizons intimately associated with the glacial series. It will, however, not be denied that the southern forms might perhaps have come from slightly higher levels within that particular series than those that yielded the northern elements, and it will therefore be conceded that *Gangamopteris*, *Glossopteris*, etc., if not actually accompanying *Rhacopteris*, *Cardiopteris*, etc., must occur shortly above this lowest plant-bearing carbonaceous zone *d*, with its northern Carboniferous flora. A search should enable this highly important palæobotanical relationship to be definitely established.

Granted that the data have been correctly interpreted, the presence of *Gangamopteris*, *Glossopteris*, *Neuropteridium*, etc., would suggest that the whole of this definitely conformable succession, down to its very base, resting discordantly upon pre-Carboniferous strata, should be regarded as forming part and parcel of the Gondwana system. In this conclusion I find myself in accord with Bodenbender, Stappenbeck, and Penck. The sections on the Río Grande and Arroyo de Jejenes are particularly clear, and, while some uncertainty attaches to the precise levels from which many of the plants have been collected, the interpretation here advanced does not seem to me to do violence to the facts.

It is most suggestive that in the chain of outcrops from the Cerro Pelado due northward to the Puna de Atacama and eastward into Famatina, the bulk of the plants appear to have been found in a zone of carbonaceous shales with occasional thin layers of impure coal that lies not far above the basal conglomerates and arkoses, beds largely of glacial origin. From the section in the Sierra Chica de Zonda it is clear that this zone (*d*, Fig. 3) is overlain by glacials as well, but how far the latter extend northward is a matter for future investigation. It is precisely, too, in this western section of Argentina, that the northern plant forms with a Carboniferous aspect are to be found, and they most decidedly indicate an age for the inclosing strata *not younger than upper Carboniferous* (*Stephanian or Pennsylvanian*), possibly even the *top of the middle Carboniferous.*

On the other hand, Bodenbender[57] is quite definite that in the region eastward, Sierra de Velasco, Sierra de los Llanos, etc., the plant-bearing beds are of similar lithological character and are all more or less on the same particular horizon, within Stage I, seemingly in its *upper half*, and hence apparently on a slightly *higher level* than in the west. It is significant too, that in the east the records of northern plant forms all but fail, but that *Lepidodendron aculeatum* occurs in the Cerro de Vilgo lower down than is usual, while near Cerro Bolá in the west *Cordaites hislopi* and *Neuropteridium validum* are represented near the top of the group. Taken in conjunction with the fact that some carbonaceous shales also occur in the Sierra Chica de Zonda some distance above the third glacial horizon, there is a definitely proved stratigraphical overlapping toward the east (referred to below), causing higher zones to come to rest on the ancient rocks, it would seem that in the west *lower horizons* may generally be represented, which tend to be missing in the east. This view is supported by the triple development of the glacials in the west and their absence, or perhaps their non-record, in the east. The first mentioned condition is certainly the case at Bajo de Velis, where I was able to examine the base of the Paganzo, for the beds with *Gangamopteris* rest directly on schists without the intervention of a glacial conglomerate.

Some remarks are needed regarding the plants themselves as indicators of age. The determinations were all made by Kurtz,[58] and in a number of cases no descriptions were published, though recently a few have posthumously appeared,[59] in most cases, however, unaccompanied by figures. I consequently have found it difficult to criticize the determinations, while, when in Córdoba, I had only time to examine the extensive collection of Rhætic plants in the museum of the university.

It might be remarked at the outset that the majority of the members of the *Glossopteris* flora are of *little or no value* in establishing the *absolute age* of the beds. Recent work has been showing more and more that certain genera and species thereof had a long range in time and these sections in Argentina are of immense importance, therefore, in demonstrating that *Gangamopteris cyclopteroides*, *Glossopteris browniana*, and *Cordaites hislopi* extend back well into the Carboniferous, as also appears to be the case in New South Wales.

[57] Bodenbender (1911), p. 83.
[58] Kurtz (1895*a*); Bodenbender (1904), (1911).
[59] Kurtz (1921–22).

Of the undoubted "northern" forms, *Asterocalamites scrobiculatus* (Schloth), described originally in 1894–95 by Kurtz as *Archæocalamites radiatus*, is found in Europe and North America, being sometimes known as *Bornia scrobiculata* Stern, extending up into the lower part of the upper Carboniferous (Pennsylvanian), but has been recorded by Walkom under the name of *Archæocalamites scrobiculatus* from Queensland, together with *Glossopteris* and *Cordaites*, the only other country in which this remarkable association has yet been recorded. *Adiantites* is a genus with a similar range, but from Kurtz's meager description thereof and the absence of a figure, direct comparison with the Culm species *A. antiquus* (Ett) is not possible. *Archæopteris argentinæ* Kurtz is compared by him with *A. wilkinsoni* Feist. from New South Wales, while with *Archæopteris obtusa* Lesq., from the Pennsylvanian, Kurtz compares his *Bergiopteris insignis*. *Botrychiopsis weissiana* Kurtz, with *Cardiopteris*-like pinnules, appears to be intermediate between *Cardiopteris* and *Neuropteris*.

Cardiopteris polymorpha (Goepp) is a lower Carboniferous form and does not seem to be known from the upper division; an undetermined species comes from the Kuttung series (middle Carboniferous) of New South Wales. *C. elegans* Kurtz stands close to *C. polymorpha*. *Rhacopteris inequilatera* (Goepp) has been referred by Dun to *Aneimites* (*Otopteris*) *ovata* (McCoy), with which Kurtz has placed *R. inequilatera* var. *ovata* from Jejenes, including also *A. austrina* Eth., the last from the Drummond series of Queensland, the first named from the Kuttung series of New South Wales, which contains other species of *Rhacopteris*. *Lepidodendron veltheimianum* is a lower Carboniferous species, while *L. pedroanum* occurs in the Bonito group of Brazil. The Sphenopterids may be upper Carboniferous forms, but only one has been figured.[60]

It might be remarked that the only records of such Palæozoic plants are from Lake Titicaca in Bolivia and from Paracas on the coast of Peru by Seward[61] and Berry.[62] No specific names are given by the former, but his *Sphenopteris* sp. recalls, however, *S. bodenbenderi* Kurtz, but appears to agree better with the description given of *S. fonsecæ* Kurtz, from Carpintería, though no figure of the latter has been published. Berry, however, has identified among others *Lepidodendron rimosum* Stern, *L. obovatum* Stern, *Calamites suckowii* Brong., *Eremopteris whitei* Berry, and *E. peruiana* Berry. He regards the flora as probably Westphalian (middle Carboniferous) and points out that on Lake Titicaca at least one of these forms occurs in strata underlying the marine upper Carboniferous (Uralian).

In spite of some uncertainties in the identifications and the necessity of revision, there can be no doubt that the northern ele-

[60] Kurtz (1921–22), Pl. XIV, Nos. 138, 138*a*, and 139.
[61] Seward (1922).
[62] Berry (1922).

ments in this western Argentine flora definitely place it on about the *border line of the middle and upper Carboniferous.* So far back as 1895 Kurtz correctly pointed out this fact and also drew attention to the parallelism with the plant-bearing Carboniferous beds of New South Wales and Queensland. The discovery of associated glacials both in San Juan and in the Seaham area of New South Wales strengthens this comparison enormously. The floras of the lowermost Paganzo and of the Kuttung [63] series of New South Wales have strong resemblances, and in each case, and also in Peru, there is the complete absence of species of the common *Neuropteris*, *Pecopteris*, and *Alethopteris* groups, all of which become very abundant in the typical middle and upper Carboniferous floras in various parts of the world. The presence of the *Glossopteris* flora and its absence from the Kuttung, so far as we know, suggest an age slightly younger than that of the latter for the lowermost beds in Argentina, which would place them at about the beginning of the upper Carboniferous (Pennsylvanian).

The flora of the beds situated to the east of San Juan, with its paucity of Northern forms, can be compared with that of the lower marine series of New South Wales that immediately follow the Kuttung, or the Queensland "Permo-Carboniferous" with species of *Glossopteris*, *Sphenophyllum*, *Cordaites*, and *Sphenopteris*. Just as in the Hunter River area glacial conditions recurred, so was the case in San Juan, where the basal glacials and lowermost plant-bearing group were succeeded by more morainic matter, all, however, still of Carboniferous age.

This strong parallel between Argentina and the eastern side of Australia must be emphasized, since under the displacement hypothesis the space separating these two regions would at this epoch have been *enormously less.* This question would, consequently, appear to be worthy of examination from other viewpoints in the light of this hypothesis.

(3) The Name "Paganzo System"

Thus far attention has been focussed almost wholly upon the basal portion of the system as developed in that section of the pre-Cordillera from Mendoza northward into La Rioja with the object, firstly, of bringing out the evidence for the existence of glacial deposits, as in other parts of Gondwanaland, and, secondly, of showing that certain of the scattered florules are actually sandwiched between glacial horizons. Before reviewing the information available regarding these and the still higher strata that are so extensively developed in the region to the east and northeast—not only in the pre-Cordillera, but in the central or Pampean ranges as well—some

[63] Süssmilch and David (1920).

discussion becomes necessary upon the limits to be set to the "Paganzo beds."

This name was given by Bodenbender[64] from the village of Paganzo to the south-southwest of La Rioja, where the several stages or divisions of this important group of strata are so well developed, but from which the so-called "Rhætic" beds were definitely *excluded*. It is true that Keidel[65] subsequently adopted a new classification, the "La Rioja system," a course in which he was doubtless influenced by his separation of the basement strata in San Juan into the two series of "Jejenes" and "Zonda." Now that it has been shown that such a division is scarcely necessary, the term "La Rioja system" becomes superfluous and there would be no genuine grounds for superseding the original and well-established term "Paganzo," which has so firm a place in geological literature. On the other hand, the exclusion of the "Rhætic" from the Paganzo is wholly indefensible, since, (*a*) these younger beds generally include some strata of upper Triassic age similar in many ways to the older groups of the Gondwana; (*b*) they are non-marine in character; (*c*) although they are generally unconformable to the lower stages of the Paganzo, places are known where no marked break has yet been recorded, or where as yet no inferior limits can be set to the group; and (*d*) they admittedly correspond with the upper part of the Santa Catherina system of Brazil, with the Stormberg series of South Africa and with a part of the middle Gondwana of the type region of India.

As will be realized from the study of the following pages, it would be difficult to make out any adequate case for the exclusion of these younger beds, excepting for their general unconformable position, which relationship, it must be pointed out, is certainly present somewhere in each of the other sections of Gondwanaland. Since the strata thus embraced range from Carboniferous to Rhætic in age, it is furthermore clear that a mere "series" would be insufficient to include them—nothing less, indeed, than a "system," so the Paganzo must be given a rank equal to the systems of the Santa Catherina, Karroo, or Gondwana, of which it is the Argentine representative.

In the following pages, therefore, though contrary to practice in Argentina, *the so-called "Rhætic" will be regarded as forming the uppermost member, i.e., Stage IV, of the Paganzo system.*

(4) The Distribution of the Paganzo

Deposited unconformably upon Palæozoic and crystalline rocks, and largely covered by Cretaceous and Tertiaries, these beds have been involved in the Andine movements, wherefore dips are often high, inversion may occur, while faulting and thrusting are common. In consequence, the beds now make their appearance along

[64] Bodenbender (1911), p. 47.

[65] Keidel (1922), p. 267.

the flanks of the various ranges, occupying a position intermediate between their Palæozoic or crystalline cores (which generally compose the mountain mass) and the Cretaceo-Tertiary (which commonly form the lower ground), and therefore crop out most usually in the form of narrow belts, not infrequently obscured over considerable stretches by late Tertiary beds or by Quaternary gravels and sands. The clarity of the exposures, due to the broken nature of the ground and the aridity of these regions, is consequently offset by the frequency with which the strata are hidden by these younger formations; rarely is any wide area to be found occupied by the Paganzo, though the system doubtless underlies many of the Tertiary-filled valleys or intermontane plains.

The principal occurrences, as described by Brackebusch,[66] Stappenbeck,[67] and particularly by Bodenbender,[68] are to be found between the extremity of the Cerro Villa Unión and the Sierra del Valle Fertil, on the western and southern sides of the Sierra de Vilgo and Sierra de Sañogasta, at the southern end of the Sierra de la Huerta, around the greater part of the edge of the Sierra de Chepes and Sierra de los Llanos and in small areas in the Sierra Bravá, Sierra de Córdoba, and at Bajo de Velis in the Sierra de San Luis. To the northwest they are represented in the Sierra de Umango and beyond in the Puna de Atacama up to the border of Bolivia, while to the northeast they reappear in Tucumán, Jujuy, and Orán, and thence have a lengthy distribution far to the north, as will be set forth in section G. Bore-holes in the northern and northeastern parts of Argentina suggest that they may occupy a considerable tract beneath the thick covering of Neogene, possibly even joining up underground with the known extension of the Santa Catherina system into the territory west of the lower Paraná River.

(5) The Stratigraphy of the Paganzo

The system can be divided into *four "pisos" or stages*, the first of upper Carboniferous, the second and third of Permian, and the fourth of Trias-Rhætic age, though extending probably into the Liassic, with the very uppermost portion thereof regarded tentatively as constituting stage V.

Stage I—This generally ranges between 150 and 300 meters in thickness, though probably well exceeding that value in San Juan, where, as remarked above, lower horizons would seem to be present. On the other hand, in certain places it is thin or even absent, owing to the transgression of higher beds, occasionally even those of stage II. Thus in the valley of the Río Nogues to the east of Cerro Villa

[66] Brackebusch (1891) and geological map (1892).
[67] Stappenbeck (1913, 1917, 1920).
[68] Bodenbender (1897, 1902, 1911, 1912, 1916).

Unión the upper conglomerate, lying just below Stage II, rests on the crystalline schists, while farther to the east, in the neighborhood of Sañogasta (Nevado de Famatina), Stage II rests on granite or quartz-porphyry. Furthermore, in the Puna de Atacama, Penck[69] has observed the red sandstone of Stage III reposing directly upon granite in the Cerro Negro de los Andes (west of Tinogasta) and Cerro Palca, more to the north.

In the extreme west there are developed at the base of the system the glacials detailed earlier, having an intercalated zone with plants of middle and upper Carboniferous genera and species, but, while stratified conglomerates (particularly well developed in the Sierra de los Llanos for example), arkoses, and gray, yellowish, and greenish sandstones occur in this inferior position toward the east, Bodenbender has stated that he had observed no evidences of glaciation in them. Penck's note of an unstratified boulder deposit, like a tillite, close to Angulos, a little north of Famatina, indicates the possible existence of glacial material in that quarter. At Bajo de Velis glacials are absent at the bottom of the system.

Not improbably the prevailing conditions are rather like those that have been made out in South Africa in passing from Natal to the Transvaal, where, owing to the uneven nature of the (glaciated) floor and to a temporary "post-glacial" exposure of the latter, coarse fluviatile sediments have come to overlap on to, and rest upon, the glaciated land surface, and the morainic deposit is only to be found preserved in the deeper hollows in the latter.

Above this coarse basal phase in Argentina is a conspicuous zone of carbonaceous shales with thin coaly streaks and layers, sometimes pyritic in its nature. It is followed by sandstones (as in the Cerro Villa Unión), by conglomerates with porphyry pebbles, and by means of a hard white sandstone *passes up by degrees and quite conformably* into Stage II. Some calcareous and siliceous concretions are to be found and also thin beds of limestone in the Sierra de los Llanos. The carbonaceous zone alluded to is, as Bodenbender[70] has remarked, a constant feature, and has yielded, as already stated, the *Glossopteris* flora at a number of points, *e.g.*, Sierra de los Llanos and Bajo de Velis (Plate VIII, *B*), an association strikingly like that of the Bonito series of Brazil succeeding the Itararé glacial series of that country, and which, from external evidence very largely, we have to place at the top of the Carboniferous.

Stage II—Not less than 300 and probably up to 500 meters in thickness, it is distinguished from the older group by the brilliant coloring of the beds—rose, red, gray, white, etc.—by clayey, calcareous, and siliceous strata, fine-grained red and partly white sandstones, thin quartzites, and bands of limestone up to some meters

[69] Penck (1920), p. 134.

[70] Bodenbender (1911), p. 64.

thick, and silicified marls. The calcareous matter may occur in the form of concretions and lenses and is often dolomitic; partial silicification has caused the strata (particularly in the middle of the group) to resemble on weathering mottled felsites, while oölitic structure is common; especially is this the case in La Rioja, though this phase is not known in Catamarca.

This group is not fossiliferous, but in its lithological characters recalls the divisions of the Iratý and Estrada Nova (Passa Dois) series of Brazil and Uruguay, more particularly as developed in the latter country. Its age is probably lower Permian.

Stage III—Transitional from the foregoing and from 300 to 500 meters in thickness, come quartzitic sandstones, dark arkoses, and conglomerates (particularly towards the top), while the softer beds are darker and there is less calcareous matter present, but limestone—occasionally silicified—still occurs and gypsum is sometimes found, as in the Puna de Atacama. On several horizons, both in this and in Stage II, have been recorded contemporaneous basaltic flows, also augite-porphyrite and occasionally tuff, for example, in the Troya Valley (Puna de Atacama), Cerro Villa Unión, Cerro Bolá, and at and to the north of Paganzo—forerunners obviously of the marked volcanicity of the late Triassic.

Unusual interest attaches to its development in the Puna de Atacama, where, according to Penck,[71] a thickness of over 900 meters is represented with some melaphyres at the top, the red-brown sandstones being fine-grained and diagonally-bedded to platy, while the calcareous thin-bedded, fine-grained beds carry siliceous layers and concretions and gray, red, and violet "marls," observations which suggest that this succession actually includes part of the Trias-Rhætic Stage IV, and may even be in part equivalent to the Estrada Nova and Río do Rasto of Brazil. In a remarkable facies arising through alteration by granite, these reddish beds have been converted into gray, yellow, red, and violet quartzites containing a fossiliferous zone of white porcellanous shales in the lofty Tolarcito Pass (lat. 27° 15′), which has yielded a scanty marine fauna (*Anaplophora*, *Avicula*, etc.), indicating a Triassic age.[72] These are the only fossils known from this stage, and should be compared with those from the Estrada Nova (see page 150).

Stage IV, the Trias-Rhætic—The so-called "Rhætic beds"—as usually indicated by the presence of the "*Thinnfeldia* flora"—outcrop in quite a number of places between Mendoza in the south and Famatina in the north and between the Andes in the west and perhaps Córdoba in the east, though occupying a more restricted area than the older stages. In the northern half of Patagonia, however, their equivalents have been found to make a wide distribution.

[71] Penck (1920), pp. 132–133.

[72] Penck (1920), p. 151.

As mentioned already, the late Permian or early Triassic earth movements (Gondwanides) led to the folding and to the subsequent erosion of the lower stages of the Paganzo, and so enabled the succeeding Mesozoic formations to transgress across the edges of the latter. At quite a number of places the *unconformable relationship* of the younger beds can be studied, but in the northwest, in the but little disturbed tract between the Sierra de Paganzo and the Cerro Villa Unión, there is reported to be an apparently unbroken succession from Stage III into Stage IV, and from the latter in turn into beds that may just possibly be Jurassic,[73] tentatively referred to as Stage V.

This region embraces by far the largest continuous area in the pre-Cordillera, the other widely scattered localities being those at Barreal and Jarillal in the valley of the Río de los Patos west of San Juan; the important elevated mass of the Paramillo overlooking the Uspallata Valley; Salagasta, San Isidro, Challao, Potrerillos, and Cacheuta among the foot-hills of the Mendoza district; and Marayes on the southwest side of the Sierra de la Huerta; but not in the Sierra de los Llanos or Sierra de San Luis. This stage is only doubtfully present in the Sierra de Umango and is not known in the Nevado de Famatina, though it has its equivalent farther to the northeast and north in the districts of Tucumán, Jujuy, and onward into Bolivia, to which reference will be made below. In the east, beds regarded as Triassic are known in various parts of the Sierra de Córdoba, while the deep bore-hole at Alhuampa on the Central Norte Railway in Santiago del Estero proved nearly flat-lying Trias-Rhætic (?) beds from the depth of about 1,340 meters downward, having Permian most probably (with *Schizoneura* and *Phyllotheca*) below 1,700 meters down to 2,111 meters—a link with the strata forming the vast Triassic plateau of Uruguay and Paraguay.

In the main region between Cerro Villa Unión and the Sierra de Paganzo, Bodenbender has recorded this stage as extending along the eastern side of the Cerro Bolá, dipping eastward and covering the wide stretch made by the Cerro Totorilillo, wrapping around the northern end of Sierra del Valle Fertil, reaching almost to the Sierra del Cerro Blanco, and occurring again on the eastern side of that range of crystallines, where, at El Molle, it reposes upon conglomerates taken, though not without some doubt, as the top of Stage III; the same relationship is seen in the Cerro Morado a little to the west and again on the eastern side of the Cerro Bolá. A thickness of between 400 and 500 meters is represented, consisting of gray arkoses and yellow sandstones, from coarse to fine, with intercalations of carbonaceous shales, carrying plant remains, chiefly *Thinnfeldia*, and a seam of coal about 1 meter thick on the western side of the

[73] Bodenbender (1911), p. 124.

Cerro Morado and impure seams at Marayes farther to the south. In addition, intercalated flows of olivine-basalt are known on at least two horizons, such volcanic rocks crowning some of the ridges, such as the Cerro Morado. These beds are most probably of Upper Triassic age.

The group is followed with *complete conformity* by Stage V, some 400 to 500 meters of strata, including marls with many calcareous nodules and sometimes of concretions of barite, by sandstones, and by whitish-yellow or grayish, white, red, and green clays, passing up into light sandstone, and by brilliant red sandstones and clays with gypsum. Trunks of *Araucarian* type have been recorded from a point east of the Sierra de Cerro Blanco. Bodenbender has proposed a Jurassic age for the lower part of this division and a Cretaceous one for the upper part, but there seem to be no valid reasons why these strata should not be Rhæto-Lias, as is suggested by the sections near Barreal.

At Hilario, a little to the north of that village, I found Stage IV resting unconformably on tilted lower Palæozoics, its base being crowded with chips of green slates and greywackés derived therefrom, followed by sandstones with cherty layers and dark fissile cherts, white shales, thin layers of volcanic ash, grits, and some conglomerates. In the Quebrada del Jarillal, a few kilometers to the south, higher beds are finely exposed (Plate IX, *A*), with soft variegated shales and dark shales carrying numerous well-preserved plants (*Thinnfeldia*, *Tæniopteris*, *Baiera*, *Cladophlebis*, *Phœnicopsis*, etc., and silicified wood, probably *Dadoxylon*) and some torbanite-like bands. Similar soft gray beds appear in the Quebrada del Salto due east of Barreal, wherein, below a band of gray clays with *Thinnfeldia*, were found some lenses of a green rock with what seemed to be traces of marine fossils, though not identifiable. Both here and at the Quebrada del Jarillal these plant-bearing beds are followed by vivid red conglomerates and sandstones (Stage V, Plate IX, *B*), which, though regarded by Stappenbeck [74] as Cretaceous, appear to be quite conformable, there being an actual interlamination of pink and gray clays with small-pebble conglomerate about the junction, a character to be found duplicated in the Mendoza district.

Time only permitted of a single rapid traverse across the high-lying Paramillo region, described originally by Stelzner [75] and Avé-Lallemant [76] and briefly by Stappenbeck.[77] On the east, resting upon tilted Devonian (?) slates, one finds gently inclined hard sandstones, arkoses, and greenish shales in which Keidel [78] has discovered *Cyzicus* (*Estheria*), like the beds characterizing the middle of the group at

[74] Stappenbeck (1910), pp. 56, 66.
[75] Stelzner (1878).
[76] Avé-Lallemant (1890).
[77] Stappenbeck (1910), pp. 60–61.
[78] Verbal communication.

Challao, overlain by andesitic lavas, and followed by similar sediments to a total thickness of several hundred meters. Conspicuous is a splendid section along the main road, displaying a large number of coniferous tree-trunks (probably *Dadoxylon*), standing upright (Plate X, *A*), rooted in a sandstone bed and surrounded by drab-colored tuff, above which comes a sandstone which the stems do not penetrate. This horizon was noticed by Avé-Lallamant and termed by him "the sandstone with Araucarias." On the water-shed these beds give place to a group of thin sandstones, dark shales, and bituminous shales with tuffs and basaltic intercalations to a thickness of perhaps 120 or 150 meters. The bituminous shales occur as thin bands, weathering with a bluish-gray or white exterior and brownish to blackish interior, giving out a wooden sound when struck with the hammer; they are clearly allied to the torbanites, and are crowded with the carapaces of *Estheria* and contain occasional scales of *Semionotus*. Some thin limestones and cherts have been recorded from these beds by Stappenbeck, while plants have been obtained at a number of points, including *Thinnfeldia*, *Tæniopteris*, *Baiera*, etc.

That the basaltic layers are extrusive, though generally quite compact, is shown by the presence of small vesicles either at top or base, or in some instances by a zone of "pipe-amygdaloid" at the bottom, and by the fact that the shales may rest in the unaltered state on a slightly uneven surface of the igneous rock. In addition to these lavas, intrusive sills of andesite cut these beds.

In the Cerro Colorado, lying to the west, the plant-bearing shales and white and gray tufaceous sandstones pass up into red and green clays and false-bedded red sandstones with clays, pierced and overlain by intrusive andesite, these strata being viewed by Stappenbeck as Cretaceous, but being more probably of Rhætic or Liassic age. The total thickness of the sediments involved in the Paramillo ascribable to Stages IV and V may perhaps possess a value of 1,000 meters.

At Challao, 7 km. to the northwest of Mendoza, the succession, which I estimate to be not less than 450 meters in thickness, begins with a massive basal conglomerate, deep red in color, resting on tilted Palæozoics, passing up through red sandstone and pale sandstone and greenish shales, arkoses, etc., into a group of well laminated shales, banded cherty shales, dark "papery shales," and torbanite-like layers standing almost vertically, of which latter thin-bedded strata some details are given by Stappenbeck, and ending in a thick mass of sandstones of red or gray-violet tint, so-called "Cretaceous." Noteworthy is the abundance of *Estheria* (*E. draperi* and not *E. mangliensis*), not only in the shales and gray cherty layers, but in the associated sandstone beds and carbonaceous bands. The latter are much weathered and plant remains are hence difficult to obtain now; *Cladophlebis mesozoica* Kurtz has been recorded here, while Keidel has discovered remains of *Gyporella* in a gray dolomite.[79] In a block of yellowish sandstone from a horizon about midway in the group and at least 200 meters below the *Estheria* beds—unfortunately too large to be removed—I obtained on development an impression of *Glossopteris*, probably *G. angustifolia*, a long pinna of *Marattiopsis*, probably allied to *M. muensteri*, and a large equisetaceous stem, which would indicate a *Triassic age* for this part of the formation.

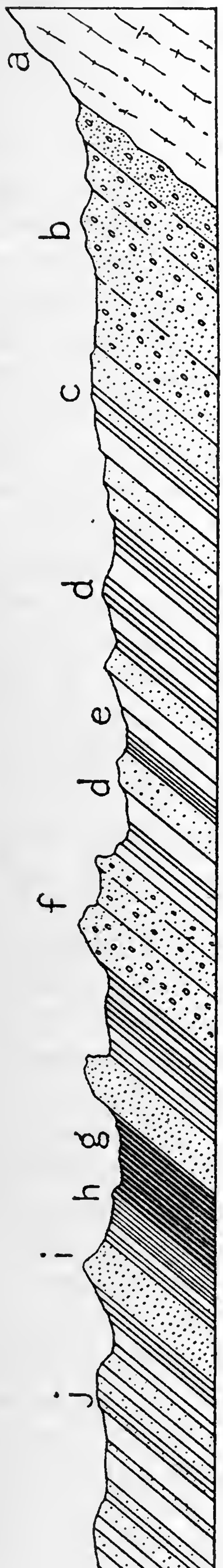

FIG. 5—General succession at Potrerillos. For explanation see text.

At Potrerillos, on the Transandine Railway between Mendoza and Uspallata, is to be found a very similar and complete section in the Cerro de las Cabras displaying fully 700 meters of beds dipping southward at moderately high angles (Fig. 5), which, in the light of the foregoing descriptions, I am inclined to interpret differently to Stappenbeck.[80] The formation is underlain by porphyritic and other volcanics (*a*) and commences with deep-red conglomerates and small pebble breccias some 150 meters thick (*b*), followed by transitional beds of pink clays and grits (*c*) into yellow sandstones, grits, gray shales and mudstones (*d*), from the midst of which *Estheria* and *Thinnfeldia* were collected at (*e*). Conspicuous is next a red small-pebble conglomerate (*f*) and some distance above that a body of 15 meters of black and gray shales with carbonaceous mudstones (*g*) yielding scales of *Semionotus*, passing up without a break into dark-maroon shales (*h*) with yellow sandstones (*i*), after which appear vermilion grits and small-pebble conglomerates (*j*), seemingly the beds regarded by Stappenbeck as Cretaceous.

There is, however, no break discernible in the entire succession and the alternation of deep red with the normal and often black strata, exceptionally well seen in the Cerro Bayo, would show that this upper and predominantly red formation must be perfectly conformable with the beds below and consequently ought to be grouped with the Paganzo, though it could very con-

[79] Stappenbeck (1910), p. 62.
[80] Stappenbeck (1917), p. 21.

veniently be considered as forming "Stage V." At Potrerillos it is overlain with a break by the tilted Pliocene "Calchaqueños."

At the southern end of the Cerro de Cacheuta, 20 km. to the southeast, is the classic section at the back of the Mina de Petroleo.[81] Here the beds dip at 20° to the south, displaying at their base porphyritic lavas and keratophyres, then 35 meters of tufaceous sandstones, 15 meters of bituminous shales (lower), 20 meters of sandstones, and 8 meters of thin-bedded gray shales with plants, 73 meters of coarse sandstones, gray conglomeratic sandstones, etc., 70 meters of bituminous shales (upper), while quite conformably above come 130 meters of red, gray, and violet and gray sandstones and shales with some gypsiferous bands (Stage V), overlain by a great mass of Tertiaries.[82] Plants are best preserved in the gray shales and scarcely in the highly carbonaceous bands—most abundantly *Thinnfeldia*, *Baiera*, *Cladophlebis*, *Stenopteris*, etc.[83] Striking is the abundance of *Cyzicus* (*Estheria*) *draperi* Jones, with which the bituminous shales are crowded, and which organism has not improbably been responsible for the petroleum seeping out from the outcrop of the lower shales, also struck in bore-holes to the south beneath the Tertiary covering, in the sandstones overlying those shales, where the formation has been bent into a dome. The petroleum is unusually high in its content of paraffin wax.

Occurrences Outside the Pre-Cordillera—Most illuminating are certain localities where the Trias-Rhætic is present in the Cordillera of Chile and Argentina and also in Patagonia.

Of particular interest is the isolated patch at La Ternera,[84] northeast of Copiapó (lat. 27° 12′, long. 69° 50′), where, in perfect conformity beneath nearly vertical tuffs including a limestone bed carrying a decidedly lower Liassic marine fauna, comes a 50-meter-thick group containing conglomerates with porphyry pebbles, sandstones, shales with cherty bands, clay ironstone, and impure coals in layers and streaks, the bottom in contact with a mass of porphyrite, apparently intrusive. From this group, which lithologically shows close resemblances with the occurrences in the San Juan and Mendoza districts, Solms-Laubach has described a flora with *Thinnfeldia*, *Tæniopteris*, etc., while *Estheria* also occurs, and fossil wood. The horizon represented here must undoubtedly be the Rhætic, and, significantly, includes certain genera not known in Argentina, such as *Dictyophyllum*, *Lesleya*, *Clathropteris*, *Copiapæa*, etc.

The presence of the upper Triassic ocean is proved to the southwest by the finding on the Río de Huasco of beds resting directly on granite and crystalline schists (of which they carry pebbles) con-

[81] Stappenbeck (1910), p. 65; (1917), pp. 22, 45.
[82] From a measured section furnished me by Mr. H. J. Hawley.
[83] Szajnocha (1888).
[84] Steinmann and Solms-Laubach (1899).

taining *Halobia*, while farther down the coast, near the Río Choapa, Groeber[85] has discovered strata containing that genus and also *Pseudomonotis*, as well as older beds of Permian or more probably Carboniferous age carrying *Productus*.

Groeber[86] has summarized information on the supra-Triassic and pointed out that at Puente del Inca, Río de las Vacas, and the region of Espinacito to the west of Uspallata the Callovian, Dogger, or Lias overlap quartz-porphyries, porphyrites, and melaphyres belonging to Stage IV (or V) which rest discordantly on possibly Devonian rocks, while, as remarked earlier, they appear again in the Sierra Pintada to the south and are of importance in the area between the Río Atuel and the Río Neuquén, where they are covered by Liassic or Jurassic marine beds, the "Paganzo" (with its original significance) being absent; quartz-porphyries and tuffs here play a very important rôle. Groeber regards this mainly volcanic assemblage of the Cordillera, extending roughly north and south and having a thickness of up to 1,000 meters, as wholly of upper Triassic age, but points out that there are actually similar volcanics in the overlying Liassic as well. Of immense importance is his discovery that near Las Lajas (lat. 39°, long. 71°) on the Chilean border the first-mentioned group of volcanics succeed marine middle or upper Triassic beds, which are resting unconformably on the ancient platform, and that the Dogger overlies these volcanics and has a basal conglomerate with pebbles derived from the latter.[87]

From the sub-Andine zone in Chubut (Patagonia) to the southeast, Keidel[88] has described crystal tuffs, brilliantly colored tuffs, calcareous shales, etc., crowded with *Estheria draperi*. Porphyrites, agglomerates, and tuffs are mentioned by Rassmuss[89] at the head of the Río Chubut, while similar beds are recorded by Windhausen[90] from the Río Chubut, the neighborhood of Sarmiento, and from the Río Deseado, San Julián, and other places farther south in Santa Cruz. Quartz-porphyries, rhyolitic rocks, and keratophyres are known in various places, but it is somewhat difficult from a study of the literature alone to obtain a clear idea as to the precise relation of these effusions to the pyroclastic rocks, more especially as Rassmuss remarks that bodies of intrusive granite and grano-diorite, probably of Jurassic age, occur in the upper part of the Río Chubut. It is certain, however, that this assemblage, with a maximum recorded thickness on the coast of over 900 meters, rests upon the crystalline basement and has been bent into moderate folds along arcs trending roughly south-southeast to southeast as the result of movements during the mid-Cretaceous, and are overlain unconformably by

[85] Groeber (1922).
[86] Groeber (1918), pp. 49–59.
[87] Verbal communication.
[88] Keidel (1917–18).
[89] Rassmuss (1922).
[90] Windhausen (1921, 1924).

almost undisturbed upper Cretaceous, Tertiary, or Quaternary; they moreover show out at intervals over a great area stretching southward into Terra del Fuego.

The presence of *Cyzicus* (*Estheria*) *draperi* and of silicified wood enables comparison to be made with the so-called "Rhætic" of the Mendoza district. In the latter are to be found the beginnings of the acid effusions and fragmental rocks that have such a development to the south and southeast, though not represented in other parts of South America. In South Africa, however, are the comparable and immense acid outpourings of the Lebombo on the southeastern side of that continent, with certain intrusive granophyric, felsitic, and dioritic masses, all of Stormberg age (Rhæto-Lias), while at Brisbane in Queensland the base of the Triassic Ipswich series is made by a bed of quartz-porphyry tuff resting on the vertical edges of schists, while rhyolites, dacites and andesites are also known from this neighborhood.

A matter to which attention should be drawn is the presence in the southwestern corner of the Neuquén district of Neocomian beds carrying molluscan fossils typical of the Uitenhage series of the Cape, such as *Holcostephanus atherstonei*, *H. rogersi*, *H. uitenhagensis*, *Trigonia ventricosa*, *T.* aff. *rogersi*, *T. transitoria* allied to *T. hertzogi*, *T. eximia* allied to *T. conocardiiformis*, *T. pusilla* and other forms related to *T. vau*, *Grammatodon jonesi*, *Exogyra imbricata*, etc.[91]

This locality, situated to the southwest of the arc of the "Gondwanides," shows therefore a very close analogy with the geology of the Uitenhage district of the Cape, as will be discussed at a later place.

The Occurrences in the Pampean Ranges—Constituting a link between the west and the center are the exposures at Marayes along the southern base of the Sierra de la Huerta, where, sandwiched between two groups of chocolate- and maroon-colored conglomeratic strata, come some 150 meters of greenish and buff sandstones with thin shales and coals (the so-called "Rhætic," Plate X, *B*); the basal group rests upon an uneven surface of the crystallines. In the sections exposed at the Rickard Mine and at Carrizal there seemed to me to be a conformable succession, but according to Rassmuss what would appear to be an intraformational unconformity is present, the "Rhætic" transgressing across the lower group of the "Paganzo" and coming to rest directly upon the crystallines when followed toward the north.[92] The upper group of deeply colored rocks, fully 400 meters thick, is referred to by him as of Cretaceous age, but since it recalls the succession already described in the region to the west, and appears to follow conformably upon the Rhætic within this

[91] Letter written me by Dr. Pablo Groeber dated June 7, 1926.
[92] Rassmuss (1922*a*).

trough, it can provisionally be considered as forming the uppermost portion of the Paganzo system, Stage V. The assemblages can hence be placed in the Trias-Lias succession. The coals at the Rickard Mine and at Carrizal are very thin, high in ash, and extremely pyritic. In addition to calcified coniferous stems, the middle group has yielded the *Thinnfeldia* flora, this being the most southeasterly point where such has been recorded in Argentina,[93] with the probable exception of the strata with *Cladophlebis mesozoica* resting on the granite in the Sierra de los Llanos.[94]

Turning attention to the Central Pampean ranges, the easternmost outcrop of beds, that on lithological grounds have been ascribed to the Triassic, are to be found in the Sierra de Córdoba,[95] forming a series of patches resting upon an uneven surface of gneiss, Palæozoic (?) limestones, etc., in some places horizontally, in others tilted and faulted. At Saldán, just north of Córdoba, the series consists of 100 meters of red conglomerates, passing up into deep-red sandstones with some red shaly layers (Plate XI, *A*). Ripple-marked and suncracked surfaces are present and the sandstones are markedly crossbedded, recalling the upper Triassic seen elsewhere. In Los Terrones, northeast of Capilla del Monte, are splendid sections through at least 200 meters of red conglomeratic beds, weathered out into striking erosional forms (Plate XI, *B*). The gneiss surface beneath is highly uneven and the junction here is not a faulted one, as maintained by Rimann.[96] Some volcanic rocks overlie the strata at La Cumbre, but the circumstances rather suggest an unconformable relationship and a much younger age.

Provisionally these sediments can be allotted to the top of the Paganzo, but, inasmuch as coals are reported to occur to the south of Córdoba along the line of strike of the Saldán conglomerates, plants should shortly be forthcoming to decide this question, which is an important one, since these are the easternmost outcrops of such beds in the republic.

The Thinnfeldia Flora—Some remarks might be made on the composition of this flora and its bearing on the age of the inclosing strata.

The several florules in western Argentina, occurring as they do each in a group of gray or carbonaceous shales, sometimes accompanied by impure coals, sandwiched between groups of coarser variegated sediments, represent with but little doubt practically *one and the same horizon* situated not very far from the middle of Stage IV, being followed by the red strata placed by me in Stage V, correlated provisionally with the Botucatú of Brazil.

From those sections of Gondwanaland, that possess beds carry-

[93] Geinitz (1876); Gothan (1925).
[94] *Vide* Keidel (1922), pp. 288–290.
[95] Bodenbender (1905).
[96] Rimann (1918).

ing the *Thinnfeldia* flora, the formation that is most suitable for age determination is undoubtedly the Molteno beds of the Stormberg series of the Cape, because this group fortunately happens to be succeeded by strata containing vertebrate remains (saurischian and pseudosuchian) of typical European Keuper and Rhætic genera, and its flora can consequently be regarded as not younger than uppermost Keuper.

Comparisons of the South African and East Australian (especially the Ipswich) assemblages with that of Argentina reveal marked resemblances, which the few published descriptions of the latter fail to do justice to, since many of those determinations were based on mere fragments. We find as common species *Thinnfeldia odontopteroides* (Morr), *T. lancifolia* (Morr), and *T. feistmanteli* John. (*Cardiopteris züberi* Szaj.), while certain large fronds from Cacheuta placed by Kurtz[97] under *T. lancifolia* are not far removed from *T. narrabeenensis* Walkom from the Triassic Hawkesbury series of New South Wales, and are also very similar to *Danæopsis hughesi* Feist, a form known from the Stormberg, Australia, and perhaps Argentina (Potrerillos). *Tæniopteris mareyesiaca* Gein. is indistinguishable from *T. dunstani* Walk. from Queensland; *T. brackebushiana* Kurtz from Cacheuta has lately been identified in the Cape, while *T. carruthersi* and *T. m'clellandi* (Old. and Morr), known from Queensland and Southern Rhodesia, have been discovered at Barreal. Another recent identification is *Cladophlebis göppertiana* (Schen.) both at Barreal and in Natal (South Africa) the forms referred to *Sphenopteris elongata*, and under *Phœnicopsis elongata* (Morr) the leaves described as *Podozamites elongatus*, the last two being known from South Africa and Australia. The form *Chiropteris copiapensis* Stein. et Solms, from La Ternera in Chile and from Cacheuta, is also known from the Molteno beds.

In addition, the widely distributed crustacean *Cyzicus* (*Estheria*) is the same species as originally described from the Cave sandstone of South Africa, *E. draperi* Jones, the associated smaller individuals then called *E. stowiana* being now regarded as representing the youthful stage. The fish-scales referred to *Semionotus mendozaensis* Gein. are, moreover, comparable with those of *S. capensis* S.-Woodw., from the Cave sandstone.

The above comparisons bring out the great similarities in the floras of western Argentina, the Cape, eastern Australia, and Tasmania, apart from strong lithological resemblances in these beds, and stage IV can accordingly be regarded as belonging with more probability to the upper Triassic (Keuper) than to the Rhætic, in which these beds have hitherto universally been placed. The flora of the Upper Paganzo is quite different in its composition from that of

[97] Kurtz (1921–22), Pl. XIX.

the undoubtedly Liassic flora with *Otozamites* and *Dictyophyllum* known close at hand in the upper part of the Río Atuel, and differs in several essentials from that at La Ternera, which, as shown by the marine fossils above, is almost certainly not earlier than Rhætic. The small assemblage described by Berry[98] from far to the south in Patagonia, in the Gran Bajo de San Julián associated with *Estheria draperi* in the upper part of a thick mass of quartz-porphyry tuffs containing a few coaly bands,[99] displays, on the other hand, Liassic affinities. Gothan[1] has also expressed doubt as to whether the beds at the Cerro Alto in Santa Cruz that have yielded the interesting cone of *Araucaria windhauseni* are as low as the Triassic, as supposed by Windhausen.

SECTION G. THE PRE-ANDINE BELT OF NORTHERN ARGENTINA AND OF BOLIVIA

Of high importance are the recent discoveries pointing to a wide distribution of the Permo-Triassic continental beds in Tucumán, Salta, and Jujuy, stretching into Bolivia as far to the north as Santa Cruz at least in the pre-Andine chains bordering the plain of the Gran Chaco. The strata are exposed, for example, in the various ranges, proceeding from south to north, of the Sierra de Lumbrera, Sierra de Santa Barbara, Sierra del Alto, Sierra de Aguaragwe, Sierra de Mandiyuti, Sierra de Charagua, and Sierra de Santa Cruz.

The southernmost outcrops, seen a little to the northeast of Tucumán, are separated by quite a considerable stretch of more ancient rocks from the patches of the equivalent Paganzo to the northwest of Tinogasta in the Puna de Atacama or those of La Rioja and Córdoba, and there is no actual connection between the latter and the "Bermejo series," as this northern facies has been named by Heald and Mather.[2] Nevertheless, a few representatives of the Gondwana flora have been found, while the generally marked lithological resemblance points to such a correlation. Further importance attaches in that there may be an unbroken succession right through into the Jurassic, whereas in the rest of South America almost everywhere either a definite unconformity or else a pseudo-conformity is present at about the top of the Permian or near the base of the Triassic.

The beds make their appearance in a series of narrow and often faulted anticlines from beneath tilted Cretaceous and Tertiary, but without the intense crumpling and the igneous injection that characterizes the equivalent formations to the south and southwest, in which structures at a number of points from Salta northward fossiliferous

[98] Berry (1924).
[99] Wichmann (1922).
[1] Gothan (1925).
[2] Heald and Mather (1922); Mather (1922).

shaly beds, of Devonian age with a typical austral marine fauna, form the cores. These ranges constitute the eastern Cordillera.

The upper limit of the Bermejo series, through a distance of many degrees, right up to the northwest and west of Potosí in fact, is formed by the relatively thin calcareous member with marine fossils—the "Limestones and dolomites with *Melania*" of D'Orbigny[3] or the "Horizonte Calcareo-Dolomitico" of Bonarelli,[4] also called by Heald and Mather the "Viticua limestone" from the range of that name (lat. 20°.15′ S.) and the "Cajones limestone" in the Santa Cruz area.

This valuable datum, from 5 to 40 meters thick, consists of white, pink, gray, or bluish hard limestones and dolomites in very regular thin layers, together with chert in layers or lenses—sometimes oölitic—the rocks being much silicified in places. They pass upward into a group of variegated Keuper-like marls with thin calcareous intercalations, also fossiliferous, up to 150 meters in thickness in the south. These various limestones are characterized by the presence of *Chemnitzia* (*Melania*) *potosiensis* (D'Orb.), and have yielded a considerable fauna, mainly gasteropods, which Bonarelli has shown to point to an uppermost Triassic or Liassic age.[5] The sandstones overlying the marls are apparently unconformable and most probably of Cretaceous age.

Perfectly conformable beneath the limestone come the uppermost sandstones of the Bermejo series—the "lower sandstones" (areniscas inferiores) of Bonarelli—but in the Puna de Jujuy the latter thin out and the limestone, according to Bonarelli, come to rest either directly or with a thin basal conglomerate on the Ordovician, the Devonian being absent.[6] In the Sierra de Zapla, close to Jujuy, the Bermejo is only some 400 to 500 meters thick, but more to the north it ranges generally from 1,300 to 1,500 meters, attaining its maximum of 2,500 meters in the Sierra del Alto (about lat. 22° S.). While the series usually rests with unconformity upon the Devonian, in certain places no marked discordance has been detected between it and that formation below.[7]

Long ago D'Orbigny had observed that over a wide tract to the northeast of the area under consideration, in the neighborhood of Lake Titicaca, the Devonian was followed by marine Carboniferous, which has since been proved over an extensive region around Cochabamba and also to the southwest of Santa Cruz on the "alta planicie" or high plateau of Bolivia. The fauna, including *Productus cora* D'Orb., *P. nebraskensis* Owen, *P. clarkianus* Derby, *Spirifer condor* D'Orb., *Spiriferina cristata* Schloth, *Fenestella retiformis* Schloth, is that of the Uralian of the Urals, Salt Range of India, and Guada-

[3] D'Orbigny (1842).
[4] Bonarelli (1921).
[5] Bonarelli (1921), p. 74; Jaworski (1923).
[6] *Ibid.*, p. 21.
[7] Meyer (1914).

lupian of New Mexico, and has species in common with the Carboniferous of the Amazon Valley and to a less degree with that of the Sahara.

On the shores of Lake Titicaca, Douglas[8] observed red and chocolate colored sandstones and breccias following the Carboniferous limestones and shales conformably, but 50 km. to the southeast, at Coniri, the highest beds of the former consist of coarse reddish conglomerates with pebbles, some of which are of fossiliferous Carboniferous limestone. These deeply colored rocks possibly represent the Bermejo series. A long distance to the southeast, not far to the southwest of Santa Cruz, the undoubted Bermejo rests discordantly on the arenaceous "Materal formation," which is believed by Heald and Mather[9] to be itself unconformable to the Devonian slates, and which may perhaps be the continental facies of the Titicaca Carboniferous.

Thus delimited above and below, the Bermejo is considered to range from the Permian to the base of the Jurassic, though, except for the mollusca at the top of the series, the only fossils yet recorded consist of *Equisetites* and *Phyllotheca* from Lipeon, northwest of Orán in Argentina, and some *Lingulas* from above the glacials in the Sierra de Santa Cruz.

Its *lowest division*—the Oquita formation[10]—is dominantly a gray sandstone followed by sandy shales and these by cream or red sandstones, or in the Sierra de Aguaragwe by massive white sandstones, while the uppermost part is composed of persistent sandy shales of various colors and thin-bedded sandstones. Certain shaly bands may possibly be of glacio-lacustrine origin, seen, for example, in the Parapiti Gorge (lat. 20° S.). The *middle division* is the striking Mandiyuti conglomerate, which builds many of the rugged cliffs and gives rise to picturesque scenery. It consists of massively bedded conglomerate and grit, together with sandstones, and varies from 500 meters in the northern part of the Sierra de Aguaragwe on the border of Argentina to 1,000 meters in the type locality in the Sierra de Mandiyuti farther to the north (lat. 20° 30′ S.); individual beds as much as 80 meters in thickness occur in the midst of the formation at several localities. The majority of the beds display brilliant shades of red and purple.

The pebbles in the conglomerates and grits are of all sizes and shapes and up to nearly a meter in length, mainly of hard rocks and mostly well rounded and polished by stream or current action, but in every locality are to be found many angular pebbles with faceted faces, and the deposit is therefore regarded by Heald and Mather as a *fluvio-glacial* accumulation. In the presumably equivalent beds in the Sierra de Santa Cruz tough clays were found carrying beautifully

[8] Douglas (1914), p. 30.
[9] Heald and Mather (1922), p. 560.
[10] Mather (1922), p. 739.

faceted grains and pebbles, while true tillite was also observed by them. These faceted inclusions scattered through both the sandstones and shales clearly indicate the presence of streams issuing from a glacier-front or from glacier-capped highlands.

Though paralleled by Heald and Mather with the (Carboniferous) glacials of the San Juan–Jachal area, it must not be overlooked that they may not improbably be much higher in the succession, possibly well up in the Permian, and that they might even be comparable with the glacials of the upper Marine series of the Hunter River area in New South Wales or perhaps those of the Congo, ascribable to a Triassic (or probably late Permian) age according to Ball and Shaler.

The *uppermost division* of the Bermejo series ranges from 250 to 500 meters in thickness, mainly massive soft green to maroon sandstones, with non-fissile shales and clays of red color, overlain conformably by the "calcareo-dolomitic horizon." Madgwick has remarked on the highly false-bedded nature of these sandstones, wherefore comparison can be instituted with the Río do Rasto series of the Santa Catherina system of Brazil, the nearest occurrences of which lie less than 800 km. due east on the railway from Porto Esperança to São Paulo.

This upper Bermejo (areniscas inferiores) appears in the Cerro Colorado, west of Rosario de la Frontera in Salta, beneath the limestones to a thickness of 600 meters at least without the base being seen, yet in the Alto de Muñoz and to the south in the Cerro de Campo this group rests directly on the pre-Cambrian; clearly the lower Bermejo does not reach Salta.[11] The upper Bermejo, the limestones, and the marls above together make up the "formación petrolífera" of Bonarelli, in which much boring has been done at the base of the various chains.

That the Permo-Triassic extends far to the east beneath the covering of Cretaceo-Tertiary is indicated by the deep boring at Alhuampa previously mentioned, in which at a depth of some 1,340 meters there was cut a group of dark-reddish micaceous sandstones and clays with occasional conglomerates, down to about 1,700 meters possibly Triassic, and below that down to 2,111 meters light feldspathic and micaceous sandstones and grits with dark micaceous shales, which at 1,860 meters yielded impressions of *Schizoneura* and *Phyllotheca*, indicating some stage of the Paganzo. It should be noticed that the volcanic rocks, so well represented in the Paraná Basin and found in borings just east of the Paraná River, and also the flows associated with Stage IV in La Rioja, are absent from the northern belt just described.

[11] Stappenbeck (1921).

CHAPTER IV

PRE-GONDWANA BASEMENT OF EASTERN SOUTH AMERICA

SECTION H. THE DEVONIAN SYSTEM

In all Brazil perhaps the most striking parallel with the Cape is afforded by the central portion of the State of Paraná with its Devono-Gondwana succession.[12] Conspicuous here is the nearly horizontal Furnas sandstone, making a belt curving from Faxina in the north past Pirahý, Castro, and Ponta Grossa to Serrinha with an outcrop of fully 300 km. in length, fading out at either end beneath the Itararé glacial beds. The escarpment that it makes picturesque because of its fine araucarias, is known in the north as the Serra das Furnas and in the south as the Serra de Sant' Anna.

The formation, which is perhaps just over 150 meters thick and marvelously like the Table Mountain sandstone of the Cape western Province, rests on an even surface cut equally across granite and the tilted Assunguy series, the beds ranging from a white fine-grained sandstone to a coarse white, false-bedded grit (Plate XII, *A*), containing a little kaolinized feldspar and tiny quartz pebbles, the rocks giving rise to a coarse sandy soil and to rather treeless plains. Either isolated in the sandstone or occurring in thin washes are pebbles up to about 7 cm. in length, smooth and oval to irregular in outline chiefly made of white or flesh-colored vein-quartz, together with some of quartzites, and occasionally of cherty rocks. At Ponta Grossa I observed none of jaspers, such as are to be found in the Clanwilliam district of the Cape, but Doctor Ferraz[13] has ascribed to the Devonian certain coarse sandstones with red jasper pebbles that cap the Morro Bahú to the southeast (860 meters) not far from the coast a little to the west of Itajahý. According to Leme,[14] diamonds have been found in the sandstones near Tibagý, a feature that has not yet been reported from the western Cape.

The concordantly following fossiliferous Ponta Grossa shales appear for a distance of over 200 km. between the Furnas sandstone and the overlapping Itararé glacials; from the descriptions available the highest zones are represented in the central part of the great curve in the neighborhood of Tibagý. At Ponta Grossa, where nearly 100 meters of these shales are exposed dipping gently beneath the Itararé, the strata recall down to the minutest detail the lowermost shale group of the Bokkeveld series of the Cape western province ranging

[12] Clarke (1913), pp. 36–41; Woodworth (1912), p. 42; Oliveira (1925); Branner (1915), pp. 311–312; (1919), p. 288; Leme (1924), pp. 159–162.

[13] Ferraz (1921).

[14] Leme (1924), p. 159.

from fine carbonaceous shales with pyritic nodules through gray and yellowish-weathering shales to soft, yellowish, sandy, and somewhat micaceous beds; limestones are, furthermore, absent, though hard, slightly calcareous nodules containing *Lingulas* are common. This horizon has yielded abundant fossils at Ponta Grossa, Tibagý, Jaguariahyva, etc., the palæontological facies being closely comparable with the faunal assemblages of the Bokkeveld, Falkland Islands, Argentina, and Bolivia, as detailed by Clarke[15] and Reed[16] and summarized in Chapter VI.

Above these beds, at Tibagý, and overlain by some more shales, is a soft, gray feldspathic sandstone—the Tibagý Sandstone—up to 20 meters thick, which is characterized by casts of large *Spirifers*, and corresponding stratigraphically with the well-known soft, red-weathering "fossiliferous sandstone" of the Bokkeveld with its molds of *Spirifers* and other mollusca, situated about 130 meters above the base of that series. This is all the more remarkable, because Reed[17] has just recently grouped the characteristic Tibagý species, *S. iheringi*, under the name of *S. ceres* Reed var. *iheringi* Kays. that is so abundant in the fossiliferous sandstone of the Hex River Valley and Warm Bokkeveld.

Except for the fact that the Table Mountain sandstone is thicker, the lithology and succession in Paraná compares almost exactly with that of the Cape system in the northeast of Clanwilliam, where the Dwyka tillite passes transgressively across the almost flat-lying Bokkeveld and Table Mountain sandstone on to the folded pre-Devonian slates and intrusive granite.

Of note is the recent discovery of such fossiliferous shales and sandstones with *Lingula*, *Orbiculoidea*, etc., in Uruguay on the Río Negro at the Rincón de Alonso underlying the Itararé glacials; they are nearly horizontal.[18]

In Paraguay, between 60 and 80 km. to the east-northeast of Asuncion, at the Cerro Aparipi, and at Arroyos y Esteros, Beder and Windhausen[19] have recorded exposures of soft, medium-grained micaceous sandstones and white, yellow, or red weathered shales with secondary limonite; these strata lie horizontally and must well exceed 70 meters in thickness. To the south they must thin out beneath the Gondwana system, for in that direction the latter come to rest directly upon the crystallines, but the distance to which they extend toward the northeast is as yet unknown, that region being geologically unexplored. Windhausen has identified among forms typical of the Ponta Grossa shales, that characteristic Hamilton brachiopod *Tropidoleptus carinatus* Conrad, known from the Ereré

[15] Clarke (1913).
[16] Reed (1925).
[17] Reed (1925), p. 52.
[18] Arocena (1926), p. 16.
[19] Beder and Windhausen (1918).

sandstone of the Amazon Valley and from the Sicasica beds of Bolivia, which accordingly suggests a mid-Devonian age and therefore a horizon somewhat higher than that present to the east in Paraná.

Just as on the western so on the northwestern side of the basin the Devonian reappears at a point 20 km. north of the town of Río Bonito not far from Goyaz, according to C. L. Baker,[20] where shales have yielded characteristic fossils. Better known, however, is the plateau of the Chapada in Matto Grosso, overlooking the plain of Cuyabá, wherein the Devonian rests unconformably upon tilted slates and limestones of supposed Ordovician age and dips gently northward beneath Triassic beds, the series extending in that direction toward Diamante and eastward to Lagoinha at least, 40 km. from Sant' Anna de Chapada. From the remarks of Evans,[21] Derby, Leme,[22] and others it would appear that the great escarpment is made by a group of soft red sandstones with basal conglomerates followed by shaly beds with thin sandstones. Smith puts the thickness of the first-named at 105 meters, with the fossiliferous shaly zone in the next 50 meters, but Leme ascribes the value of 500 meters to the series, remarking that the molluscan fauna occurs in a ferruginous sandstone in the upper part of the group, a statement seemingly more in accord with the observations of other visitors. The unfossiliferous sandstones below are clearly the equivalent of the Furnas sandstone and the fossiliferous beds above of the Ponta Grossa shales.

The fossils described by Derby and Von Ammon have been exhaustively reviewed by Clarke,[23] who points out the great similarity of the fauna to that of Paraná, and to a lesser extent with that of Bolivia, but contrast to the Maecurú fauna of Amazonas, and remarks that the presence of the uncommon trilobite *Phacops braziliensis* of boreal aspect would suggest that the Chapada Devonian, if more closely studied, would disclose additional affinities with the fauna of the Amazon Valley, which in view of its geographically intermediate position is only to be expected.

A point worthy of note is the statement that the diamonds of this region have been concentrated from these Palæozoic sandstones and conglomerates. Scattered observations suggest that the Chapada Devonian passes to the northeast and east beneath the Triassic sandstones and basalts and the Cretaceous Baurú sandstones ("sandstones of the Taboleiros" of Evans),[24] and to the northwest of Cuyabá beneath the Matto shales, Permian (?), while inliers to the southwest in the Chiquitos of the Gran Chaco form links with the Devonian of Bolivia.

An occurrence in Uruguay is worthy of mention, though ascriba-

[20] Baker (1923), p. 67.
[21] Evans (1894).
[22] Leme (1924), p. 158.
[23] Clarke (1913), pp. 41–46, p. 148.
[24] Evans (1894), p. 98.

ble only with doubt to the Devonian, but, if so, forming a link with the strata in the Sierra de la Ventana. This is the limited outcrop recorded by Walther[25] in the neighborhood of the station of Piedras de Afilar on the Montevideo-Maldonado Railway, and quite near the coast. Resting with presumed unconformity on the granite, though this is not assured, and striking northwestward, the beds make a narrow strip with a moderately high dip to the southwest, and give rise to a sharp ridge. Though regarded by Walther as a faulted-down outlier of the São Bento series, the descriptions of the rocks and the appearance of the latter in hand specimens incline me after a discussion with Professor Walther to suggest a greater age for the strata, which consist mainly of a hard, fine-grained, grayish to faintly greenish white quartzite, together with some hard reddish sandstones. While there is the possibility that the beds may represent a pre-Devonian formation, they resemble the quartzitic sandstones of the Sierra de la Ventana. On the assumption that such is the case, it should be noted that their strike is nearly parallel to the course of the "Gondwanides" within the region to the southwest, and hence at right angles to the older "Brasilides" to be mentioned below.

SECTION I. THE EARLY PALÆOZOIC BEDS

The several terrains of early or of pre-Palæozoic age, though occupying great extents of country, are surprisingly little known, and even their relative ages are under dispute. Much discrimination will be required in reading Branner's[26] account, for his extensive areas classed under the Permian actually include beds ranging from lower Palæozoic to late Cretaceous.

Prominent are the various belts of pre-Devonian strata in the lengthy stretch between the Río de la Plata and Pernambuco, of which some are probably of Ordovician age, while others may be older. They, however, have a general lithological resemblance to the folded Nama succession on the eastern side of the Atlantic, between Cape Town and Lüderitz, and also possess a strike that is more or less parallel to the coast. This likeness is heightened by the fact that in certain localities the granite by which these belts are flanked is intrusive, just as in the Nama beds between Cape Town and Namaqualand.

Termed many years ago the "Brazilian system" by d'Orbigny, this tectonic structure is most probably of Silurian age, extending into eastern Argentina, where, by no means conspicuous, it is crossed nearly at right angles by the Permo-Triassic "Gondwanides" (see Fig. 7).

In Uruguay these beds—phyllites, crystalline limestones and

[25] Walther (1919), p. 10, p. 77.

[26] Branner (1919).

dolomites, and quartzites—which with great probability correspond with those of the Sierra de Tandil, occupy a well-marked belt commencing on the coast a little to the west of Maldonado and trending between north and north-northeast through the departments of Minas, Treinta y Tres, and Cerro Largo, in the last-named of which they pass beneath the Gondwana beds; within the belt local deviations from the mean strike are not unusual.[27] Where I saw them in the Arroyo Fraile Muerto, to the southwest of Melo, the calcareous rocks consisted of blue-gray, fine-grained limestones and brown and sometimes red-weathering dolomites with subordinate dark slates, dipping at high angles, thus resembling those of the Nama system of Namaqualand. No fossils have yet been found in them in Uruguay.[28]

In southern Brazil the distribution of the limestones in the crystalline complex is all but unknown in Río Grande do Sul, though a narrow belt possesses, so far as I can gather, an easterly strike at Caçapava, but in Paraná the folded slates, limestones, and quartzites of the "Assunguy series," veined and injected by granite and quartz-porphyry, have again a northeasterly strike, appearing from beneath the Furnas sandstone near Curitíba, near Castro at Iporanga, and below Xiriricá and Iguape in the Ribeira Valley, and trending through São Roque and Jundiahy to the northwest of São Paulo. By the Brazilian Geological Survey these beds have been placed in the Ordovician.

To the northeast of the São Paulo border appears the similar and apparently equivalent "Bambuhy series" of limestones and slates, which stretches in a wide belt down the valley of the Río São Francisco and Río das Velhas to about the thirtieth parallel.[29] Where I saw this group on the railway between Bello Horizonte and Pirapora the thick gray and black limestones were followed by soft micaceous shales and flagstones, the strata dipping usually at low or moderate angles, though near Curvello they were folded along two axes directed northeast and northwest and the slates displayed a cleavage and were traversed by quartz veins.

These beds were regarded by Branner as Permian, but Leme has pointed out that they are probably continuous with the strata at Bom Jesus de Lapa on the bank of the Río São Francisco in the north, from the limestones of which Derby described *Favosites* and *Chætetes*. The long-reported occurrence of fossils in the limestones of the Río das Velhas and the recent statement of the finding of *Spirifers* in limestone at Dores de Indayá, respectively north and northwest of Bello Horizonte, and at Paracatú west of Pirapora, as cited by Leme, all point to a Palæozoic—probably an Ordovician or Silurian—age for

27 Walther (1919), pp. 28–38 and Plate XV.
28 Oliveira (1918), p. 8, (1925); Leme (1924), p. 138.
29 Leme (1924), pp. 139–143.

this extensive formation with general north-northeasterly trend. It should be noted that these foldings must be of pre-upper Carboniferous age, since the glacial beds at Areado in the Abaeté Valley rest undisturbed on the tilted Bambuhy series.

North of Bello Horizonte the series must rest on the granite, but between Corintho and Diamantina it is in contact with and appears to repose unconformably upon the ancient Espinaço or Caraça quartzites. It is true that this relationship has been called into question, but to my mind the section seen in the ascent of the Serra da Toccaia at Rodeador Station clearly shows the quartzites, here bent into an anticline, passing beneath the gently inclined limestones.

It is possible that the strata in the Serra de Caetité and those covering so wide an area farther to the northeast in Bahía, such as the Tombador-Caboclos-Paraguassú series described by Branner[30] and Crandall,[31] resting on granite or the ancient tilted Jacobina series, are the representatives of this formation. They are bent into open folds, with axes usually trending north-northeast and northwest, are overlain unconformably by the Lavras series, and this in turn with probable disconformity by the Estancia beds and Salitre limestones, which, as will be shown in Section M, belong to the Permo-Carboniferous.

Immense interest attaches to the Lavras series of gray and pink quartzites with conglomerates, inasmuch as they are most definitely the source of the diamonds and carbonados of Bahía, with which the similar gem-bearing quartzites of Grão Mogul in northern Minas have been paralleled. If the stratigraphy of this region has correctly been interpreted in the foregoing account, then there is a strong probability that the Lavras series may be of Devonian age. Branner has grouped it in the Carboniferous, though without palæontological evidence; Leme, on the contrary, emphasizes the significance of the fact that elsewhere the diamond is known to occur in Devonian sandstones, namely, in Paraná and the Chapada.

SECTION J. THE PRE-CAMBRIAN FORMATIONS

A striking feature in the geology of Minas Geraes is the long belt of somewhat metamorphosed sediments called by Derby the "Minas series," deposited, it is stated, unconformably on the granite, gneiss, and crystalline schists, but complexedly faulted and thrust by movements directed from the east and southeast.

Most fully developed between Bello Horizonte and Ouro Preto, its basal member is the thick Caraça or Espinaço quartzite, which forms the "backbone" or watershed coursing northward through Diamantina and thence northeastward toward Bahía. Above comes the important "itabirite" or iron-ore formation, associated with

[30] Branner (1910; 1919).

[31] Crandall (1919).

dolomite, slates, etc., and followed by a group of quartzites. These itabirites are identical with the rocks called "banded ironstones," so marked a type in the primitive systems of South Africa. In Bahía, according to Crandall, the Jacobina series is probably the representative of these rocks of Minas.

Harder and Chamberlin[32] have regarded the Minas series as Algonkian, a view which the strong local metamorphism fully justifies; for instance, I observed kyanite in certain of the highest beds present at the summit of the Itacolumi Peak near Ouro Preto.

Because of its alleged diamondiferous character, the Espinaço quartzite has by certain geologists been correlated with the Lavras quartzites of Grão Mogul and Bahía, but there are excellent reasons for concluding that the former is a much older formation. The allegation that the gem can actually be traced up to these quartzites in the neighborhood of Diamantina is by no means secure, several high authorities having wholly denied this association. It is true that diamondiferous gravels rest upon a peneplain cut across the quartzites round about Diamantina, but the gems may well have been derived from other sources. My examination of the famous Bôa Vista Mine east of Diamantina showed most definitely that it was an eruptive "pipe" piercing the Espinaço quartzite, the gem-bearing but wholly "non-igneous" breccia being crowded with fragments derived from the shattering of that formation, its somewhat schistose character proving the antiquity of this peculiar phase of volcanicity; not improbably its age is pre-Devonian. Draper's[33] researches suggest that several of the other diamondiferous occurrences in this part of Brazil are of a similar kind.

It is hence likely that the gems in the Lavras series were in part derived from the waste of the Espinaço quartzites because of these diamond-bearing pipes. Again, it is a matter of more than ordinary interest that in South Africa the diamond should be known as a detrital mineral in at least two formations of "pre-Kimberlite" age, namely, in the "bankets" of the (probably) pre-Cambrian Witwatersrand system in the Transvaal and in the upper Triassic sandstones of Somabula in Southern Rhodesia.

[32] Harder and Chamberlin (1915).

[33] Draper (1911; 1920; 1921).

CHAPTER V

GONDWANA SYSTEM IN BRAZIL, URUGUAY, AND PARAGUAY

SECTION K. THE PARANÁ BASIN

This covers a region of close on a million square kilometers, without taking into account certain outliers to the south and northwest, and is therefore comparable in size with the Karroo "basin" in South Africa, but, in contrast, the volcanic group at the top occupies a relatively much greater area.

Within this immense territory the dips inward toward the northeast-southwest axis are generally extremely slight, it being rare to find inclinations of more than about 3°. Two feeble cross-ridgings athwart the basin run northwestward through Paraná and Río Grande do Sul respectively, while the base has been brought down to below sea-level at Torres on the coast. In Uruguay, warping has brought up the basement granite inside the basin in the Departments of Riviera and Cerro Largo. On the southwest the very flat syncline passes beneath the Neogene of the lower Paraná along a line that runs rather regularly north and south.

Stratigraphy

Termed by I. C. White[34] the "Santa Catherina system," the subdivisions and their nomenclature have been altered from time to time, while a different classification is employed by the Geological Commission of São Paulo to that adopted by the Federal Geological Survey of Brazil. I furthermore discovered that in Uruguay the classification used by Professor K. Walther and by the State Boring Department was still practically the same as that put forward by White, but that the boundaries chosen for the several subdivisions seemingly did not each fall at precisely the horizons adopted by the Brazilian Survey. Such differences, however, are only to be expected with a number of geologists laboring in an enormous territory independent of one another and unable to meet and discuss essentials from time to time. Attention is drawn to this feature, since uncertainties in the way of exact correlation had arisen that I found to be due very largely to such causes and not to errors of observation and record.

It is regrettable that the Brazilian Coal Commission should have labored in an area in which the highly important basal glacial division was so feebly developed, thus necessitating a revision in terminology for the lower part of the system at the hands of Doctor Oliveira.[35]

[34] White (1906), p. 36.

[35] Oliveira (1918), pp. 11–12.

I also find it impossible to subscribe to the general opinion that the basal beds of the system are so young as Permian and am compelled to place them in the upper part of the Carboniferous. The stratigraphical break between the Triassic and Permian was for a long time suspected and its recognition has come only after comparison with other parts of Gondwanaland has indicated the presence of such a gap in the succession. The determination by Doctor Reed of a Triassic age for the upper part at least of the Estrada Nova necessitates a radical alteration in the grouping of the beds and further stratigraphical investigation is now urgently needed.

The following classification is to some extent tentative (the wavy line indicates an unconformity or stratigraphical hiatus):

São Bento series	Serra Geral eruptives	Rhætic-Liassic
	Botucatú sandstone (where separable)	Triassic
	Río do Rasto group	
Passa Dois series	Estrada Nova (upper part)	
	∿∿∿∿∿∿	
	Estrada Nova (lower part)	Permian
	Iratý group	Upper Carboniferous
Tuberão series	Palermo group	
	Bonito group	
Itararé series	(Glacial beds)	
	∿∿∿∿∿∿	

(1) The Succession at Fraile Muerto in Uruguay

Before entering into a discussion upon the stratigraphy of the basin, it will be useful to give some details concerning this small tract of country situated 380 km. northeast of Montevideo, on the railway to Melo, because of the interesting stratigraphical points that can be established there and because of the marked similarity in the succession to that in San Juan in Argentina.

It was from the upper part of the Arroyo Fraile Muerto, at Laguna la Tuna south of the railway that Guillemain[36] in 1911 reported the presence of glacial beds. This area was examined in more detail by Walther[37] and described by him in several instructive writings, in which use was made of the important data arising out of borings made by the Sección de Perforaciones of Uruguay, mainly within the stretch between the pre-Gondwana rocks forming the Cerro Largo on the southeast and the railway from Fraile Muerto to Melo on the northwest.

[36] Guillemain (1911); also (1912).

[37] Walther (1919).

On the Arroyo Fraile Muerto, at the Casa de Comercio belonging to Señor Gonsalez (the Paso Tía Lucía), the basement rocks are schistose greywackés evidently constituting an uneven surface, overlain by pale sandy tillite (lower) with finely striated boulders up to 80 cm. in diameter, which, apparently following the contours of the floor, is dipping gently northeastward, succeeded by about 1.5 meters of shales—hard, banded, and drab in color at the bottom, and soft and blue higher up, followed with sharp junction by the upper tillite, a clayey material with well-striated boulders of fine-grained quartzite, granite, gneiss, quartz-porphyry, phyllite, limestone, and dolomite, and this in turn by hard shales, exposed along the road leading up to the rising ground toward the east. This compound tillite constitutes the *first and lowest glacial horizon.*

The base of the glacials is not to be seen here, but is exposed about 2 km. farther downstream, just below the homestead of Paso de la Cruz, the foundation rocks consisting of highly tilted and folded blue-gray limestones and dolomites with dark slaty bands—probably lower Palæozoic. The floor is uneven, having been cut into hollows that do not always follow the strike of the beds, but commonly the direction of glaciation, and not improbably owe their origin to ice action. The tillite is in places tucked in beneath such low ridges and at one spot is banked up against a vertical wall of limestone, where it is crammed with lumps of that rock and is furthermore calcareous in its matrix and rather hard. Well-grooved surfaces can be found with the striæ directed north 40° west (true) and though "chattermarks" were not seen, it was noticed that on the northwestern side of cross-joints in the pavement flakes had sometimes been dislodged, leaving small gaps bounded by the vertical joint on the southeastern side, which is sharp-edged, but shallowing out on the northwestern, where the lip is sometimes weakly striated. This, to my mind, suggests a movement of the glacier toward the northwest rather than in the reverse direction, which will be observed to be in agreement with that deduced in Argentina.

Whereas the rock filling the hollows is a tillite of normal character, its matrix gets coarser on approaching the low ridges, and, when overlying the latter, may become a hard, coarse grit with small boulders, many of them striated, the material arching over and dipping at high angles toward the tillite in the hollows. The phenomena recall those to be seen in the "kames" of the Pleistocene glaciation, wherein a glacial sand has become molded over protuberances of the floor beneath the ice-mass. The glacial beds are not many meters thick hereabouts, and on passing upward the irregularities in stratification disappear and the material grades upward into grits and sandstones that are lying flat, though sometimes false-bedded, and carry only small pebbles of hard rocks. Features just like these are well known in and have been recorded from the "northern" Dwyka of South Africa.

A few kilometers to the west, along the railway at Cerro de las Cuentes, the basement complex displays typical *roches moutonnées* on which the glacials are resting, and the sections, which I was unable to examine in detail, should well repay study.

Returning to the account of the sections at the Paso Tía Lucía, the shales referred to as overlying the first glacial horizon are succeeded to the north by at least 15 meters of grits with very small pebbles and by a bed of gritty stuff in which are set boulders up to 75 cm. across, well glaciated, which makes the *second glacial horizon.* The homestead of Señor Gonsalez stands on this band, which, followed by a conspicuous sandstone, is traceable toward the east up to the main road, a distance of fully a kilometer, while, according to the account given by Walther[38] a sandstone of this description carrying boulders crops out between this locality and Cerro de las Cuentes and plays an important part in the western end of the Cerro Largo district.

At about 20 meters above this glacial band, seen at several points to the east along the ridge which the main road to Fraile Muerto follows and finally passing below higher strata at the Establecimiento Quebrachal to the north, is the *third glacial horizon*, much thinner and indicated only by scattered inclusions in the gritty sandstones, mostly small and composed of hard rock, some of them certainly well striated; lumps of silicified wood are also present in this sandstone.

Sandstones and shales follow thereon, all dipping northeastward at 3° or 4°, giving a total thickness of fully 130 meters of beds from the floor to a horizon where first are seen the dark sandy but "papery" shales with occasional thin limestones and silicified wood that continue to Fraile Muerto, being well exposed in the railway cutting to the east of the station and also pierced by a bore-hole in the village (No. 48) to the depth of 54 meters.

These are broadly equivalent with the Iratý group and thus furnish the datum plane from which the stratigraphical succession can be determined. The 130 meters of beds beneath this zone correspond, therefore, with the Bonito and Itararé of Brazil, though it is impracticable in Uruguay to draw a sharp line between the two divisions, while even the precise base of the Iratý is a little in doubt. I have taken the latter at the horizon where the highest of the sandstones and grits is to be found; below that level the strata, as disclosed by borings, consist of white, fine to coarse sandstones and limonitic sandstones, dark shaly sandstones, sandy shales, and some bituminous shales. All these beds that lie above the glacials will be referred to in detail later on.

[38] Walther (1919), p. 97.

(2) The Boulder Beds in Brazil

Proceeding to the consideration of the "Paraná Basin" we find the Itararé series, so called by Oliveira,[39] consisting of a series of beds of glacial origin, alternating with conglomerates, grits, sandstones, and shales that are just like those of the succeeding Bonito or Coal Measures, the first-named varying from unbedded, true ground-moraine or tillite through boulder-shale to bedded shale with small inclusions and even "pelodites" on the one hand, and through "sandy" rocks with glacial erratics to sandstones (sometimes cross-bedded), with waterworn pebbles (fluvio-glacial beds) on the other. The succession, as well as the relative proportion of "normal" sediment to glacial material, appears to vary in different parts of the country, just as is true of the Pleistocene glacial deposits of the Northern Hemisphere, and, while in places the top of the group is sharply defined, as, for example, to the northwest of Jaguariahyva in Paraná, the upper limit is commonly vague, the chief criterion being the absence higher up of any pebbly bands displaying characters not purely fluviatile. It is obvious that in borings the upper limit of the Itararé would often be rather indefinite, just as is the case in Uruguay, while certain conglomeratic strata at present mapped with the Bonito may in the future be found to be of fluvio-glacial origin and therefore have to be placed with the Itararé.

The northeasternmost point from which this series has been reported is in the Abaeté Valley in Minas Geraes, where, according to Rimann,[40] the glacials and the succeeding "Areado sandstone" rest upon the tilted lower Palæozoic Bambuhy series, the existence of the tillite in that neighborhood having long previously been noted by D. Draper.[41] This area is not improbably an outlier from the main basin, for to the west, so far as can be gathered, the Triassic sandstone rests directly upon mica-schists at the Agua Suja diamond mine, and on granite between Sacramento and Franca. The tillite appears more to the south near Mocóca, is relatively thin at Monte Santo, and runs in a widening belt southward through Casa Branca past Campinas and Sorocaba, at the same time becoming thicker. Excellent descriptions have been given by Woodworth[42] and Coleman[43] of the glacials in the region both to the northwest and west of Campinas, while a fine photograph of the boulder-beds has been reproduced by Branner.[44]

From Sorocaba the belt curves southwestward to Tibagý and then turns abruptly southeastward past Ponta Grossa, Serrinha, Río Negro, and onward, the group ranging in thickness from 250 to 350 meters in Paraná, but becoming progressively thinner in the direc-

[39] Oliveira (1918), p. 12.
[40] Leme (1924), p. 178.
[41] Branner (1919), p. 214.
[42] Woodworth (1912).
[43] Coleman (1918), pp. 312-317; (1926), pp. 156-162.
[44] Branner (1919), Pl. X.

tion of Santa Catherina. Woodworth's[45] detailed section of the group between Itaicý and Piracicaba shows a huge development—between 700 and 1,000 meters, mainly of sandy tillite and sandstone, with at least two important partings of shales, although much of the material can not strictly be referred to as tillite, consisting as it does of sandstones with occasional small boulders, while similar erratics occur in certain of the shaly bands. The succession is consequently rather like that described by various geologists at Bacchus Marsh in Victoria, though fossils have not yet been recorded therefrom.

The accounts by Woodworth and by Coleman of the glacials at Jaguaricatú, Sengéns, Itararé, and Ponta Grossa give a very good idea of the variable nature of the deposits, but much of the rock, when fresh, is actually a dark-blue massive tillite, often weathering spheroidally, with rather small inclusions, though at times boulders of over a meter across can be seen; the rock thus recalls the Dwyka conglomerate. From near the railway station of Elias Fausto, Doctor Pacheco has reported some unusually large granite erratics, one of them measuring fully 3 by 3 by 2 meters. The material at Ponta Grossa, on the contrary, I found to be a yellowish soft sandstone with only a few conglomeratic bands in which striated stones are decidedly rare. Boulder beds in verity with abundant and large inclusions were, however, observed between Río Negro and Campo do Tenente on the railway to Serrinha.

Whereas the floor beneath the Itararé is, so far as can be gathered, rather even in the States of São Paulo and Paraná, the features visible at Serrinha and the description given of the glacials there by Woodworth[46] indicate an irregular floor and indeed suggest to me the presence of a "pre-glacial" gorge in the Furnas sandstone, cut right down into the pre-Devonian slates beneath, the northern wall of which is made by the sandstone cliffs a few hundreds of meters from Serrinha, along the railway to Curitíba, the hollow being filled in with a sandy tillite overlain by a fluvio-glacial sand. The general aspect strongly reminds me of several well-established cases of such a kind in Natal (South Africa), where the Dwyka tillite is resting in ravines cut in the Table Mountain sandstone and in places lies banked against cliffs of the latter, for example, on the Umtamvuna River near the road bridge between Izingolweni and Bizana. The high irregularity of the pre-glacial landscape is, moreover, obvious between Serrinha and Lapa, a little distance to the south.

The sections between Río Negro and Canivete on the Porto União Railway reminded me very much of the Dwyka in parts of Natal and Zululand—the blue, solid tillite, blue uniform mudstone with hardly any stratification, and bedded blue shales. The latter, in thickness from a few decimeters upward, run regularly for good

[45] Woodworth (1912), pp. 54-61.

[46] *Ibid.*, pp. 65-66.

distances and probably mark, just as they do in Natal, the temporary cessation of morainic deposition within an estuary, but opportunity for detailed examination was wanting. The discovery by Doctor Oliveira of marine fossils close to Teixeira Soares on the railway southwest of Ponta Grossa and again at Río Negro in black shales sandwiched between two banks of boulder shales—so far as I can gather in the upper part of the Itararé—indicates that the ice was at a certain stage discharging into the ocean, just as was the case with the Dwyka ice-cap between Keetmanshoop and Mariental in the Warmbad district in Southwest Africa. The fossils, which are as yet undescribed, consist of small forms of *Lingula*, *Discina*, *Leda* (?), a pentamerid brachiopod, a gasteropod resembling *Pleurotomaria*, other indeterminable forms, scales of ganoid fishes, and wings of insects.[47]

To the south of Río Negro the Itararé is still thick—over 270 meters on the Lages-Florianopolis road—though there it includes 152 meters of beds at the base doubtfully grouped with the Gondwana, but regarded by Oliveira as forming an integral part thereof. Approaching the Tuberão Valley the Itararé must thin rapidly, being there represented by 32 meters of strata, of which the well-known massive "Orleans conglomerate" forms the bulk, a stratum in which the pebbles are sometimes from 20 to 25 cm. in diameter, and perhaps only a local deposit. Some 2 km. below the station of Lauro Müller, resting directly on granite, are shales enveloping a large granite erratic which is in contact with the floor, as figured by both White[48] and Woodworth.[49] From this point the boundary with the granite runs southward past Cocál and the group ends near the mouth of the Urussanga River.

In Río Grande do Sul, the Itararé is thin or *missing* between Porto Alegre and the Uruguayan border. In the Gravatahý coalfield a little to northeast of Porto Alegre, according to data kindly supplied me by Doctor Simch, the bore-holes pass directly through shales and clays belonging to the Bonito into granite, which indicates the *overlapping of the higher group on to the Carboniferous floor*. Due west of Porto Alegre, between Xarqueadas and Butiá,[50] a basal conglomerate is erratically developed, resting on granite and containing large blocks of that rock; important is the section revealed by the old Isabel shaft near São Jeronymo, where the 42 meters of beds referred to as the "Orleans conglomerate"[51] include shales, some of them dark and bituminous. Between Suspiro and Jaguary,[52] on the Cacequy–Río Grande Railway, an unbedded gray shaly rock 1 meter thick with inclusions resting on the granite probably alone

[47] Oliveira (1918), p. 14.
[48] White (1908), plate facing p. 28.
[49] Woodworth (1912), Fig. 23.
[50] White (1908), pp. 43, 47.
[51] *Ibid.*, p. 119.
[52] Oliveira (1918), p. 27.

represents the glacials, being overlain by conglomeratic sandstones, sandstones, shales, and coals—the Bonito beds.

(3) The Boulder Beds in Uruguay

The distribution of the boulder beds in Uruguay is hardly known, except in the vicinity of Fraile Muerto, as described above in (1), but there can be no doubt as to the highly diversified character of the "pre-glacial" surface in northeastern Uruguay. While the dip of the formations is everywhere low, knobs of the crystalline floor project through the covering of Gondwana beds at a number of places, the surrounding strata being formed in some instances by the Estrada Nova even. Such a granite inlier occurs along a tributary of the Arroyo del Chuy, north-northeast of Melo, one just to the east of that town, another to the south, forming the Cerro Verde, and two in the Arroyo Quebrebracho to the northwest of the station of Cerro de las Cuentas. The conspicuous Cuchilla de Cerro Largo has all the appearance of being a glaciated range that must have remained exposed long after the ice had disappeared and its undulating base had become buried beneath glacial, fluvio-glacial, and normal sediments.

The bore-hole of Zanja Honda, situated in the valley on the northwestern side of this great ridge, passed down into phyllites at about 70 meters, the section showing several meters of blue-gray conglomerate and breccia, which from the cores preserved I believe to be of glacial origin, overlain by 14.8 meters of sandstones and these by 12 meters of the curious banded shales described by Walther[53] under Woodworth's name of "desmopelodite," and which, from their alternating light and dark laminæ of differing texture (in thickness from 12 down to below 1 mm.), have been compared with the seasonally banded glacial clays of the Pleistocene. Similar beds were described by Guillemain at Laguna la Tuna in the head of the Arroyo Fraile Muerto, which not improbably correspond with the "inter-glacial" shale parting in the lowest glacial horizon at Paso Tía Lucía a short distance farther down the valley. These shales were obviously laid down in tranquil water (limno-glacial deposits) and display on their faces what are supposed to be crustacean tracks. If the 33 meters of strata at Zanja Honda immediately above them represent the Iratý, as stated by Walther, though this with good reason is doubted by Arocena,[54] then a great overlap has taken place within a distance of 25 km. with the suppression of the Bonito, which, taking into account the physiographical conditions that must have been present, would not be altogether unexpected.

While Walther's account[55] shows that coarse sandstones with

[53] Walther (1919), p. 91 and Pl. X.
[54] Arocena (1926), p. 5.
[55] Walther (1919), pp. 97–98.

boulders, possibly the second glacial horizon, play an important rôle to the west of Cerro de las Cuentas, so far west indeed as the Arroyo Cordobes, and while glacials have recently been discovered in the region immediately beyond, it would appear that a little to the north of Durazno the Triassic has overstepped the lower series. As regards the deep boring at Tacuarembó,[59] it is just possible that glacial beds here form an important group, my examination of the cores showing that from 310 meters downward they are perhaps as much as 40 meters thick, including a dark gray clayey rock and a pale gray gritty material with grains of quartz and rock fragments, passing down at about 349 meters into a typical tillite containing pebbles of granite with the granitic basement struck at about 350 meters. No similar rocks have yet been noticed at the base of the system shortly toward the east along the Tacuarembó River, where again the Triassic appears to transgress on to the basement.[60]

It is unfortunate that so little should be known about the north-western side of the Paraná Basin. No glacials have yet been reported from Paraguay or southern Matto Grosso, though they are known to occur close to Río Bonito in the southern part of Goyaz, resting apparently on the Devonian, and not unlikely are present in the upper part of the Parnahyba Valley also.

(4) The Position of the Glacial Center

Although the rounded granite surfaces recorded close to Campinas in São Paulo do not bear any definite striæ, and *roches moutonnées* have not been recorded elsewhere in Brazil, a certain amount can be deduced regarding the probable position of the Carboniferous glacial center from the inclusions in the tillite of São Paulo and Paraná. Coleman[61] has mentioned erratics of a peculiar coarse conglomerate near Capivary containing pebbles of brilliant red jasper derived from some ancient formation unknown in the country, and which I have elsewhere remarked are very like those found in the Dwyka of Southwest Africa that must have been derived from the Matsáp series of Griqualand West lying hundreds of kilometers to the east. Recently, however, Dr. L. C. Ferraz[62] has recorded a practically identical conglomerate *in situ* far to the south, in the Morro Bahú, on the north side of the Itajahý River close to Blumenau, in Santa Catherina, which, if not the source of the blocks in question, would indicate at least the likelihood of a southerly origin.

Furthermore, Woodworth[63] has drawn attention to certain inclusions of fine-grained white sandstone (whetstone), which are indicative of an easterly derivation. In Uruguay, as has been pointed out, the center seemingly lay toward the southeast, and a similar direc-

[59] Walther (1919), p. 100.
[60] Arocena (1926).
[61] Coleman (1918), p. 314.
[62] Ferraz (1921).
[63] Woodworth (1912), p. 63.

tion is prompted by the Argentine occurrences, all of which suggest an area lying out in the present Atlantic, and with which the sporadic development of the glacials and the overlapping of the higher beds on to the crystallines in the extreme south of Brazil would appear to support. A certain amount of speculation on this problem will be indulged in later on.

(5) The Tuberão Series

Doctor Oliveira has restricted the name Tuberão series to the strata above the Orleans conglomerate or the Itararé glacials, namely, to the *Bonito group* below and the *Palermo group* above, the former about 180 meters thick, the latter about 80 meters, or 270 meters in all.

The Bonito consists of soft, yellowish and grayish-white sandstones, sometimes in massive beds, interbedded with bluish or gray and occasionally micaceous shales, often plant-bearing; conglomerates are rare and thin. Important is the occurrence therein in Brazil of seams of coal upon at least five horizons that are identifiable over pretty wide areas. The workable seams are those of the Bonito coal about midway in the succession and the Barro Branco or São Jeronymo coal near the top; partings of shale are general, and the coals are always high in ash and often extremely pyritic. They are well developed in the Tuberão-Treviso area in Santa Catherina and again along the Jacuhý Valley west of Porto Alegre in Río Grande do Sul, while coals have also been proved at intervals on the Río Grande Railway, such as at Suspiro, Río Negro, Candiota, and between Cerro Chato and São João do Herval down to the Uruguayan border, and also in the opposite direction in the belt west of Ponta Grossa and Tibagý in Paraná and on the Río das Cinzas northwest of Itararé. A wealth of detail is to be found in the monumental report of the Brazilian Coal Commission[64] and in the supplementary memoir by Doctor Oliveira.[65]

The Palermo group is formed mainly of soft shaly beds of a gray or blue color (though red tints have occasionally been observed in Paraná) and passes up without a break into the Iratý shales. It is marked off from the Bonito in Brazil by a calcareous horizon with large nodules of chert, while silicified wood of the genus *Dadoxylon* is common, but the group is difficult to delimit in Uruguay.

It might be noted that in two areas where coals are locally developed in the basal part of the Bonito,[66] a thin seam rests directly upon the top of the tillite forming part of the Itararé, for example, in the valley of the Río das Cinzas and at Butiá to the southwest of São Jeronymo, and seemingly also near Suspiro on the Río Grande Railway, thus recalling to some extent the features to be seen at Vereenig-

[64] White (1908). [65] Oliveira (1918). [66] *Ibid.*, pp. 34, 103.

ing in the Transvaal, where the Ecca coals may rest directly upon either tillite or pre-Devonian dolomite.

It is further interesting to observe that the Tuberão series, when followed northward into the State of São Paulo, where it is termed the "Tatuhy" by Doctor Pacheco, is largely made by greenish sandstones, and that coals are absent, save for a seam at Jacuha, 20 km. southwest of Campinas, overlain by a boulder bed supposed by him to be of glacial origin, but which is supposed by others to be *remanié*, as in the succession at Vereeniging. Between Limeira and Río Claro, in São Paulo, the Tatuhy, followed by the Iratý, has become quite thin.

In the opposite direction the Gondwana beds make a basin near the Uruguayan border and the Tuberão is found to the south of the Jaguarão River,[67] where, in three bore-holes at least, 92 meters of beds were proved beneath the Iratý group with *Mesosaurus*, disclosing a seam of impure coal 1 meter thick that probably corresponds to one of the upper coals of this series in Brazil. This being the first locality in Uruguay where coal was struck, borings were thereafter undertaken at a number of points in the Department of Cerro Largo and also at Tacuarembó—the sections of which have been detailed by Walther[68]—but without success, from which it would appear that the limit of the area characterized by the coal-bearing facies of the lower Gondwana has been reached somewhere about Melo, though I am inclined to agree with Walther that the borings at Buena Vista and Isla de Zapata were stopped too soon. The boring in the town of Melo showed no less than 301 meters of strata ascribable to the Tuberão without the crystalline floor being reached, though it is not improbable that toward its base fluvio-glacial beds like those described from Fraile Muerto were actually cut.

It is undoubted that to the southwest of Melo the thickness of strata decreases considerably, which is in great part due to the uneven character of the floor upon which the beds repose, as proved by the isolated inliers of granite in the midst of the nearly horizontal sediments, as already referred to. The equivalent of the Palermo is more arenaceous than in the coal-fields of Brazil, making it practically impossible to separate this group from the Bonito. The same is the case to the west, the Tacuarembó boring exhibiting only 84 meters of strata between the Iratý and the granite, of which perhaps only just over one-half can be relegated to the Tuberão (Bonito and Palermo).

Westward in Argentina the Bonito is apparently represented in the San Cristobál bore-hole in Santa Fé at between 1,140 and 1,384 meters, some of the sandstones being reddish, like the Paganzo, a feature still more marked in the Tostado bore-hole (1,600 meters) to

[67] Walther (1919), pp. 92–93.

[68] *Ibid.*, pp. 99, 100; see also (1924).

the northwest, but the strata in the Alhuampa bore-hole, from 1,700 meters down to 2,100 meters, are whiter again.

Our knowledge concerning this series on the northwest and north of the basin is of the scantiest. Information given me by Doctor Beder and an examination of the specimens collected by him in Paraguay show that carbonaceous shales occur about Santa Maria to the west-northwest of Posadas and grits, sandstones, conglomerates, and carbonaceous shales like those of the Bonito at Paraguarý close to Asunción and similar strata at Villa Hayes, a little above that town, on the right bank of the Paraguay River, the latter constituting the only solid rock exposed in the broad alluvial plain west of that river.

(6) The Flora of the Bonito Group

D. White [69] and G. Lundqvist [70] have materially added to Zeiller's original description, while the former has also made it clear that the plants occur on various levels from almost immediately above the Orleans conglomerate upward. Those from the lower part of the group in striking fashion consist solely of typical members of the southern flora, such as *Gangamopteris cyclopteroides* (*G. obovata* White), *Glossopteris browniana*, *Cordaites hislopi*, *Phyllotheca griesbachi* and *P. muelleriana*, but on a higher horizon in association with *Glossopteris indica*, *G. ampla*, *G. occidentalis*, and on some unknown level *Neuropteridium validum* and *Annularia australis*, appear *Lepidophloios laricinus*, *Sigillaria brardii*, *Lepidodendron pedroanum*, *Sphenophyllum oblongifolium*, *Pecopteris* spp., and perhaps *Lycopodiopsis derbyi*, though the last is regarded by White as a southern form.

It is instructive to observe that in western Argentina these latter, as well as other northern Carboniferous forms, appear to have been found, together with the southern types, in the lowest stage of the Paganzo, so that in Brazil these "exotic" forms make their entry at a somewhat later date apparently. In South Africa they entered at a later period still during the Ecca, subsequent indeed to the deposition of the Iratý group. It is to be hoped that further systematic collecting may be undertaken to afford additional information on this important question. These observations rather lessen the probability of White's [71] supposition that those northern forms were able to penetrate the region only because of a progressive amelioration of the climate.

In making age determinations we have to eliminate the preponderant southern element as being of no direct value, though of course that assemblage is closely related to the floras of the equivalent Talchir-Kárharbári series of India, the Greta Coal Measures of New

[69] White (1908), pp. 361–373; also (1907), p. 617.
[70] Lundqvist (1919).
[71] White (1908), p. 399.

South Wales, and the Ecca Coal Measures of South Africa. Considering merely the northern forms, the five just mentioned, together with *Samaropsis* (*Cardiocarpon*) *barcellosa* are all identical with or very closely related to typically *upper Carboniferous species*, and in my opinion form useful confirmation for a pre-Permian age, such as has been arrived at from other considerations, though this view differs radically from the conclusions reached by D. White and certain others.

(7) The Passa Dois Series

This embraces the Iratý, some 70 meters thick, below, and the Estrada Nova (or Corumbatahý), fully 150 meters thick, above, two groups that are extraordinarily constant throughout the basin, though not yet recognized in central or western Argentina.

The *Iratý group*[72] is composed chiefly of black, carbonaceous, and often "papery" shales, in places pyritic, and which on being freshly broken may give out an odor of petroleum; small veins of bituminous matter—albertite or grahamite—are sometimes to be found. On weathering they bleach to pale bluish, and finally to white or faintly pink, flaky clay shales with secondary gypsum, exactly as in the case of the "White band" of the Dwyka shales. Characteristic are nodules of chert and thin layers of limestone (particularly toward the base), sometimes fibrous in structure.

In Uruguay the shales are not so argillaceous, while thin bands of white sandstone and darker micaceous sandstone are also present, making it difficult to delimit the group from the "Palermo" beneath, which fact explains the excessive value given by Walther for its thickness, though such figure must certainly exceed 100 meters. In Paraguay the beds are also more arenaceous. On the other hand, the group becomes more calcareous to the northeast, and in the neighborhood of Río Claro in São Paulo, white and gray fine-grained crystalline limestones play an important part, being actually quarried as a source of lime.

The group is traceable from Palmeira in that quarter southwestward, making a sweeping curve through Paraná that passes 60 km. to the west of Tibagý and then turns east of south through Iratý to Lauro Müller and thence to the Atlantic coast. Possibly overlapped just a little to the northeast of Porto Alegre by higher divisions, the Iratý has been proved by occasional outcrops and by borings along the southern side of the Jacuhý River, running nearly due westward, passing to the north of São Sepé and thence through São Gabriel, after which its exact course is not known with certainty, but it is exposed on the Uruguayan border between Paso Maria Isabel and Paso Minarano, and turning southwestward stretches along the base

[72] White (1908), pp. 181–191; Oliveira (1918), p. 16.

of the Cerro Largo and, curving through Fraile Muerto, strikes west-northwestward toward the Río Negro. It was cut in the boring at Tacuarembó beneath the Triassics and is known to reappear on the farther side of the basin at Villarrica in Paraguay, where fossil bones occur, while Millward has reported the extension of this and the Estrada Nova in the south of Matto Grosso and Goyaz, apparently from the foot of the Sierra de Aquidauana northeastward past Río Bonito to Río Verde, but this quarter is as yet only slightly known.

Fossils—Important is the frequency with which the singular little reptile *Mesosaurus* has been found at various points along the known huge extent of outcrop within certain layers in the black shales. In places the shales are just crowded with skeletons and indeed, not infrequently, such remains are discovered in bore-hole cores. Along with it occurs the very closely allied but generally larger form *Stereosternum*, though curiously it is stated that the latter is practically confined to the limestone layers. Some splendid show specimens of both these reptiles, and of *Stereosternum* embedded in white limestone, are displayed in the State Museum at São Paulo.

It is essential to observe that long ago Lydekker, and recently that high authority Von Huene,[73] have refused to recognize the generic status of *Stereosternum*, both regarding it as a species of *Mesosaurus*, and for the present we shall therefore consider them as *Mesosaurus tumidus* and *M. brasiliensis* respectively. Von Huene, reviewing the known South African species, has furthermore placed them all in the one form, *M. tenuidens*, with the opinion that the latter is probably distinct from the two species represented in Brazil. Noteworthy is the fact that this unique creature—clearly a free-swimming reptile—has as yet been found only in the Paraná basin and not elsewhere in South America, although strata of equivalent age are certainly represented elsewhere in that continent, while across the Atlantic it has been recorded at intervals from the Kaokoveld in Southwest Africa down to the south of the Karroo, though not to the east or northeast (see Fig. 7, on which the approximate limits are indicated).

Walther has mentioned the finding on the Río Jaguarão in northeastern Uruguay of impressions resembling those described by White from the Bonito of Santa Catherina under the name of *Hastimima*, originally thought to be a plant, but later discovered to belong to an eurypterid. Doctor Pacheco has informed me of the occurrence in São Paulo State of *Schizodus* (?), while Broili in a letter to Walther has identified certain fish-scales from the boring at Isla de Zapata near Melo as belonging to a ganoid. Not improbably the fossil wood *Dadoxylon pedroi* Zeill. comes from the Iratý of São Paulo. Derby has furthermore remarked upon the association in São Paulo State—an

[73] Von Huene (1925), pp. 118–120.

important one—of *Psaronius* with *Stereosternum* and *Lycopodiopsis derbyi*, and the latter has been discovered even above the Iratý group.[74]

Just as in the Cape Province with the shales of the White band, so the bituminous nature of the Iratý shales has led to much prospecting for coal, while their petroliferous odor when broken has incidentally been responsible for the drilling of several deep boreholes in search of oil; in both countries, it might be remarked, the shales are often sapropelitic in character and will furnish oil on distillation.

The exclusive presence of *Mesosaurus* and the outstanding lithological similarities, down to minutiæ, render the *correlation of the Iratý group with the White band of the Dwyka series absolutely assured*, although a distance of 6,300 km. separates their nearest outcrops, whereas these two zones are traceable not more than 1,000 km. away from the Atlantic shore in either case.

(8) The Estrada Nova Group

The Estrada Nova group, or, as it has been called in São Paulo, the Corumbatahý group, follows the Iratý with seeming conformity from just south of Palmeira in that State to Tacuarembó in Uruguay, an assemblage that seldom has good exposures, crumbling readily and so releasing the cherty concretions that form so characteristic a feature of it.[75]

The beds are arenaceous shales—gray, dark greenish or reddish, pink, lavender or lilac—always well-laminated, with intercalated bands of relatively pure sandstone very rich in siliceous nodules, and nodules of chert, together with some white limestone. While most of the bright coloration is certainly due to weathering, some of it is original, as borings have proved, and the superficial pink, heliotrope, or lilac tints help materially to distinguish this group from the lower division, although proving a source of trouble when attempting to discriminate it from the succeeding deeply colored strata. Taken by I. C. White as the top of this group, because it was overlain by the Triassic Río do Rasto series, is the Rocinha limestone, a band attaining the maximum thickness of 3 meters, though only rarely exposed, and known along the Río Rocinha in Santa Catherina, at Therezina in Paraná, and Fartura in São Paulo, but which is supposed to be represented at other points by cherty beds with fossil mollusca.[76] The thickness of the group is taken as 150 meters, but the inclusion of certain higher beds in Paraná that can be placed in the Estrada Nova would bring up the value in that State to fully 300 meters.

The Estrada Nova is important because of its fossiliferous charac-

[74] White (1908), p. 371.
[75] *Ibid.*, pp. 191–195.
[76] Oliveira (1918), p. 17.

ter, indicative of deposition in an estuary with occasional incursions of the ocean. At Río Claro, east of Marechal Mallet Station in Paraná, mollusca have been found in the cherts and siliceous oölites (Zone 1) and also at a slightly higher level in a calcareous sandstone (Zone 2), these two fossiliferous horizons having been recognized at several other points to the west of the railway between Marechal Mallet and Iratý, these occurrences having been detailed by Oliveira and certain of the forms described by Holdhaus.[77] (See below.)

The sequence that I was able to examine between Marechal Mallet and Río Claro is a rather important one. In the first bore-hole, situated 4 km. to the west of Río Claro, there are fully 200 meters of beds—bluish-green shales with white calcareous and sandy well-banded layers—overlying the Iratý group. The soft fossiliferous sandstone with "*Solenomorpha*," etc., taken by Oliveira as the top of the Estrada Nova, crops out about 40 meters higher still, yet above the latter the rising ground on the road to Marechal Mallet displays for a vertical distance of 40 meters similar strata, except for the absence of cherts. Above this the beds become more arenaceous, yet not until nearly 75 meters above the "*Solenomorpha*" band do strata make their appearance, having strong red coloration, from which point red and purple sandstones and mudstones are visible, followed by buff fine-grained sandstones and greenish mudstones and shales, with intrusions of dolerite up to the summit of the Serra do Tigre.

The upper portion of these 300 meters of beds overlying the Iratý could preferably be included in the Estrada Nova, despite the absence of cherts, the higher strata with bright-colored shales and mudstones being allotted to the Río de Rasto.

In Río Grande do Sul this group has nowhere been mapped, but in Uruguay, entering from Brazil, it is known to run southward down the Cañada de Ibañez past Melo and a little to the north of Fraile Muerto and thence northwestward across the Río Negro and up the Tacuarembó Valley, covering a wide area to the south and east of the town of that name. It is also known to surround much of the granite inlier of the Department of Riviera.

The only place where I was able to study these beds in Uruguay was in the shallow basin crossed by the railway between Fraile Muerto and Melo, where, proceeding from the former station, the laminated olive and buff clayey shales with ribs of sandstone and limestone belonging to the Iratý pass up at kilometer 390 into greenish, lavender, and then into red, carmine, and white laminated beds, with thin layers of white cherty rock, and are hence very like the Corumbatahý group of São Paulo. Between kilometers 392 and 393 some red sandstones appear, and, though the well-laminated character of the shales persists for a short distance, the beds give way

[77] Holdhaus (1919).

to a group of less well bedded red and variegated clays and mudstones and red sandstones somewhat evenly stratified, sometimes cross-bedded, as at 395. At kilometer 400, just before reaching Bañado de Medina, a thick sandstone of this kind rests on red clays, and such arenaceous beds extend almost to Melo and occupy a considerable area to the north and northwest. All the rocks from about kilometer 394 onward can, I think, be taken as representing the Río do Rasto group. The bore-hole at Buena Vista, 20 km. north of Melo, reveals a similar sequence with about 245 meters of strata ascribable to the Estrada Nova, while Walther states that to the south of Melo siliceous concretions have weathered out from these beds in great numbers.

In Paraguay, according to Beder,[78] there are at Villarrica, in addition to the undoubted Iratý cherts, some with oölitic structure and also some higher reddish friable sandstones that have yielded species of "*Solenomorpha*." According to Leme,[79] Millward has found in the south of Goyaz similar beds with plant fossils and lamellibranchs, presumably belonging to this group and covering a wide area round about Río Bonito and Jatahý and thence southwestward towards Aquidauana on the railway to Porto Esperança.

(9) The Fossils of the Estrada Nova

The stratigraphical position of the Estrada Nova is at the moment involved, as this so-called "group" would appear to include beds of rather different ages. Of the lamellibranchs that occur at a number of points in Paraná, Holdhaus[80] has described several species of *Solenomorpha* and one of *Sanguinolites*, maintaining a Permian age for the formation. Dr. Reed, who has determined the mollusca collected by me from Zones 1 and 2 at Río Claro, doubts Holdhaus's identifications, having discovered in these two horizons *only Triassic forms*, such as *Pachycardia*, *Anodontophora*, *Myophoria*, and *Schäfhautlia*, as detailed on page 150.

Although the sequence has hitherto been regarded as an unbroken one, a *stratigraphical hiatus must be present*, though the precise plane thereof has not yet been located in the field. Any beds *below* this surface of discontinuity must lie conformably upon the Iratý and hence belong to the Permian; those *above* it being of Triassic age, must perforce be associated with the overlying Río do Rasto and are presumably conformable therewith. Future work will no doubt bring about a better re-arrangement of the Estrada Nova.

Fish scales and bones have been discovered, also silicified wood has been determined by D. White as *Dadoxylon nummularium*, a species in which no annual rings can be made out, though Walther has found

[78] Beder (1923), p. 11. [79] Leme (1924), p. 179. [80] Holdhaus (1919).

other kinds in Uruguay in which the rings are perfectly well defined. At kilometer post 124 on the railway, 17 km. south of Iratý, I obtained a fragment of *Glossopteris*, while, from near the top of the group in the area between Marechal Mallet and Roxo Roiz, Zeiller [81] has determined *Glossopteris browniana, G. angustifolia, Tæniopteris* possibly *T. feddeni, Pecopteris* sp., *Cladophlebis* sp., and equisetaceous stems. A frond in the Geological Survey Museum, Río, labeled "*Glossopteris*" belongs probably to the Triassic genus *Sagenopteris*.

(10) The Triassic Overlap

Before proceeding to the description of the higher groups, it will be proper to discuss this particular question because of the light which it sheds on the succession, more particularly in Paraná.

Evidence, palæontological as well as stratigraphical, has gradually been accumulating, as can be found on perusing the writings of Walther, Baker, and others, to show that a break must exist within the Paraná basin between beds that are certainly Triassic and those that are definitely Permian or older, thus tending to bring the stratigraphy of this part of the continent into harmony with that of western Argentina. Future work will have to be directed toward the mapping of the "disconformity," but the gap, so far as can be made out, seemingly represents *the whole of the uppermost Permian and perhaps much of the lower Triassic.*

In the north of São Paulo the Triassic Botucatú sandstone reposes on the ancient floor of schists near the Agua Suja diamond mine and at Franca, while farther south, at Monte Santo the Pyramboia—the equivalent of the Río do Rasto—rests directly upon the Itararé tillite. West of Mocóca, on the border of Minas Geraes, Doctor Pacheco informs me that the lower groups have suffered some flexing, which action may have been due to inter-Triassic earth-movements. At Palmeira the Pyramboia rests on the Iratý, and farther south on the Corumbatahý or Estrada Nova, which relationship, so far as can be gathered, thenceforward holds good into Santa Catherina, though the latest geological map of Paraná (1925; scale 1:1,000,000) by Doctor Oliveira makes the Río do Rasto transgress across the Itararé and Passa Dois in the vicinity of Thomazina. In Santa Catherina, I. C. White observed the contact with the Rocinha limestone to be an unconformity over the short length exposed.

The Río do Rasto extends on the coast from Morro Conventos (lat. 29°) to Conceião do Arroio and thence westward to the north of Porto Alegre, but according to information from Doctors Rego and Löfgren this formation also builds the large hill to the east of that town and stretches past Vumião into the Serra Geral (*not* the great range of that name in Santa Catherina), immediately to the east.

[81] Holdhaus (1919), p. 30.

It is not improbable, judging from the height to which the granite rises at Porto Alegre, that the Río do Rasto overlaps across the Bonito group of the Gravatahý coal-field to come to rest on the granite in the south. Proceeding up the Jacuhý Valley, with its extensive alluvial plains, shales regarded as Iratý were observed by Doctor Rego, 3 km. west of Río Pardo, the beds round about belonging to the Río do Rasto. The deep boring at Ferreira, however, close to Cachoeira, which I saw in progress, proved the Río do Rasto, down to 73 meters at least, with the Estrada Nova (including a 30-meter sheet of dolerite) beneath and the top of the Iratý at 260 meters.

While the Tuberão and Iratý make a sweeping curve around the granite axis in the country between São Sepé and Bagé, followed farther to the north by the Río do Rasto in regular fashion, Walther's[82] observation of an area at Caçapava made by the Triassic resting directly on the crystallines is of great importance. Between Caçapava and the Seibal Copper Mine the sediments are only from 6 to 8 meters thick, with a red basal conglomerate, and are covered by highly vesicular amygdaloids, presumably the equivalents of the Serra Geral eruptives. At São Sebastião, on the railway to Bagé, another outlier occurs.

Over much of Uruguay, just as in Brazil, the Río do Rasto has not yet been carefully delimited from the top of the rather lithologically similar Estrada Nova, and a pseudo-conformity probably exists, as, for example, in the Department of Cerro Largo, the younger group being distinguishable by the predominance of red sandstones, often massive and cross-bedded. But in the important section described by Walther[83] in the Cerro Miriñaque east of Tacuarembó, 80 meters of these arenaceous red beds rest directly on the granite, whereas at Tacuarembó, where such strata compose both the plain and the neighboring spurs, the rocks cut in the deep boring embrace the whole of the Iratý and Tuberão. Examination of the core leads me to believe that the bright cream, red, and brown sandstones, gritty at their base, are here 126 meters thick and rest upon 24 meters only of maroon and heliotrope mudstones that can be ascribed to the Estrada Nova and these in turn upon the Iratý, etc. The overlap is also discovered far to the south, nearly 100 km. away from the main basin, where, on the Barrija Negro in the Minas district, Walther[84] has recorded, resting upon the crystal lines, gray, yellow, and dark-red ripple-marked sandstones, coarse conglomerates, etc., overlain by vesicular basalt. Boring No. 51 in the soil-covered region at Santa Rosa on the Melo Railway, 55 km. from Montevideo, proved red and chocolate-colored amygdaloid down to 78 meters at least, and, after piercing some softer rock beneath, penetrated a red con-

[82] Walther (1912) and (1912*a*).
[83] *Ibid.* (1919), p. 112.
[84] *Ibid.* (1912), p. 401.

glomerate with boulders of gneiss, grits, quartzites, etc., down to 111 meters. The red gritty sandstones at Sauce, however, appear to me to be probably of Cretaceous or Tertiary age.

From the record of the San Cristobál bore-hole[85] in Santa Fé, Argentina, the Río do Rasto apparently rests on the Bonito at about 1,140 meters, the Iratý not being identifiable, while that at Galeguay in Entre Rios east of Rosario shows beneath 463 meters of Neogene 36 meters of volcanics (fine-grained porphyrites) resting directly upon amphibolite without any Botucatú. According to Leme, the transgression is again to be found far to the northwest, where, on the west side of the basin at Aquidauana, the Botucatú followed by volcanics reposes upon schists.

These various and isolated observations, though scattered over an enormous area, collectively justify our concluding that the Río do Rasto must in a number of places, chiefly be it noted on the *margins of the basin*, overlap and be unconformable to the lower groups, thus forming a parallel to the Karroo system. Within the basin, however, the molluscan horizons (Triassic) would prove that this plane of overlapping is there situated somewhere within the limits of the Estrada Nova as correctly defined, presumably nearer its base, these marine beds being elsewhere overstepped by the continental Río do Rasto. The tracing out of this break will be an important investigation for the future. The circumstances in the Paraná basin would seem to form an almost exact parallel to those in the north of the Orange Free State in South Africa, where, by the dying out of the Molteno beds, two maroon and mainly argillaceous formations are brought together, the upper Triassic Red beds coming to rest directly upon the lower Triassic upper Beaufort beds in that area, but in the central Transvaal upon the lower Permian Ecca beds generally.

Attention can also be drawn to the transgression of the Trias-Rhætic (Stage IV) in Argentina across Stages III, II, and even I of the Paganzo, as detailed earlier,[86] of which Stage II displays many points of lithological similarity with the Passa Dois series. In the Paraná basin, however, unlike the pre-Cordilleran region, the older groups were only slightly warped and eroded during the early Triassic.

(11) The São Bento Series—Triassic

In the Paraná basin this is divided into:

3. Serra Geral eruptives, up to 500 meters in thickness
2. Botucatú sandstone ....0 to 100 meters in thickness
1. Río do Rasto beds ...100 to 400 meters in thickness usually

This arrangement, it will be observed, differs slightly from the scheme proposed by I. C. White.

[85] Hausen (1919), p. 35.

[86] Section F (5).

The placing of the lowest of these devisions in the Permian, as has been done by Oliveira,[87] has nothing to support it, since the molluscan remains found beneath it belong to undoubtedly Triassic forms.

The beds again with vertebrate fossils while overlapping the older groups in certain places, pass without a break into the Botucatú, where that division is recognizable, overlain in turn by and intimately associated with the basic lavas or "traps."

The Triassic occupies a huge region—the greater part of the basin in fact—for which the volcanic group is mainly responsible areally. In places it is unconformably covered by patches of the Baurú (Cretaceous) beds, while to the west the succession passes beneath the Neogene of the lower Paraná River, though whether some faulting has been responsible for its lower position in that direction is not yet assured.

(12) The Triassic Continental Sediments

The *Rio do Rasto*,[88] also called the Pyramboia group in São Paulo, is so closely associated with the Botucatú (or São Bento) sandstone, that the two groups must be described together. Apparently only in the south of Paraná and in Santa Catherina, according to the account of White, is the upper division well differentiated and clearly distinguishable from the lower; in Río Grande do Sul it is in places not clearly separable, while over much of Uruguay the paler color of the top of the sedimentary formation is largely a secondary character. The term Botucatú, furthermore, seems to have been also used by the Geological Survey of Brazil for the sedimentary intercalations between the lavas.

The friability of the lower red sandstones and mudstones, coupled with the hardness of the overlying Botucatú or the traps, has been responsible for an escarpment traceable nearly right around the basin, this feature being bordered by many picturesque outliers, from table-topped to conical. To a wonderful degree the rocks and scenery recall the "Basalt-Cave sandstone—Red beds" topography around Basutoland or in the Kaokoveld and parts of southern Rhodesia. The development in Santa Catherina is from all accounts most like that of Basutoland and the features seen elsewhere like those in Rhodesia.

The Río do Rasto or Pyramboia consists of friable red, often vivid, sandstones with occasional white blotches often false-bedded on a large scale; layers of fine-grained pink, red, purplish, and occasionally greenish clays are also present, but there is not the well-marked lamination and alteration of shales and thin sandstones characteristic of the Estrada Nova, while the diagonal bedding in the sandstones is also most conspicuous.

[87] Oliveira (1918), p. 11.

[88] White (1908), pp. 197–211.

At Taquara, north of Porto Alegre, where the upper part of the brown-red sandstones was of uniform character through a thickness of fully 75 meters, I found the false-bedding most pronounced, the planes often dipping at angles up to 40° from the horizontal in opposite directions in surprising fashion through individual thicknesses in some places of 12 meters or more of rock. The sandstone is quarried for paving slabs (Plate XII, *B*), being built up of alternate laminæ of fine-grained rather clayey material and coarser, friable "millet seed" grains in strictly parallel fashion and not in lenses; mica is practically absent, but iron ores are abundant and a calcareous matrix is indicated. In the coarser bands not only the grains of quartz, but even those of feldspar (which are quite fresh), are well rounded, and up to a millimeter in diameter, and there can be no doubt that this formation is of *eolian origin*. The same was found to be the case about Sant' Anna and Riviera, on the border of Uruguay, the smaller grains tending to be subrounded. Doctor Pacheco informs me that the sand grains in the Pyramboia of São Paulo are well rounded, each coated with a thin pellicle of iron oxide.

In the basal part of the group, as seen along the railway between Porto Alegre and Santa Maria and again between Rivera and Tacuarembó in Uruguay the sandstones become fine-grained and pass into mudstones of uniform nature and wonderfully brilliant hue wherever freshly exposed, while irregular calcareous patches are common. Crumbling readily, they give rise to sandy or loamy soils of wide distribution, from which the red tint has been removed by bleaching. What were considered to be the basal beds were cut in the Tacuarembó boring at 126 meters and were coarser and gritty. Some curious veins or reefs, within which the sandstones have been partially or wholly silicified, are frequent in northern Uruguay, as described by Walther; from examination of two of these near Paso del Cerro it seems not improbable that they have been produced by heated waters descending through fissures from the lavas above.

In the northeastern part of Paraguay the red sandstones interbedded with and capped by basalts occur at Bella Vista and build the Sierra de Amambay, while they extend northeastward from Aquidauana into Goyaz and onward, with a large outlying area to the northwest in the Chapada.

The thickness of the group must be considerable; at least 400 meters between Taquara and Santa Maria, but less than half that in Paraná, Santa Catherina, and Uruguay, and according to Baker[89] under 100 meters in the north. In the San Cristobál bore-hole it is perhaps 240 meters thick.

The Botucatú sandstone is a little coarser and paler, generally creamy or gray, though sometimes terra-cotta or red, and then hard

[89] Baker (1923), p. 68.

to distinguish from the underlying Río do Rasto, particularly as it tends to display the same conspicuous false-bedding. Pacheco states that in São Paulo the grains are usually angular, but at Ityrapina I found the sandstones, with which basalt flows are interbedded, to be pinkish, gritty though friable, with quartz grains up to 3 mm. in diameter, many of them oval or spherical, while the bulk were subangular and not angular. Here the group was over 200 meters thick.

In Paraná and Santa Catherina the sandstone, according to White,[90] is very massive and makes long lines of yellow cliffs sinking in a southerly direction until they come down almost to sea-level behind Torres. The deep bore-hole No. 3, situated 20 km. inland from that place, proved, according to Doctor Löfgren, 122 meters of Botucatú overlying 145 meters of Río do Rasto at least, but, curiously to the southwest, neither at Taquara nor at Santa Maria, is the upper member represented, though it is reported that a pale sandstone underlies the lavas in the ragged escarpment between these two towns.

Traced from Rivera to Tacuarembó, the top of the Río do Rasto immediately underlying the basalts develops a harder facies, paler in exposures, and thus resembles the Botucatú superficially, but is actually red when fractured, and moreover shows the same degree of false-bedding as in the Río do Rasto below. This feature can be ascribed mainly to the indurating action of the basalts, for the top is often brecciated. This material commonly makes scarps and sometimes caps isolated hills, as in the symmetrical Tres Cerros east of Tacuarembó or in the similarly styled elevations to the north of Uruguayana in Argentina mentioned by Hausen.[91]

Whether the Botucatú is merely a slightly different facies of the uppermost part of the Río do Rasto, or whether it is really a separate formation only partially developed or missing in certain portions of the basin, thus allowing the basalts to repose directly upon the lower division, is not quite clear, and only detailed mapping could settle this point, which is of no great importance, fortunately.

There can hardly be any doubt, however, as to the predominantly *eolian origin* of the São Bento sediments, which is all the more compelling when comparison is made with the obviously equivalent Cave and Forest sandstone (Stormberg) of the Cape and Southern Rhodesia, with their underlying red beds. The first named is similar lithologically to the Botucatú, displaying features indicative of a loess-like origin, while the second, as shown by "millet-seed" grains and strong false-bedding, is of eolian origin, the sediments in both cases being followed by effusion of basalts in which certain interbedded sandstones occur.

[90] White (1908), pp. 211–217.

[91] Hausen (1919), Pl. VI.

(*a*) *Fossils*—Under such circumstances the life of the period would have been scanty and the poverty of fossils would thus find an explanation. Silicified wood is abundant at many points in the Río do Rasto, both low down as well as at the top, for example at Rivera; such is probably mainly referable to *Dadoxylon*.

Of Filicales we have only the record of *Cladophlebis*, determined by Kurtz[92] as *C. denticulata* Brongt. from the base of the Tres Cerros near Tacuarembó, but which after an examination I feel sure is a distinct and probably new species, though closely related to the foregoing, which is a Rhætic-Liassic form.

From a point a little to the south of Santa Maria da Bocca do Monte the remains were obtained of *Scaphonyx fischeri* S. Woodw.,[93] a dinosaur allied to *Euskelesaurus* from the upper Triassic Red beds of South Africa, below which latter horizon dinosaurs have not yet been discovered. Leme[94] mentions the finding of a dinosaur allied to *Scaphonyx* at Cambembe, 50 km. to the north of the Chapada in Matto Grosso, while Von Ihering has recorded a dinosaur tooth in the sandstone of São José do Río Preto, 450 km. to the northwest of São Paulo. Baker has noted the presence of bones near the coast to the northeast of Torres.

A layer in the core from the bore-hole at Ferreira in Río Grande do Sul, cutting the lower part of the Río do Rasto, yielded me valves of a small *Estheria* almost circular in outline and certainly distinct from the *Cyzicus* (*Estheria*) *draperi* so common in Argentina.

It is important to note that as yet no forms ascribable to the Permian have been found in the sediments of the São Bento series which must be considered as of *Trias-Rhætic age*.

(13) The Serra Geral Eruptives or Traps and the Associated Sediments

Crowning the Botucatú, or the Río do Rasto, where the former can not definitely be differentiated therefrom, comes a great capping of lavas, basaltic to andesitic in composition, while in certain localities sediment must have been in course of deposition during intervals of quiescence to show up now as intercalations between the lavas, though only in the lower part of the volcanic group. Elsewhere, as in western Paraná and Santa Catherina and in parts of Uruguay, only volcanic material is to be found.

Attention must be drawn to Woodworth's account[95] dealing with the trap plateaus of Santa Catherina, and particularly to the valuable summary by C. L. Baker entitled "The Lava Fields of Paraná."[96] As shown in Baker's map, the eruptives of the Paraná basin form a complete elongated area, 1,300 km. long, but of rather variable width, 500 km. across at the broadest, narrowing toward the south-

[92] Walther (1919), p. 107, footnote.
[93] White (1908), pp. 217–225.
[94] Leme (1924), p. 189.
[95] Woodworth (1912), pp. 91–99.
[96] Baker (1923); the scale on the map is incorrectly given.

west and occupying a tract of fully 800,000 square kilometers in extent, including certain stretches concealed beneath the Baurú beds. Excepting on the west, the lavas generally terminate in erosional escarpments; they frequently give rise to terraced features and are responsible for the multitude of rapids and cataracts on the rivers, outstanding among which are the magnificent falls of the Iguassú[97] with a height of 60 meters and those of La Guayra on the upper Paraná.

While the contact between the volcanics and the sediments beneath is as a rule a perfectly even surface, attention must be drawn to certain irregularities first studied in the town of Taquara, north of Porto Alegre in Brazil, and seen again close to the railway near Paso del Cerro and in the Cuchilla de Tambores 10 km. south of Tacuarembó in Uruguay. These disclosed the fact that the basalts in these three spots were resting upon and filling up shallow hollows in an originally uneven surface of sandstone, which depressions in every case trended a little south of west, a feature worthy of record, since in South Africa several cases are known of a similar kind along the Basalt-Cave sandstone contact; these apparently represent primitive drainage lines over the sandy surface in existence at the commencement of the period of volcanicity. The section shown in Figure 6 may therefore be not an uncommon one.

Flows earlier than those usually seen were found deep down in the Botucatú sandstone at Ityrapina in São Paulo, where the deep boring gave the following downward section, starting at the base of the main traps: sandstone, 85 meters; basaltic flow, 15 meters; sandstone, 77 meters; basaltic flow, 3 meters; sandstone becoming redder, more clayey, and calcareous, and hence transitional to the Pyramboia, 48 meters. In South Africa such a similar case has been recorded from the Maclear district of the Cape Province, where local eruptions antedated the dominant period of volcanicity.

Thin sandstone intercalations are recorded by Baker generally, by Walther in Uruguay, and by Sobral and Hausen in Misiones, and are almost always medium to fine grained—sometimes finer and coarser banded—red, red-brown, terra-cotta, or even purplish colored, poorly or cross bedded sandstones or not unusually intensely hard, glassy quartzites breaking with a conchoidal fracture and so making very stony outcrops. While probably much of this induration was effected by heat from the overlying lava, the depth through which such hardening extends rather suggests the action of hot solutions carrying silica. On the other hand, it should not be overlooked that they might possibly have acquired some of this exceptional character through original silicification *prior to* the outpouring of the succeeding lava-flow, for it is well known that under an arid climate sands may be converted into "surface quartzites" or "silcretes" under

[97] See Hausen (1919), Pl. IV.

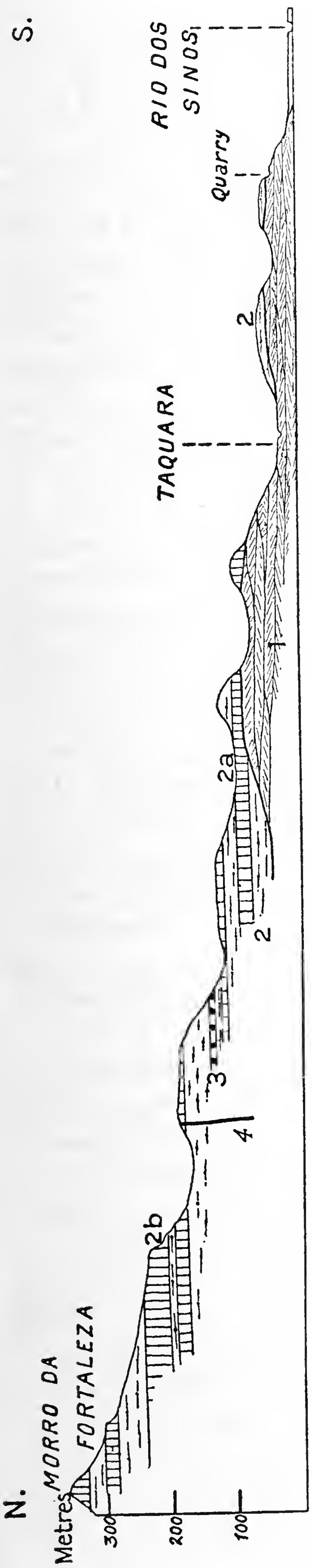

Fig. 6—Section, 10 km. in length through Taquara, Río Grande do Sul, showing the Triassic volcanics (2) resting on an undulating surface of the false-bedded Río do Rasto sandstones (1) (the more massive flows, such as *2a*, *2b*, are ruled vertically); 3, agglomerate; 4, dolerite dike.

purely natural conditions, as in the Kalahari in South Africa, and that the Botucatú was apparently accumulated under such desert conditions. This is suggestive because of the very similar silicified character beneath the basalts of the Triassic Forest sandstone of Rhodesia, also a formation of eolian and presumably of desert origin. A noteworthy type of rock extensively used as ballast on the railways at Santa Maria is a coarse gray grit, which from inquiry I afterward found came from Barras, on the railway close to Passo Fundo, apparently from an intercalation relatively high up in the volcanics, though of this I can not be sure. It is remarkable in that the samples picked up contained tiny "dreikanter." Conglomerates have been reported to occur in the Botucatú, and these are manifestly worthy of detailed study in view of the information they might yield regarding the geographical and climatic conditions in Brazil at the close of the Triassic epoch.

Above Taquara, on the road to Morro Fortaleza, not far above the base of the lava group, there crops out an agglomerate bed (Fig. 6, *3*), with a fine, pinkish, sandy matrix in which was set an abundance of subangular to rounded fragments of different kinds of lavas, which bed passes upward into red cross-bedded friable sandstone exactly similar to those of the Río do Rasto seen in the town below, and ending in a sharply defined "baked" junction against the flow overlying; the band totals 8 meters in thickness. Ten meters higher up occur thin sandstone veins running vertically down into cracks in the underlying basalt from a higher thin intercalation of red sandstone; clearly, just as in South Africa, eolian conditions seem to have lingered on while the earliest lavas were being erupted.

Some of the thin intercalated sandstones and quartzites in the basin are reported to contain fragmental igneous matter, and indeed, in the Territory of Misiones in northeastern Argentina, such layers may be tufaceous in their character.[97] Such bands have been passed through in certain of the borings, for example in those at Posadas, Solari, and Mercedes (Corrientes). It is worthy of note that tufaceous layers should also have been found at a lower horizon (in the Río do Rasto) in the bore-hole at San Cristobál (Santa Fé) still farther to the west, where the volcanics were struck beneath the Neogene at 735 meters, the Triassic sediments being cut at 900 meters, underlain by possibly Bonito beds from about 1,141 to 1,384 meters. A rather similar succession was intersected between 860 and 1600 meters in the boring at Tostado, a little to the northeast, which helps to link up the strata of the Paraná basin with the Paganzo of the Córdoba and La Rioja districts. In Laguna Paiva No. 2, a little to the north of Santa Fé, the amygdaloids were struck at 602 meters and not bottomed at 638 meters.

(14) The Volcanics

As various observers have pointed out, many of the flows are relatively coarse-grained, compact rocks difficult to distinguish from intrusive sheets, but as a rule such types, when satisfactorily exposed, display vesicular structure at the top, if not at the very base. Though not recorded by previous workers, I found "pipe amygdaloids" developed at the bottom of the flows in several places and at Taquara also "vesicle cylinders" and "bubble trains" set vertically in non-vesicular basalt, just as can be instanced from the Stormberg series.[98]

Some of the lavas are highly vesicular and even cavernous, Brazil and Uruguay being noted for the large quartz-filled geodes and hydrolytes that have become weathered out in the red loamy soil; others are very dense, in which case there is sometimes a columnar structure. In color they range from black to dark green, purple, brown, red, or chocolate. Native copper is occasionally to be found in them. The thickness of the individual flows varies from 0.5 meter upward, the general value being probably anything up to 50 meters or thereabouts, though Woodworth has spoken of sheets from 95 up to perhaps 190 meters thick in the eastern part of Río Grande do Sul. There are no references to the occurrence of thin layers of red bole or earth between successive effusions, and in this respect the volcanics are like those of South Africa, for which the evidence points to the rapid welling out of flow after flow without any lengthy time interval, probably under a dry climate such as would have hindered the rapid weathering of the lava crusts.

As regards the thickness of the group, Baker[99] states that in different parts of the basin figures of from 250 to 500 meters have

[97] Hausen (1919). [98] Du Toit (1907). [99] Baker (1923), p. 72.

been measured, although much rock must have been removed by erosion from over this great region. In one of the borings at Curuzú Cuatiá, on the lower Paraná River, between Corrientes and Concordia, the base of the volcanics (from which intercalated sediments were absent) was not passed through at 486 meters even. In this respect, therefore, the group is comparable with the Stormberg basalts, wherein a thickness of over 1,000 meters has been recorded in Basutoland and 400 meters in the Kaokoveld.

(15) Petrology

The bulk of the flows are "melaphyres" in which olivine is absent or else in small individuals, usually much altered to serpentine, or, as in Uruguay according to Walther, to iddingsite, while the structure is in general ophitic to subophitic, features that exactly duplicate those of the Stormberg volcanics. Hausen observed no porphyritic structures in Misiones, but Walther mentions types approaching the porphyrites in Uruguay, while Baker refers to augite-porphyrite and Branner records the presence of such types in Río Grande do Sul and Hussak in Santa Catherina and São Paulo. This is instructive because, although porphyritic basalts are unrepresented in the Union of South Africa, they appear occasionally up the Zambezi-Linyanti Valley and are well marked in the Kaokoveld of Southwest Africa. Andesitic varieties are sometimes present in Brazil, as at Santa Maria.

Doubtless the lavas issued mainly from fissures, now occupied by narrow vertical dikes of basaltic or doleritic rock, but at Santa Maria what was taken to be a volcanic neck was observed in the face of the spur north of the town, facing Pedreira and overlooking the railway to Passo Fundo. It cuts the hard interbedded sandstone capping the ridge and is filled with a pale scoriaceous rock, banded in nearly vertical fashion parallel to the wall of the pipe.

Regarding the age of the Serra Geral eruptives, it can hardly be doubted that, like those in western Argentina and Patagonia, they are Rhæto-Liassic, though direct evidence thereon is wanting.

(16) The Intrusive Dolerites or Diabases

Penetrating the strata of the Santa Catherina system, but more commonly its lower half, are these well-known extensive sheets and dikes of basic rock that are manifestly closely allied to the Serra Geral eruptives, though, so far as can be gathered, of slightly more basic composition. Numerous references will be found in the geological literature to such sills, but no comprehensive account thereof. Baker has indicated on his small-scale map the areas outside the basin proper where they have been observed by him, and he notes that they also penetrate the basement formations in Paraguay and the southern part of Matto Grosso.

They are common in the Itararé, Bonito, and Iratý beds, but the impression that I obtained from journeys between Porto Alegre through Santa Maria and Rivera to Montevideo, where excellent sections are furnished by numerous railway cuttings, was that such intrusions were distinctly scarce in the upper part of the system and then generally dike-like, just as is the case in the Karroo. Further, it may be affirmed that the relative proportion of igneous rock is much less than in the dolerite-riddled portion of the Union of South Africa. Their precise relationship to the eruptives has not yet been worked out, but arguing from analogy from South Africa[1], they would most probably have been injected into the framework of South America during or probably just after the eruptive phase, and hence probably date from the beginning of the Jurassic.

They display no unusual petrological characters, ranging from dolerites without olivine to olivine-dolerites, and having subophitic or ophitic structures. A typical sample from a bore-hole near Río Claro in Paraná possessed a specific gravity of 3.02.

SECTION L. THE NORTHEASTERN REGION OF BRAZIL

Mainly to Lisboa,[2] Crandall,[3] and Small[4] is due our knowledge of the quite considerable area of Permo-Triassic in Maranhão, Piauhý, and the northeastern part of Goyaz. Quite unjustified is its southerly extension, as shown on Branner's geological map of Brazil, so as to join up with the strata of the Paraná basin, the formations filling the broad gap being either pre-Carboniferous or post-Triassic, though probably the latter may conceal some Gondwana beds.

The strata are lying nearly flat, resting on crystallines, but in the east, according to Small, unconformably on the thick Serra Grande series, described elsewhere (possibly of early Palæozoic age), and are overlapped to the north by the Cretaceous and the coastal Tertiaries.

The lowest beds, of Permian age, make a broad, sweeping horseshoe, extending from the north of the Parnahyba River southward through Piauhý, then westward to the Río Tocantins and down the latter to the borders of Pará. The higher horizons lie within the curve, the Triassic appearing toward the north and covering a limited area about the headwaters of the Mearim River in Maranhão.

Called by Lisboa the "Parnahyba series" and divided by him into several groups totaling a few hundred meters in thickness, so far as one can gather, the beds consist successively of gray calcareous shales and gray to white sandstones, a thick red sandstone having purple spots and with pisolitic limestone, a gray sandstone followed by green and chocolate shales, and limestones with cherty bands. Glacial signs are absent at the base. *Psaronius* associated with gymnospermous wood has been found in many localities in this wide region throughout the full thickness of strata, together with the cast of a stem referred to *Sigillaria* in Piauhý. Since the first-named occurs,

[1] Du Toit (1920). [2] Lisboa (1914). [3] Crandall (1910). [4] Small (1914).

according to Derby, in São Paulo State associated with *Stereosternum* and *Lycopodiopsis*, such would suggest that the Parnahyba series probably represents horizons from about the Iratý upward and hence mainly of Permian age, the beds being all of fresh-water origin, apparently.

The succeeding "Mearim series" consists of a few hundred meters of white, splotched, and red sandstones overlain by flows of basic amygdaloidal lavas, which are also intercalated in the red sandstones, the strata building table-topped hills, well represented between Grajahú and Pastos Bons, while they and the underlying beds are, furthermore, cut by intrusive dolerite in the form of sheets and dikes.

There can be no doubt that this upper series, older than the Cretaceous and so like the São Bento of southern Brazil, is of Triassic age, support for which is found in the discovery of scales of *Semionotus* near Floriano on the Parnahyba River.

Attention might furthermore be directed to the general parallelism in facies with the "Karroo" succession of the Lower as contrasted with the Upper Congo basin in Africa, namely, in the absence of glacials, the shaly and often slightly calcareous character of the Lualaba beds with fish and crustacean remains, and the succeeding yellow or pink friable Lubilache beds, though volcanic rocks are not known to overlie the latter.

SECTION M. EASTERN BRAZIL

In the coastal region of Bahía and Sergipe, Branner [5] has described under the name of the "Estancia beds" certain strata, which he placed in the Permian, that occupy the region from Bahía northward to the Río São Francisco, though much concealed by Cretaceous and Tertiary formations. Subsequently Soper [6] has removed a part of this to the Cretaceous and has furthermore stated that the Estancia beds pass down, apparently without a break, into a thick series of rocks that rest unconformably upon an uneven surface of crystallines and proterozoic (?) quartzites. It totals no less than 3,700 meters, the beds being tilted and sometimes considerably disturbed, and even faulted, the foldings trending generally a little east of north, but along other axes as well, overlain discordantly by gently inclined Cretaceous and by horizontal Tertiaries.

In the lower part are seen shales, slates, and gray to pink limestones, followed by a great mass of green, blue, dark or dark red, often micaceous, shales, succeeded by red sandstones and by blue limestones. The finding of *Alethopteris branneri* White in a dark shale beneath red Cretaceous sandstone at Aracy, and according to Leme [7] of *Psaronius* near to Conselho, would suggest an upper Carboniferous or more likely a lower Permian age for the *upper part of the series;*

[5] Branner (1913). [6] Soper (1914), pp. 25–37. [7] Leme (1924), p. 181.

consequently the basal portion may extend well back into the Carboniferous.

Comparisons may be instituted with the gently tilted formations in the western part of the Belgian Congo, particularly the middle portion of the Kundulungu, called by Cornet the "Mpioka series," with its red coloration.

It is just possible that the horizontal limestones and shales of the Salitré Valley in Bahía, extending over wide areas to the southwest thereof, resting unconformably upon much older formations, and tentatively placed by Branner[8] in the Permian, may belong to the Estancia series, but palæontological data are essential before any further advances can be made. In the coastal zone to the south of Bahía near Cannavieiras beds occur on the Río Pardo and Río Jequitinhonha that have yielded plants referred by Hartt to *Asterophyllites* (?) *scutigera*, suggested by D. White as perhaps a *Phyllotheca*.[9]

Nevertheless, the following important points have been established: (1) The presence of some undoubted late Palæozoic continental beds in the coastal region; (2) their partially calcareous nature; and (3) their disturbance by early mesozoic movements not altogether coinciding in trend with the ancient "Brasilides," the significance of which will be remarked on in Chapter VI.

SECTION N. THE CRETACEOUS OF THE INTERIOR

Brief reference only will be made to the continental Baurú beds of São Paulo State that rest horizontally and unconformably on the Triassic traps and are probably of Cretaceous age. Their precise distribution being not very well known, these beds are not indicated on the accompanying geological map, but it might be remarked that they occupy wide areas, forming much of the higher ground bordering the Parnahyba, Río Grande, Tieté, and Paranápanema, and extend down the valley of the Paraná to Guayra, while beyond at San Ignacio near Posadas the sandstones have been brought down to river-level by warping. The transgressive base is indicated by the fact that they rest on the traps between Baurú and Agudos, but on the Triassic sandstone at Botucatú. They are composed chiefly of massive and often false-bedded white to red sandstones with a calcareo-argillaceous cement. Farther north they form a broad covering along and west of the Río São Francisco, known here as the "Pirapora sandstone," and appear to connect up with the slightly younger but marine Cretaceous of rather similar character of Piauhý and Ceará. These beds rest very largely upon a peneplain cut across the underlying formations of Brazil, and thus reveal the very considerable denudation of the continent during the Jurassic epoch.

[8]Branner (1913), p. 626; (1919) p. 237; Crandall (1919), p. 244. [9]White (1908), p. 423.

CHAPTER VI

GEOLOGICAL HISTORY OF THE AFRO-AMERICAN LAND MASS

That these two continents were intimately connected during several geological epochs will, I venture, be acknowledged after the perusal of the preceding pages, though the manner of such union would admittedly be speculative. In preparing this review an attempt was made first of all to write the historical account, irrespective of any hypothesis as to the manner of such union or of the ultimate mode of separation of the land-masses though it became evident, as the data were assembled, that they pointed very definitely in the direction of the displacement hypothesis, and that they could most satisfactorily be interpreted in the light of that brilliant conception.

It was finally decided to treat the subject from this viewpoint rather than from any other, but only in such a way as to bring out particular features the significance of which would otherwise be overlooked; the hypothesis itself could then be discussed independently and without prejudicing this particular chapter.

THE SILURO-DEVONIAN

Knowledge concerning the early limits of the Afro-American mass only becomes definite during the late Silurian, when the ocean must have covered the central Sahara, western Africa, the lower portion of the Amazon Valley, parts of Bolivia, Jachal, San Juan, and Mendoza, but not the Nevado de Famatina. The faunas up to the very close of that epoch were, it is essential to note, *boreal* in their aspect.

Attention has more especially to be focussed on far distant Bolivia, because of the light which its splendidly developed lower Palæozoics shed on the precise age of the unfossiliferous sandstone formations of Paraná and the Cape, customarily ascribed to the lower Devonian. The valuable accounts of the stratigraphy of this country by d'Orbigny,[10] Steinmann,[11] Ulrich,[12] Knod,[13] and others, supplemented recently by Kozlowski[14] and Bonarelli,[15] clear up many points, although showing the need for further investigation.

Following Knod and Kozlowski, the normal Bolivian succession, resting usually on the Ordovician, is divisible into: (1) The lower or Icla sandstone, about 170 meters thick, with unfossiliferous lower

[10] D'Orbigny (1842).
[11] Steinmann (1904).
[12] Ulrich (1893).
[13] Knod (1908).
[14] Kozlowski (1923).
[15] Bonarelli (1921), pp. 39-56.

half (a greenish gray or whitish quartzose sandstone overlain by gray calcareous sandstone and calcareous flagstone; (2) the Conularia and Crinoid beds some 200 meters thick (dark shales and sandy shales with calcareous nodules, like those of Paraná); (3) the upper or Huamampampa sandstone up to 250 meters thick (grayish and unfossiliferous). These 700 to 800 meters of beds are generally agreed upon as representing the lower Devonian alone (Oriskany), but Kozlowski has stated that around Lake Titicaca there is (4) the Sicasica formation (quartzites of a warm color, micaceous brown or white shales with sandy layers and black siliceous nodules), with a fauna showing middle Devonian forms together with a few lower Devonian types followed by unfossiliferous sandstones and shales—Onondaga–Hamilton.

Now, both in Paraná and the Cape the sequence is almost identical, the barren Furnas and Table Mountain sandstones being respectively followed by the dark fossiliferous Ponta Grossa and Bokkeveld shales, which are unquestionably equivalent to the Conularia and Crinoid shales of Bolivia, as borne out by their particular faunas.

On the other hand, Kozlowski[16] and Bonarelli[17] have independently pointed out that in parts of Bolivia this important system actually includes in its basal section strata that belong to the uppermost Silurian, and which, although of no great thickness, are widespread to the north and southeast of Sucre, being characterized by the presence of *Clarkeia antisiensis* (*Liorhynchus bodenbenderi*) and several other forms not found associated with the typical Devonian faunas. At Tarabuco, east-southeast of Sucre, the succession resting upon the Ordovician consists of 40 meters of barren white quartzite, 30 meters of yellow to red sandstones with *Clarkeia*, overlain by some hundreds of meters of yellowish sandy shales, in the upper part of which fossils characteristic of the Icla shales occur; at Finca Constancia to the north of Sucre a rather similar order can be seen. That is to say, where the normally unfossiliferous basal group of whitish quartzitic sandstones has developed a *marine facies*, the latter now carries not Devonian but Silurian forms, wherefore the presumption is strong that the basal part of the equivalent Furnas and Table Mountain sandstone is in each case of *uppermost Silurian age*. It is significant that the only molluscan remains yet found in the Cape formation—unfortunately not identifiable—should occur at the very base of the sandstone.

A parallel is forthcoming from Jachal, where Keidel,[18] studying the unbroken succession in the Lomas de los Piojos, has recorded the zone with *Clarkeia antisiensis* and *Monograptus priodon*, composed of

[16] Kozlowski (1923), pp. 8–10.
[17] Bonarelli (1921), pp. 46–53.
[18] Keidel (1921), pp. 32–37, 51–54; Clarke (1913), p. 332.

green and dark micaceous shales, which are followed by 800 meters of "Devonian," the basal 500 meters being unfossiliferous sandy shales, greenish and bluish gray sandstones with dark sandstone ribs, followed by similar gray and green beds, but with the typical forms of the "austral" Devonian of Bolivia, Paraná, Falklands, and Cape.

THE DEVONIAN OSCILLATIONS

These illuminating sections in Bolivia prove, therefore, that the great "Devonian" transgression really began just prior to the close of the Silurian. At that period Central Africa had been land probably as far northward almost as Nigeria and southward right to the Cape, while most of eastern and southern Brazil, Uruguay, southeastern Bolivia, and northern, central, and eastern Argentina were bound to that continent.

Along the margins of this land-mass were then accumulated the siliceous deltaic deposits of Paraná, Matto Grosso, Sierra de la Ventana, the Falklands, and the Cape (from Clanwilliam in the west to Zululand in the east), while, as the ocean advanced and the area of this section of Gondwanaland decreased, the delta fringe crept inward and marine muds and sands with a lower Devonian fauna of austral type came to be laid down on them. In Africa, the Gold Coast region was ultimately submerged, and in the opposite direction the southern third of the Cape and the whole of the Falkland Islands; whether the Córdoba–San Luiz region remained as an island is unknown, but certainly Jachal and Salta were inundated, though probably not the Famatina, Puna de Atacama, or the center of La Rioja.

A cool climate is expressly indicated by the glacial zone of the Table Mountain series, and indirectly by the dark gray, blue, and green coloring of the marine strata, by the absence of limestones, and scarcity of corals in them; everywhere a shallow ocean has to be postulated, which would explain the widespread transgression of its waters in certain territories.

THE DEVONIAN FAUNAS

With the lower Devonian, for reasons not yet understood, came strong faunal differentiations. The boreal element still predominates in the Sahara,[19] as shown by species from Rhineland and North America, but an austral bias is signaled by such forms as *Homolonotus herscheli*, *Leptocoelia flabellites*, *Spirifer rousseauxi*, etc. The Maecurú (Amazon) assemblage, while showing alliances with the European, displays the North American—Oriskany–Onondaga—facies, but the austral element is nevertheless quite marked in certain

[19] Haug (1905); Lemoine (1913), p. 19.

groups, particularly among the trilobites, with peculiarities among the brachiopods, *e.g.*, the *Spirifers*, which are more marked still in the Bolivian and west Argentine areas. The fauna of Matto Grosso is not far removed from that of Bolivia, but the west Argentine one again stands apparently closer to that of the Falklands than to Paraná. Clarke[20] has commented on the fact that the Falkland fauna is much closer allied to the Bokkeveld of the Cape than to the South American assemblages, peculiar only so long as one disregards the doctrines of the displacement hypothesis, for under the latter these islands would have been nearer geographically to South Africa than to Brazil. We know that some high ground must have lain in early Devonian times to the west and northwest of the Cape (sufficient to support local glaciers), while the sources of the siliceous formations of Sierra de la Ventana and Paraná probably lay to the east rather than the west. Consequently the Paraná region might well have occupied an embayment with a promontory intervening between the Brazilian and Falkland shore-lines.

Our knowledge concerning much of the periphery of Gondwanaland ceases with the lower Devonian, but during the mid-Devonian the ocean persisted in the Amazon region and in northern Bolivia. The Brazilian Ereré fauna shows increased affinities with the North American, in addition to forms from the Maecurú, but it also has alliances with the Sicasica fauna of Bolivia through such forms as *Tropidoleptus carinatus* and *Homolonotus dekayi*, typically Hamilton species, the latter represented also in Gold Coast Colony.[21] In Ahnet (Sahara) the mid-Devonian carries *Agoniatites vanuxemi*, characteristic of the Marcellus stage of New York, while the upper Devonian of Tassili shows affinities with North America. Faunas of late Devonian age are not yet known in South America outside of the Amazon Valley.

THE CARBONIFEROUS EPOCH

The oscillating shallow seas then withdrew—probably the continent rose isostatically—for in South Africa, the Falklands, and the Sierra de la Ventana area siliceous estuarine and fluviatile beds of presumably upper Devonian–lower Carboniferous age (derived in the first-named from the erosion of the old Devonian land-mass) succeed the marines with but a few plant remains. At Paracas on the coast of Peru are the only other known plant-bearing strata, probably of middle Carboniferous age.

Only in southern Peru, a little north of Lake Titicaca,[22] are marine beds represented in South America, of undoubted lower Carboniferous (Avonian) age, though present in Gold Coast Colony and the Sahara, and it would appear that the ocean then retreated to beyond

[20] Clarke (1913), pp. 13, 56. [21] Kitson (1925). [22] Douglas (1920).

its limits during the Silurian, thus presenting an increased area of land to erosion. A certain amount of folding occurred in the pre-Andine regions about this time, seemingly with the injection of granites in Peru and Bolivia.

With the upper Carboniferous came a return of the ocean, which entered the lower Amazon region and occupied a large part of Peru and Bolivia, but the block between the Puna de Atacama and Potosí remained land, around which a gulf of the sea must have crept to penetrate into the western part of San Juan and parts of Chile on about the same parallel of latitude; all the country to the northeast, east, and southeast of San Juan probably remained unsubmerged.

The upper Carboniferous occurs on either side of the Amazon River with wide extension—a group of limestones, shales, and sandstones, perhaps 600 meters thick, with an abundant fauna, including *Productus cora*, *P. semireticulatus*, *Athyris subtilita*, *Spirifer cameratus*, etc., allied to the upper Carboniferous of the United States and Urals and showing resemblances to the Carboniferous of Bolivia and Peru on the one hand and of the Sahara on the other. Most curiously, as Doctor Reed has well pointed out, the equivalent fauna from Barreal is quite distinct from those recorded elsewhere in North or South America, the forms being nearly all either closely allied to or comparable with established species from the lower Carboniferous of Europe or the middle or upper Carboniferous of Russia or parts of Asia. Probably, therefore, the western part of San Juan was not in direct communication with the ocean to the north. The fauna, it might be noted, displays no affinities with those of eastern or western Australia.

THE CARBONIFEROUS GLACIATION

Time is revealing more and more the number of places where the Carboniferous glaciers passed into a shallow ocean and, melting, dropped their burden, for example in Tasmania, New South Wales, Western Australia, the Salt Range in India, the San Juan district in Argentina, and Paraná in Brazil. It has furthermore become evident that over wide areas the ice must have traveled across a gently undulating surface nearly at, if not below, sea-level, as is proved by the shales with marine mollusca in Paraná and Southwest Africa, by the Dwyka shales of South Africa, Bonito coal measures of Brazil, etc. The general low relief of the ice-ridden territory is indeed one of the most unexpected peculiarities of this Palæozoic glaciation.

I have adduced evidence to show that in South Africa[23] the glaciation apparently started at several centers, in each case over somewhat higher ground, but that the ice-sheets at the maximum stage of glaciation seem to have coalesced, to discharge southward into a

[23] Du Toit (1921).

body of probably fresh water. An important center was situated in Southwest Africa, but it is not at all unlikely that a similar feature lay to the northwest or even west of the Cape (from which direction had indeed come the local glaciers of the Devonian), suggestive being the "boulder pavement" at Eland's Vlei on the Doorn River, with its groovings directed nearly west-east.

In South America the evidence consistently favors an ice center situated out in the present Atlantic, the significance of which will be appreciated from the study of Figure 7. The position allotted to the Falkland Islands in this geographical scheme is determined approximately by a series of rather pretty comparisons: (1) The folding is along two axes, one directed west-northwest and the other at right angles thereto, but of fairly open character as a rule, with dips elsewhere generally low over wide areas, and thus comparable with the Ceres-Clanwillian region, and neither with the Caledon-Riversdale sections nor with Argentina, where the first-mentioned set of foldings is dominant and intense; (2) the lower Devonian sandstones are gritty and pebbly, as in the Cape-Clanwilliam region or in Paraná, and not quartzitic, as in Mossel Bay or in the Sierra de la Ventana, moreover, the glacial horizon of the western Cape may, according to Baker, just possibly be represented in West Island; (3) the fauna of the Devonian shales in the Falklands is very closely related to that of the Bokkeveld, less so to that of Paraná; (4) the Devono-Carboniferous quartzites of the Falklands are identical with the Witteberg series of the Cape and not closely comparable with the greywacké phase of the Sierra de la Ventana; (5) the strongly cleaved tillite of the islands is slightly disconformable to these quartzites, as in Clanwilliam, whereas the glacials of the Río Sauce Grande are conformable to the strata below, just as in the south of the Cape (Worcester); (6) the tillite is of great thickness, with some intercalated shales, and hence like that of the southern Karroo and the Río Sauce Grande; (7) the Lafonian sandstone, just above the tillite, has no lithological representative in the Cape, but finds its equivalent in the Itararé series of Uruguay and Brazil; (8) the absence of the "*Mesosaurus* zone" links the islands with Argentina; (9) the great development of Lafonian sediments devoid of coals recalls the facies of the Sierra de Pillahuincó and the Karroo of the southern Cape rather than that of the northern Karroo or of Paraná; (10) the upper Lafonian beds show lithological resemblances with the upper Karroo and not the Triassic of South America; (11) the few dolerite intrusions suggest again the Cape-Clanwilliam region.

If we admit the displacement hypothesis, these affinities would collectively assign the Falklands to a position along the northern edge of the broad belt of foldings that linked the Cape with Argentina, but would place them somewhat nearer to Africa. Despite the fact that these islands rise from the Patagonian coastal shelf, and that the late Mesozoic foldings (Patagonides) strike southeastward near the Gulf of San Jorge, and therefore toward them, as remarked by Windhausen,[24] the Falklands, if we ignore the mere tectonic parallelism, display not the slightest affinities with Patagonia, where the late Triassic volcanics and sediments rest upon the crystallines, with no representatives of the Palæozoics. It must accordingly be concluded that this outpost of Gondwanaland belongs to the northeast rather than to the west and actually affords very striking support to the displacement hypothesis. The record by Schwarz of granite, probably from volcanic ejectamenta, in Tristan da Cunha is an indication of crystalline plutonics underlying part of the South Atlantic basin.

The north-south directed groovings beneath the tillite in the Falklands would lend a modicum of support to such an hypothetical ice-center situated out in the Atlantic, though impinging on Brazil, as indicated by the common absence of the glacials in the southern corner of that country, by the fluvio-glacials in Santa Catherina, Uruguay, and San Juan, and the marine glacials in Paraná and near Barreal in San Juan. The conditions in Goyaz and Matto Grosso are not yet known, while it is uncertain that ice formed at this date in Bolivia, since the glacials of the Bermejo series may perhaps be of Permian age.

In 1921,[25] I ventured to point out that the evidence in South Africa favored the deduction that the several centers had become glaciated in turn, the earliest on the west, the latest on the east. Both in New South Wales (Seaham area) and in San Juan *Rhacopteris* and *Cardiopteris* are present between the lowermost glacials, while such is not the case in Brazil, South Africa, India, Victoria, or Tasmania. Although the palæontological evidence on all these points is not as definite as could be desired, it would appear that glaciation commenced in the middle or early upper Carboniferous in the Southern Hemisphere in the Seaham area, extended to Argentina, then to South Africa, to the west of Australia, Tasmania, and India during the upper Carboniferous, and recurred during the early Permian in New South Wales and perhaps still later in Bolivia and the eastern Congo.

Under the displacement hypothesis, not only would all the areas affected be brought together in the most simple manner, within an oval perhaps no larger than the African continent, but the non-synchronism of glaciation in the several parts would find their explanation as the natural outcome of an extensive active ice-cap, the margins of which progressively advanced in one direction and retreated in the other, so that with time the sheet had as a whole *migrated over* the surface, glaciating various sections in turn, exactly

[24] Windhausen (1921*a*), p. 6.

[25] Du Toit (1921).

as seems to have been the case with the Pleistocene Ice Age in the Northern Hemisphere. This view would perhaps meet Coleman's well-founded criticism of the excessive size of the single ice-cap under this supposition.[26]

The causes of this intense refrigeration, lasting through about an entire geological epoch, are still largely speculative, but some additional suggestions may be thrown out. I had tentatively advanced the hypothesis of "eccentric ice-capping" to explain the growth and migration of ice centers, but a second aspect, not yet brought forward, is a possible variation in the crustal heat of the earth locally, all explanations having hitherto sought for such causes outside the lithosphere. Admitting the probability of Joly's theory of the connection between radioactivity and diastrophism, it would follow that periods of liquefaction of the subcrust and the abnormally rapid escape of internal heat by volcanism and hypabyssal injection would be succeeded by intervals of quiescence, endothermic reactions, and reduced heat transference. A certain section of the crust might thereupon come to have over a period an exceptionally low geothermic gradient, under which refrigeration would at least be facilitated, provided that climatic and other well-recognized predisposing agencies were concurrently present. That the entire crust of the globe should have been simultaneously affected in any such manner is, however, almost unthinkable.

CARBO-PERMIAN SEDIMENTATION

During the closing stages of glaciation, the upper Carboniferous ocean, with its characteristic *Spirifer* and *Productus* fauna, occupied the Amazon region, Peru, and Bolivia, and penetrated into the western part of the San Juan. In some extraordinary fashion, the remarkable *Eurydesma* fauna of the Salt Range and Hunter River area makes its appearance in Southwest Africa, though by what channel this specialized lamellibranch form reached this spot is unknown, but presumably via the Cape, for a route across Africa from Mozambique, while not yet proved impossible, is rather unlikely.

In southern Brazil, Uruguay, Paraguay, and western Argentina deltaic deposits were laid down, the "*Glossopteris* flora" flourished, and the coals of Brazil were formed; the areas marginal thereto received estuarine, lacustrine, or "basin" deposits, for example the Cape, Southwest Africa, and eastern Argentina. A deepening of the waters then drowned these deltaic or shallow-water deposits, except in western Argentina, Bolivia, and Africa north and east of the Cape, in which directions the ground presumably stood higher, and within this immense area of open water the black, sulphureted, and often limy muds of the Iratý-upper Dwyka shales were, as suggested by

[26]Coleman (1926), p. 260.

the writer, deposited in an estuary or land-locked sea like the Gulf of Bothnia.[27] The deeper, sulphureted waters were unfavorable to bathyal life and almost the only forms were fishes, the swimming *Mesosaurus*, and crustacea. The development of bedded limestones in São Paulo indicates communication in that direction with the northern Permo-Carboniferous ocean—a broad region of marine deposition in the Triassic after an intervening period of elevation and erosion.

In Natal, Transvaal, and Rhodesia[28] deltaic coal measures were laid down on an extensive scale, into which crept a few relics of the northern flora, introduced presumably by way of Brazil, though failing to reach Rhodesia or India. In the west and south of the Cape, in the Falklands, and in eastern Argentina the deposits were of the kind called "basin" by the writer for want of a better term—a monotonous succession of fine sands and silts, often ill-differentiated, with occasional "marls" and calcareous nodules, laid down on interior plains or in very wide and shallow depressions subject to flooding and desiccation like those of Turkestan. The conditions were, however, favorable for vertebrate life, as shown by the wonderful reptilian and amphibian fauna of the Beaufort beds of southern Africa, the forms appearing earliest in the southwestern corner of the Karroo and spreading thereafter to the northeast, through East Africa to Madagascar, India, and even Russia, accompanied by members of the *Glossopteris* flora.

THE PERMO-TRIASSIC MOVEMENTS

Hitherto crustal movements had been mild and generally in the vertical direction over this section of Gondwanaland, but at the close of the Permian a lengthy arc of compression (the Gondwanides) came into being, extending east-west through the south of the Cape, the Sierra de la Ventana, Sierra Pintada, and northward to the Puna de Atacama, the strata therein becoming crumpled and in places overturned to the north and northeast. That these may have been "coastal" ranges is suggested by the presence of marine Triassic and Liassic beds at a few localities *outside* the arc, whereas just inside the area inclosed by the latter—a "foreland"—only continental deposits have been found. During the early Triassic these border ranges were, however, actively eroded, so that in the later part of that epoch sediments and volcanics were being deposited unconformably upon the tilted Devono-Permian succession, both in the Cape and Argentina, to the south of the fold-belt in places upon the pre-Devonian basement, and to the north and northeast thereof upon only slightly disturbed Permian, and hence without marked discordance as a rule.

[27] Du Toit (1921).
[28] The conditions are more fully discussed by Du Toit (1926), Chapter XXI.

THE ARIDITY OF THE CLOSING TRIASSIC

The climate, which presumably had generally been warm and dry, appears to have finally become more and more parched, until toward the close of the Triassic the material being deposited over wide areas in Brazil, Uruguay, Paraguay, and the southern half of the African continent consisted of fine-grained, cream, pink, or red sands, sometimes with well-rounded and polished grains and with marked false-bedding, stuff which must largely have been of desert origin, *e.g.*, the Botucatú and Río de Rasto in the Paraná Basin, the Forest-Bushveld-Cave sandstone of the Union, Southern and Northern Rhodesia, the Lubilache of the Congo basin, and probably the Adigrat beds of Abyssinia, covering areas totaling several millions of square kilometers.

Lithologically these various deposits in no small degree resemble the Quaternary Pampean loess of Argentina, with its prevalent pinkish, sandy material with calcareous concretions, largely windborne in its origin and of great thickness in places; in other respects the Tertiary-Quaternary Kalahari beds of Bechuanaland, with fluviatile and dune sands overlying in places marls, clays, and some conglomerates. The fact that the conditions in Europe during the closing part of the Triassic were largely desert would almost suggest a period of universal desiccation, although animal life could by no means have been scanty. Fluviatile and lacustrine phases have yielded the well-known *Thinnfeldia* flora (together with *Estheria*), significantly on the margins of this gigantic region, *i.e.*, western Argentina, Chile, Cape Province, peninsular India, Tonkin, New South Wales, Queensland, and Tasmania.

THE MESOZOIC ERUPTIONS

Outstanding too, is the enormous scale of the basic effusions at the close of the Triassic, under which vast territories in the two continents were flooded with basalts, in places to depths of over 1,000 meters, *i.e.*, the Paraná basin, the limited region in Maranhão, the much-dissected relics in western Argentina, together with extensive outpourings, mainly of acid character, in Neuquén and Patagonia, the Stormberg lavas of the Union of South Africa, Lebombo, Southern Rhodesia, lower Zambezi Valley, and Kaokoveld. In practically every case thin sedimentary intercalations are to be found in the basal part of the volcanic groups, certain of which indicate the persistence of arid conditions.

Conspicuous too are the accompanying sills and dikes of dolerite (diabase) that, avoiding the folded region, ramify through the Gondwana beds or penetrate the basement in the Karroo region, the Zambezi Valley, Tasmania, Antarctica, the Paraná basin, and possibly Guiana, and that were injected during or immediately after the eruptive phase, probably during the Liassic.

THE JURASSIC TRANSGRESSION

The upward transfer of these enormous volumes of magma led to instability along the borders of Gondwanaland and to the transgression of the Liassic and Jurassic ocean across its margins, and the breaking-up of that continent seemingly dates from this period. We find fossiliferous marine beds with dolomite and gypsum in Tunis and Abyssinia, a wide development of Jurassic through British East Africa, Tanganyika Territory, and Madagascar, while on the opposite side of the land-mass about the border of Chile and Argentina the Liassic is characterized by eruptive matter—rhyolite, dacite, and spilite—while marine beds of this epoch covering many stages were laid down along an enormous stretch of the Andine region.

THE CRETACEO-TERTIARY

It is a striking fact that no early marine Cretaceous should fringe the coasts either in the section between Bahía Blanca and Bahía or that between Cape Agulhas and Angola, suggesting, indeed, that the two continents may have still been united at the commencement of that epoch, although Madagascar and India must almost certainly have parted from Africa by that time. The early Cretaceous ocean nevertheless assuredly trespassed over the southern extremity of Africa, and also covered parts of Neuquén and the Andine region.

The mid-Cretaceous, so far as can be elucidated the Turonian, saw a great renewal of orogenic movement in Africa, directed east-west over the wide belt traversed by the earlier Cape foldings, with considerable marginal fracturing both there and in the Natal-Zululand coastal area. Evidence of synchronous crustal movements has been discovered in Neuquén, with arc-like flexures bridging the gap between the Gondwanides and the (posthumous) Andine foldings, while correlated flexures strike southward through Chubut, curving eastward to the mouth of the Río Deseado, disturbances that have been called the "Patagonides" by Windhausen.[29] Then came a period of extensive erosion, after which the later Cretaceous ocean transgressed into those regions, entering by an arm situated between the Sierras of Buenos Aires and the Patagonian platform, as far inland as the Sierra Pintada.

The weight of evidence would ascribe the base-leveling in the Sierra de la Ventana and the accumulation of the "high-level gravels" to the well-established Eogene transgression that followed the first phase of the Andine movements, while the upheaval thereof would synchronize with the second phase and, preceding the "Paraná" ingression, date from the early Pliocene. The correspondence with the southern Cape is hence remarkably close.

[29] Windhausen (1924), p. 202.

A wealth of information will be found in the writings of Windhausen on the palæogeography of northern Patagonia, the outstanding item being the fact that the Cretaceo-Tertiary (San Jorge) fauna of the Río Negro and Chubut is of South Atlantic and Antarctic facies and does not show North Atlantic affinities.

The little that is to be gleaned from Eastern Brazil is confirmatory. The late Tertiary lacustrine deposits stand at a relatively high level, *e.g.*, Curitíba, São Paulo, and near Diamantina, and point to a comparatively recent uplift, while the physiography of the Parahyba Valley between São Paulo and Río de Janeiro strongly suggests that the lengthy crystalline chain of the Serra da Itajubá running parallel to the coast is a fault scarp with downthrow on the ocean side. In South Africa, too, the general movement of the continent has been in an upward direction to the amount of several hundred meters.

THE ANDINE MOVEMENTS

Under the displacement hypothesis the South American continent is viewed as having proceeded to drift westward during the latter part of the Mesozoic, crumpling up in its path the marine sediments bordering the western side of the Brazilian "shield," a process that led to the extravasation of magma and the injection of hypabyssal and plutonic matter into that belt of extreme compression and of upheaval. The Tertiary foldings and overthrustings, directed usually toward the east, that characterize the Cordillera and extend from Venezuela to Terra del Fuego, find their explanation in logical fashion under this hypothesis, the eruptive matter being regarded not as the cause of such movements, but as the product of such compression upon the zone underlying this belt of crumpling, an action that has, moreover, not yet ceased.

Hindered by the birth of these western ranges, the drainage of the continent would have been reversed, while the spasmodic elevation of the chains would have caused oscillations in the level of the slowing earth-block and encroachings and retreats of the waters of the Atlantic. In the broadening gap between Africa and South America the presumably basaltic ocean-floor with its accumulating mantle of pelagic deposits would normally have been in tension, and foundering of sections thereof is a possibility that can be invoked to explain the volcanicity of the South Atlantic basin, as exemplified by its many volcanic islands.

Much could be written on the Tertiary history of this vast ocean basin having an intimate and vital bearing on the subject under review, but enough has, I venture, been set down to impress the reader with the exceptionally illuminating and outstanding character of this stimulating theory of earth structure, undoubtedly the most fascinating of geological hypotheses to-day.

CHAPTER VII

BEARING ON THE DISPLACEMENT HYPOTHESIS

While the general geological resemblance between those portions of the two continents that face the South Atlantic basin has long been perceived, the outcome of these present studies is essentially to emphasize this geological parallelism, which is nothing less than extraordinary, considering the enormous stretches of ocean parting these two land-masses.

Such points of resemblance have now become so numerous as collectively almost to exceed the bounds of coincidence, while they are, moreover, confined not to one limited region nor to one epoch, but implicate vast territories in the respective land-masses and embrace times ranging from pre-Devonian almost to the Tertiary. Furthermore, these so-called "coincidences" are of a stratigraphical, lithological, palæontological, tectonic, volcanic, and climatic nature.

Of prime importance, moreover, is that evidence obtainable from the study of the phasal variations displayed by particular formations when traced within their respective continents.

In illustration, let us consider the case of two equivalent formations, the one in South America beginning on or near the Atlantic coast at A and extending westward to A' and the other in Africa starting similarly near the coast at B and stretching eastward to B'. Then it can be affirmed that more than one such instance can be designated, where the change of facies in the distance AA' or BB' is *greater* than that found in AB, although the full width of the Atlantic intervenes between A and B. In other words, these particular formations along the two opposed shores tend to resemble one another more closely than either one or both of their actual and visible extensions within the respective continents. With the multiplication of such examples, drawn from more than one geological epoch, such a singular relationship can no longer be regarded as wholly fortuitous and a definite explanation therefore has accordingly to be sought. An analysis, moreover, shows that this unexpected tendency is equally marked, whether the formations involved be marine, deltaic, continental, glacial, eolian, or volcanic.

If, on the other hand, the two land-masses are pictured as having been moved closer together, as in Figure 7, a great number of observations and deductions are now found to be brought into apparent harmony, and these possible "coincidences" are disposed of in the simplest fashion.

This is precisely what the displacement hypothesis effects, thereby providing a simple explanation of many otherwise puzzling observations. The fact that many eminent scientists have cast doubt upon its geophysical possibility should not be permitted to cloud the issue any more than that the existence of former "land bridges" should be denied because of cogent objections based upon the doctrine of isostasy.

It is not proposed to discuss here the physical basis of that hypothesis, nor is it desired to deal with this problem as a whole, such as has been done by Wegener.[30] The intention is merely to set forth some of the data regarding Africa and South America and to state the conclusions to be drawn therefrom, that are distinctly awkward of explanation under the current and orthodox view of "land bridges," but which, on the contrary, appreciably favor the "hypothesis of continental disruption." Incidentally, some few observations will be made having a bearing upon other parts of Gondwanaland, that in turn suggest lines of future research in those particular countries.

Of prime importance is the extraordinarily close correspondence in the outlines of the opposed shores of the two continents, as has been pointed out and discussed by others long before Wegener, and which is particularly marked when comparison is made not with maps, but on the face of a terrestrial globe. Next is the presence of the central Atlantic rise beneath the ocean, with its surprisingly symmetrical position nearly midway between the Old World and the New.

Interpreted *mathematically*, the great regularity of these three features, extending through the entire length of the South Atlantic, would betoken an *enormously high probability* that such features had owed their origin to one and the same set of tectonic forces at a relatively late geological period. Upon this rise are, furthermore, aligned certain of the volcanic islands of the southern Atlantic. This otherwise profitable subject must, however, be relinquished in favor of the more momentous geological aspect.

Commencing in the south, the following relationships can be considered as more or less established:

(I) The section south of Bahía Blanca and that below the Zuurberg in the Uitenhage district show several points of agreement in that: (*a*) The upper Triassic (1) is predominantly of volcanic origin, (2) rests discordantly upon Permian or older beds that are affected by Permo-Triassic movements, (3) is influenced by mid-Cretaceous disturbances following more or less the older tectonic axes, and (4) is overlain by marine Cretaceous and Tertiary, the former of which contains variegated clays and is in places gypsiferous. In the Cape the volcanics are, however, basic, in Argentina largely acid, though in Mendoza and San Juan basaltic flows are represented. (*b*) The lower Cretaceous in northwestern Neuquén on the southern side of

[30] Wegener (1924).

the "Gondwanides" contains a typical "Uitenhage" invertebrate fauna, this being the only part of South America where such a faunal assemblage has yet been found, and like that in the Sundays River Valley has been tilted before late Cretaceous times. (*c*) There are great developments of nearly flat marine Tertiaries from Eocene to Pliocene in age, in which most strikingly an "Atlantic" fauna is not at all or only partially represented.

(II) The ranges north of Bahía Blanca undoubtedly correspond with the Cape Fold ranges, in each case showing: (*a*) Intense folding, with overturning toward the north or northeast, strata up to the Permian being involved. (*b*) The quartzites of the Sierra de la Ventana correspond lithologically with the Table Mountain sandstone of the region about Mossel Bay and George. (*c*) The fossiliferous Devonian is like that of the latter region, but the equivalent of the Witteberg series is composed of greywackés instead of hard white quartzites. (*d*) The thick, folded and cleaved glacials in Argentina duplicate the characters of the Dwyka tillite and are conformable with the beds below, as in the Cape south of latitude 33° S. (*e*) In Argentina, dark shales overlie the glacials, as in the Cape, and pass up into beds like the Ecca of the southwestern Karroo, only somewhat more quartzitic, but in the first-named, just as in Pondoland, the horizon with *Mesosaurus* is not recognizable. (*f*) Dolerite intrusions are absent in each case. (*g*) Consolidated ferruginous "gravels" rest on bevels cut across the folded beds on the northern flanks of the Sierra de la Ventana and duplicate in most extraordinary fashion the early Tertiary "high-level gravels" of the south of the Cape, having similarly been raised and dissected at a subsequent date. (*h*) Traced northwestward from Sierra de la Ventana into San Juan and Jachal, the lower Devonian quartzites have become darker and less like the Table Mountain sandstone, the fossiliferous slates greener, the equivalent of the Witteberg is apparently represented by grits and greywackés, the glacials now rest unconformably on the older divisions and show characters very different from those in the Cape, at the same time becoming compound; the plants include northern Carboniferous forms, while the succeeding strata, the equivalent of the Ecca, become quite unlike those of the western Cape.

(III) To the northeast of the Sierra de la Ventana the "Gondwanides" are fading out, and at Olavarría and Tandil the pre-Devonian rocks are only slightly affected by them, though a folding transverse thereto, trending northeastward, can be made out, thus paralleling the conditions between Clanwilliam and Namaqualand. Closer comparison is impossible, since the Pampean of the lower ground round about conceals these older groups.

(IV) Comparing the region stretching from Uruguay to Minas in Brazil with that between Clanwilliam and the Kaokoveld, we find: (*a*) The almost horizontal Furnas sandstone of Paraná is similar to the equivalent Table Mountain sandstone of Clanwilliam and Van Rhynsdorp. (*b*) Each is thinner and softer than in the south and each carries small quartz pebbles. (*c*) Each is succeeded by the marine Devonian shales with calcareous nodules—Ponta Grossa shales and Bokkeveld beds—with closely allied austral faunas. (*d*) The soft Tibagý sandstone with *Spirifers* duplicates the "Fossiliferous sandstone" of the Bokkeveld of Ceres and Clanwilliam. (*e*) The base of the Itararé glacials is unconformable and transgressive, exactly as is the case with the Dwyka in Calvinia, which stratigraphical relation is maintained toward the north. (*f*) There is irregularity in the character and thickness of the glacials in each country, owing to the uneven nature of the floor, etc. (*g*) The glacials are absent at the base of the Gondwana system in Río Grande do Sul and in Santa Catherina, just as in parts of the Transvaal. (*h*) A southeasterly source is presumed for the Brazilian glacials, a northerly, northeasterly, and perhaps northwesterly origin for those in the western Cape and in Southwest Africa. (*i*) The Iratý shales are identical lithologically and palæontologically with the White band of the Dwyka, each containing the reptile *Mesosaurus*, not known in other parts of the world. The South African formation is fully developed from Robertson across to Grahamstown and northward to Mariental, but is not represented in Natal, the Transvaal or about Palapye; the South American extends from Uruguay to São Paulo and westward into Paraguay, but is unknown in the bore-holes in Argentina west of the Paraná River or in Bolivia. Thus the basin within which this uncommon type of originally organic sulphureted mud was deposited is fairly well defined and must have formed an estuary opening probably to the north, where the facies becomes calcareous, a conclusion to which the presence of a marine phase in the glacials in Paraná and Southwest Africa would give support. (*j*) An important difference is to be found through the Brazilian Bonito or "coal measures" underlying this horizon, whereas the Natal and Transvaal Ecca "coal measures" succeed the latter, but I should like to record that in the western Karroo I have found a zone of gray fissile sandstones such as is unrepresented farther to the east or northeast, in corresponding position in the upper Dwyka shales. Presumably the Bonito is a deltaic phase that "invaded" the basin in which the "post-glacial" deep-water shales were being laid down. (*k*) The Estrada Nova, which shows resemblance to stages II and III of the Paganzo, but not to the presumably equivalent horizon of Bolivia, strongly recalls the Ecca of southwest Africa, which again is widely different from that of the Cape, Transvaal, and Rhodesia. Silicified wood is common in both countries, but marine mollusca of this age have not yet been found in South Africa. (*l*) The higher Permian beds are apparently absent from the Paraná basin and from Southwest Africa, which has seemingly been the result of the positive earth movements at the close of the Palæozoic. (*m*) The São Bento series is pseudo-conformable to the underlying strata in the Paraná basin, just as the Stormberg series rests without angular break upon the upper Beaufort series in the north of the Orange Free State or upon the Ecca in the central Transvaal. (1) Each series transgresses across the lower Gondwanas, *i.e.*, along the margins of the Paraná basin and in the region lying to the north and northeast of the Cape Province; (2) strata with the "*Thinnfeldia* flora" are developed toward the base, almost solely in the south, *i.e.*, in the Cape-Basutoland region and in western Argentina and the fresh-water crustacean *Cyzicus* (*Estheria*) *draperi* is common to both these areas; (3) the brilliantly colored Río do Rasto parallels the Stormberg Red beds and Bushveld marls and like the latter formations contains dinosaurian remains belonging to allied forms; (4) the Botucatú and uppermost portion of the Río do Rasto agree lithologically with the Cave-Bushveld-Forest sandstone, all of which have been formed largely by eolian agency under an arid climate; silicification of the sandstones is common; (5) the succeeding and widespread volcanics are interbedded in their basal portions with thin sandstone bands or tufaceous sandstones; (6) the only places where the volcanics form the actual coast are near Torres and in the Kaokoveld respectively; (7) the lavas are basalts with but little olivine or else basaltic andesites, but, while ophitic and subophitic structures are the rule in the Cape, a porphyritic structure is occasional in southern Rhodesia and is dominant both in the Kaokoveld and in the Paraná basin, while tuffs are rare. They show bands of pipe-amygdaloid and were evidently poured out in rapid succession, apparently under a dry climate and presumably from fissures, for except in the Basutoland region volcanoes are practically unknown; (8) these effusions terminate the succession in both countries. (*m*) Widespread injections of dolerite characterize the flat-lying Karroo of the Cape, Natal, and southwest Africa and also the Paraná basin, but are not found in the south of the Cape, northern Transvaal, or Southern Rhodesia generally, nor in southern or western Argentina. (*n*) Marine Jurassic and Cretaceous beds are absent from along the opposite coasts. (*o*) Kimberlite and melilite-basalt of presumably late Cretaceous age pierce the strata in the form of pipes both in South Africa (for example, in Namaqualand and the Gibeon district) and in eastern Brazil (for example, in the Serra das Lages 100 km. from Río de Janeiro,[31] and at Patos, in the western half of Minas, where a neck penetrates Triassic sandstone). (*p*) The Cretaceous of east-central Brazil is largely a conti-

[31] Rimann (1915).

nental deposit covering a huge region in the interior, overlapping the São Bento volcanics and paralleling in certain ways the extensive Kalahari beds of southwest Africa. (*q*) The detrital diamonds of southwest Africa that have been derived from Tertiary marine beds near Lüderitz are quite unlike those won from the kimberlite pipes of South Africa, but show crystallographic and physical points of resemblance with the gems obtained in eastern Brazil from gravels or from pipes, such as the Bôa Vista Mine, piercing the Espinaço quartzites and apparently of pre-Gondwana age. (*r*) The pre-Devonian beds consist of quartzites, limestones, and slates folded along axes roughly parallel to the respective coasts and injected in places by granitic bodies, *i.e.*, the Bambuhy and Assunguy series, at intervals from Bahía to Uruguay, and the Nama system from Lüderitz to Cape Agulhas. (*s*) Brouwer has called attention to the presence of several centers of alkaline rocks, both plutonic and effusive, on either side of the Atlantic, for example, in Southwest Africa the important group of foyaites of the Granit Berg, etc., and the phonolites of the Klinghardt Mountains near Lüderitz, and in Brazil the well-known Poços de Caldas north of São Paulo, the various similar occurrences in the State of Río de Janeiro, such as the Serra de Gericinó, Serra de Tingua, Cabo Frio, etc.

(V) Proceeding farther north we find: (*a*) Opposed to the disturbed area of Cretaceous and Tertiary of Angola and Loanda are those of Bahía and Sergipe, in which their equivalents, with similar faunal elements of the Atlantic and Mediterranean types, display somewhat less tilting. (*b*) Inland therefrom in Brazil are the folded Permian and probably Carboniferous Estancia beds, with some resemblances to the Kundulungu of the lower Congo region, while beneath the latter lies a great calcareo-dolomitic formation, which may perhaps be compared with the ancient limestones of Bahía.

(VI) Farther north is found a belt of Cretaceo-Eocene along the coast from Natal westward that rises up to form the plateau along the boundary of Ceará with Piauhý and is seen again in the northern part of Maranhão. These strata can be compared with the beds of approximately similar age in the coastal portions of Gold Coast, Dahomey, and Cameroons, extending up the valleys of the Niger and Benue and occupying a wide area to the north. In Nigeria the Cretaceous is somewhat folded and faulted. Reference might be made to the well-known volcanic line of the Cameroons that extends southwestward into the ocean, in view of the presence off the corner of Brazil of the phonolite island of Fernando Noronha.

(VII) The Gondwana outlier of Maranhão and Piauhý constitutes a fairly close parallel with the development known as the Lubilache in the western part of the Congo Basin in (*a*) the absence of the glacial group, (*b*) the absence of coals, (*c*) the equivalence apparently of the upper red sandstones of Brazil with the cream and red friable sandstones in the Congo. Mesozoic volcanics are, however, not yet known in west-central Africa, whereas the Brazilian strata are overlain by basalts and penetrated by dolerites.

(VIII) The Silurian and Devonian strike south-southwestward through the Sahara and southwestward through West Africa, with isolated patches of the latter system in Gold Coast Colony, and are apparently not much disturbed generally, a condition that can be paralleled with the corresponding systems forming the syncline of the lower Amazon Valley resting on the Archæan granite, with trend oblique to the coast-line, the more so in that the Devonian in each case includes, in addition to European elements, some North American forms, and also displays certain important affinities with the austral fauna. Presumably land lay to the south, and along that Devonian coast migration was possible toward Europe in the one direction and toward Amazonas, Matto Grosso, and Bolivia in the other. A point that might be noted in view of the diamondiferous deposits of the Guianas is the frequency with which that gem occurs in the coastal belt of West Africa, *e.g.*, in Liberia and Gold Coast.

While the above can be taken as merely summarizing the evidence on the subject, it will be clear to all acquainted with the literature that many other points of similarity or else of analogy could readily be discovered in the geology of these two land-masses. Sufficient, I venture to think, has already been set down to bring out the astonishing geological agreement between more or less comparable sections of the respective coastal zones, from which it will be conceded that the evidence so far would distinctly appear to favor the displacement hypothesis rather than orthodox ideas. It is nevertheless highly desirable that more impartially minded persons should criticize the data here given and judge whether those amazing resemblances have been correctly interpreted or whether some more rational explanation for them could not be formulated.

Accepting provisionally this hypothesis, it will next be instructive to attempt some graphic representation thereof.

Regarding the various possible dispositions of the continental masses, it can first of all be remarked that actual contiguity of the opposed shore-lines can most definitely be ruled out, and, secondly, that even apposition of the borders of the continental shelves, as favored by Wegener, may perhaps hardly be warranted, for utilizing the line of reasoning based on *phasal variation*, the differences actually noticed between the various facies of the equivalent formations where they come closest together are of such a degree as to demand a fairly wide gap. *One of the order, perhaps of from 400 to 800 km., would indeed seem to be needed, if all the observed phenomena are to be satisfactorily accounted for.*

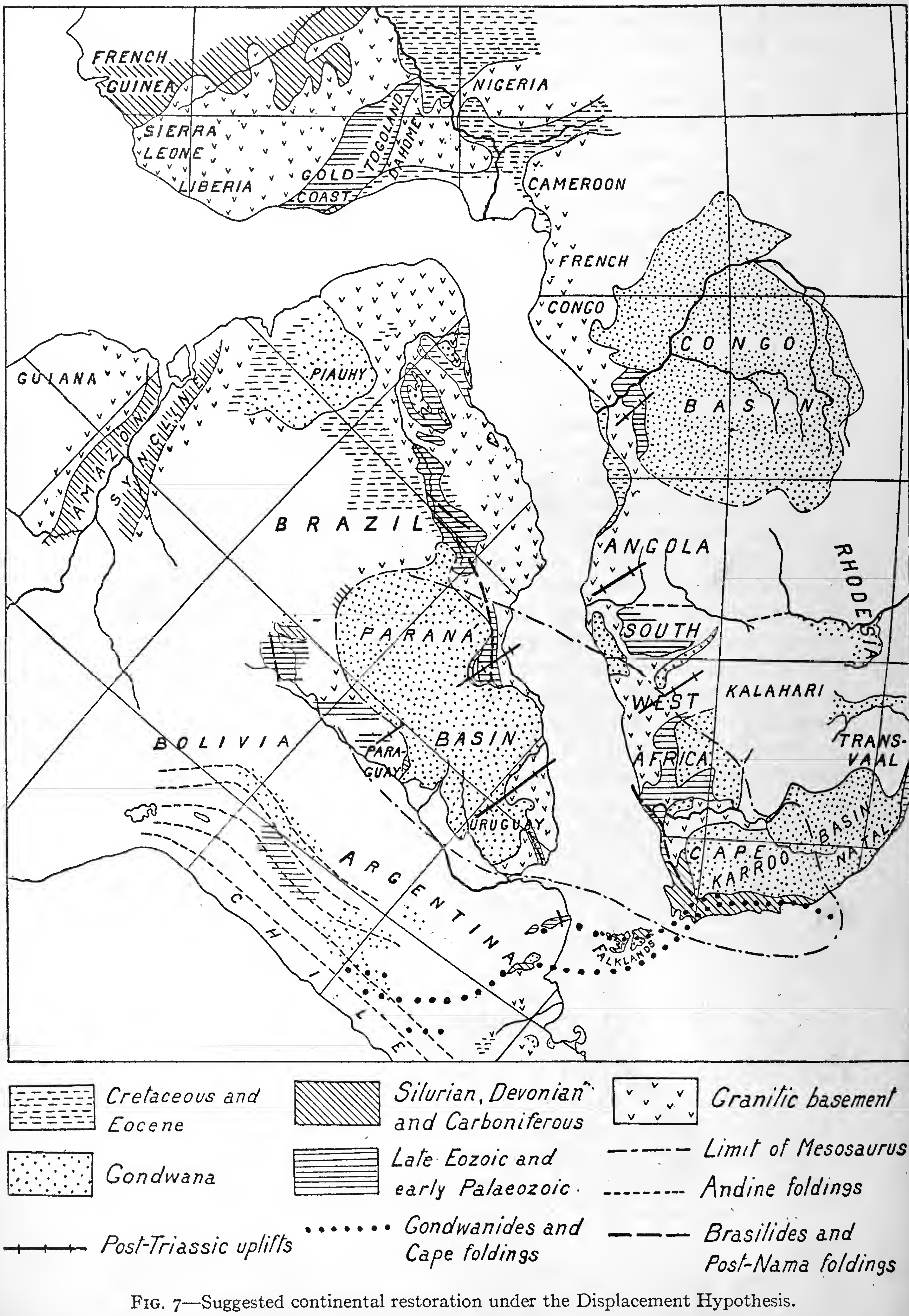

FIG. 7—Suggested continental restoration under the Displacement Hypothesis.

Such is schematically represented in Figure 7, which is tentatively suggested as perhaps best meeting the needs of the case, though the intervening space is actually a little less than the phasal variations would rightly demand.

Further critical comparative studies should enable a better orientation to be made, the diagram advanced being admittedly only a first approximation. Granted, too, that such crustal slipping could have taken place, it must not be overlooked that some regional distortion might have resulted during the drifting apart of the floating continental blocks, an action inferred from the inflection of the Andine foldings in the neighborhood of Cape Horn.

It will be noticed that in this figure the Falkland Islands have, following the discussion in Chapter VI, been moved up into a position between Cape Town and La Plata. Only now can the remarkable correspondence of the various fold-lines, and even of the more moderate archings, of different ages be properly appreciated. The rupture of the Afro-American mass is also more than hinted at in the strict parallelism of the zigzagging of the two coast-lines near Río de Janeiro and Angola respectively. It is surprising, too, though not deliberately arranged, that the space between the two shores should correspond so closely in its two boundaries with the plan of the "central ridge" of the South Atlantic. These two sections of coastline, it should furthermore be noted, are composed of crystalline rocks, whereas both to the north and south considerable stretches can be found where late Tertiary and Quaternary marine sediments fringe the shores and consequently tend to obscure the original outlines of the supposedly fractured masses.

Further elaboration is hardly necessary, and the diagram is accordingly left to the criticism of the reader.

CHAPTER VIII

CONCLUSIONS

Throughout this work the intention has been to detail the geological peculiarities of the opposed sections of the two land-masses, to point out their resemblances and differences, and to draw such legitimate conclusions in regard to the geographical, climatic, and other circumstances in each country as the facts would appear to the writer to warrant, though irrespective of any particular theory of continental union during the past, for that they were so united is indicated by a wealth of evidence of a practically indisputable character.

But, having proceeded thus far, one could scarcely avoid making use of these data and indulging in a certain amount of speculation as to their possible manner of union during the later Palæozoic and early Mesozoic eras. Such an analysis, it can be affirmed, does *not* favor the notion of one or more relatively narrow connecting links or "land bridges" lasting down into the early Mesozoic, but on the contrary supports the presumption of some continuous land area embodying those sections of Gondwanaland that are now represented in the two continents. It furthermore strongly favors the admittedly revolutionary idea that geographically these two portions were appreciably closer in the past; indeed, the evidence is, I think, of sufficient weight to warrant such a viewpoint being adopted, as a working hypothesis at any rate. Upon studying the remnants of Gondwanaland in the other continents—India, Australia, etc.—we find the facts and the deductions therefrom in similar accord, and the impression becomes decidedly strengthened that the displacement hypothesis, if not an actual explanation of the phenomena, would at least seem to contain more than a germ of the truth, despite its revolutionary and heterodox nature and apparent lack of agreement with geophysical considerations.

Nevertheless, as already remarked, *geological evidence almost entirely* must decide the probability of this hypothesis, for those arguments based upon zoö-distribution are incompetent to do so, being as a rule equally, though more clumsily, explicable under the orthodox views involving lengthy land connections afterward submerged by the oceans.

The hypothesis sets forth to explain in simple and logical fashion a host of problems—geological, palæontological, tectonic, climatic, and biological—that have hitherto proved difficult or impossible of satisfactory solution, and is incidentally serving to stimulate geological thought in fashion almost unparalleled in the history of that science. For example:

(1) It condenses all the sections of Gondwanaland with their markedly similar formations and geological histories within the compass of *one moderately sized continent*, instead of demanding a land-mass very much larger than Eurasia.

(2) It brings into close association *away from the equator* all the areas glaciated in the "Permo-Carboniferous" and thus succeeds in eliminating an outstanding difficulty in necessitating somewhere or other a refrigeration in the subtropics or tropics, a trouble inherent under any other hypothesis, even in those postulating a wide movement of the South Pole.

(3) It can explain the apparent *non-synchronism of glaciation* in the several sections and many other observed peculiarities as primarily due to the progressive migration of the main ice center or centers.

(4) It simplifies the problem of the distribution of the "*Glossopteris*" and "*Thinnfeldia*" floras.

(5) It brings together the wide areas over which arid conditions seem generally to have prevailed at the close of the Triassic. In making a review of this problem nothing is more conspicuous than the tendency under the orthodox viewpoint of overlooking the enormous improbability that over widely separated parts of the globe, situated in different latitudes and longitudes and under totally differing oceanic environments (and therefore of atmospheric distributions) there should have coexisted huge areas throughout the entirety of which the climate should consistently have at any one epoch been either frigid or pluvial or arid.

(6) It assembles the earlier Mesozoic lava-fields.

(7) It would explain Gondwanaland as a well-defined and almost isolated unit down to about the end of the Jurassic epoch, after which the continental mass is viewed as proceeding to break up and the sectors to begin drifting apart, with the Cretaceous ocean progressively penetrating between the blocks and generally coming to overlap their borders in the fully established marine transgressions of the late Mesozoic.

In the hypothesis as formulated by Wegener, the New World is regarded as having parted from the Old up the full length of the Atlantic from south to north at quite a late stage in the Tertiary, against which supposition many objections could be raised. Elsewhere[32] I have tentatively suggested the radically different conception of *two* such parent continents, that to the south being Gondwanaland, which, by impinging on each other, gave rise to the enormously extended orogenic structures made by the Atlas, Alps,

[32] Du Toit (1921*a*).

Carpathians, Caucasus, Himalayas, etc., or, as Suess has called them, the "Posthumous Altaides." Concentrating attention upon the southern continent, it can be pointed out that one of the determining factors in the conjectured breaking up of the mass may have been the development around the continental "shield" of the peripheral trough of subsidence or "fossa," within which sedimentation had proceeded through lengthy periods during Palæozoic, Mesozoic, and even Cainozoic times, whereby an engirdling zone of crustal weakness would have been produced favoring the centrifugal separation postulated.

These encircling oceanic deposits would thereafter have been pushed up into folds in advance of the drifting crustal sectors, a process that would ultimately have served to arrest their outward movement, for, in conspicuous fashion, excluding "Angaraland," all the known portions of Gondwanaland now lie within a practically closed orogenic ring constituted by the Atlas, south European, Iranian, and Himalayan folds on the north, the Malay, Polynesia, and New Zealand crumplings on the east, the west Antarctica belt on the south, and the Andine flexures on the west, curving eastward into Venezuela. Along certain sections of this "orogen," to use Kober's term, intense compression and overthrusting then took place, accompanied by considerable magmatic activity.

Such a view would, moreover, serve to explain the temporary reunion of certain of the continents at some stage in the Tertiary, as the facts of zoögraphical distribution would apparently demand. A rather similar process is conceived to have operated in the Northern Hemisphere, where the continental fragments lie within a great oval ring of mainly Tertiary foldings, from Mexico to Alaska, Japan, the Himalayas, and onward as before. These two orogenic belts are pressed together in the section extending from the West Indies to the East Indies, in which two regions distorted arcs with marked inflections have originated from their supposed mutual interference. As will be observed from a map, these two orogenic "fossæ," when rolled out into one plane, come to resemble a figure **8**, while the remainder of the surface of the globe constitutes the immense basin of the Pacific, along the margins of which the two fold-systems have crowded.

SOME GENERAL REMARKS

These pages have of necessity dealt in very summary fashion with this fascinating subject, more particularly as related to those territories beyond the respective opposed regions known personally to the writer. It is therefore to be hoped that scientists acquainted with those particular outside regions may be induced to set down their observations on those areas, supporting or else refuting the presumptions here put forward on behalf of this hypothesis, since a strict and impartial criticism is indeed required if this riddle in early history is to be deciphered. The coöperation of geologists, palæontologists, zoölogists, botanists, and physicists is urgently needed, the discussion advanced here dealing admittedly with only a very limited, albeit extremely important, section of the globe, from which, under the eclectic hypothesis of crustal instability, corroborative or destructive evidence might reasonably be expected. By virtue of their enormous lengths of opposed coast-line and extraordinary geological parallelisms, the two most favored continents from which evidence is to be drawn would appear to be Africa and South America, and, should the details herein set forth appear to be worthy of serious consideration, it is to be hoped that more detailed investigations may shortly be instituted elsewhere on the two sides of the Atlantic for the purpose of clearing up some of the many crucial questions that must be regarded as *sub judice*.

Even if the facts collected should cause the displacement hypothesis to be discarded, the researches made through its stimulus would have served a most useful purpose in establishing data for the fuller comprehension of this problem of the past history of our planet.

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APPENDIX

UPPER CARBONIFEROUS FOSSILS FROM ARGENTINA

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With four plates

GENERAL REMARKS

The fossils submitted to me by Doctor Du Toit from the Quebrada del Salto, Barreal, San Juan, Argentina, are mostly preserved in a tough purplish sandy mudstone rather than shale, with an irregular subconchoidal fracture, and, though often fragmentary and imperfect, are occasionally in a good state of preservation.

R. Stappenbeck,[1] in 1911, recorded the following fossils from the same locality and apparently from the upper of the two fossiliferous horizons herein discussed, which he referred to the stage of *Spirifer supramosquensis*, a Russian species which Nikitin regarded as characteristic of the Gshelian:

Spirifer supramosquensis Nik.
Productus cora D'Orb.
Productus lineatus Waag.
Productus pustulatus Keys.
Orthis sp.
Chonetes sp.
Platystoma sp.
Pleurotomaria sp.
Euomphalus sp. aff. *parvus* Waag.
Orthoceras sp.
Cyathocrinus sp.
Bryozoa.

No description or figures of the species were given, and there has not been, to the best of my knowledge, any later account of the fauna.

In the succeeding descriptions the figures 7281 to 7376 represent the catalogue numbers of the specimens, which are preserved in the South African Museum at Cape Town.

DESCRIPTION

Fenestella aff. *perelegans* Meek

Most of the specimens of *Fenestella* in this collection are poorly preserved and fragmentary and only in one case is the poriferous face well preserved. In this specimen (7324) the branches are subparallel, the dissepiments slender and equidistant, the fenestrules rectangular and oblong, being about 1½ times as long as wide and 9 to 10 occurring in a distance of 10 mm.; there are 4 to 5 rather widely spaced small cells to each fenestrule, one of the cells usually lying at the base of the dissepiments, and the low median carina bears a row of much smaller pores (or hollow tubercles) numbering 7 to 9 to each fenestrule. The reverse face is rather coarsely striated longitudinally. The poriferous keel occurs in many species of the genus and was figured by McCoy[2] in *F. formosa* from the Carboniferous limestone of Ireland. But it is on upper Carboniferous horizons that this type of *Fenestella* is most common, and we may especially compare our form with *F. perelegans* Meek[3] of the coal measures of Nebraska, but also recorded by Waagen and

[1] Stappenbeck, Geol. Aufbau d. Vorkordillere, Geol. u. Palæont. Abhandl. N. F., Bd. IX, Heft 5, 1911, pp. 31, 32.

[2] McCoy, Syn. Carb. Foss. Ireland, 1844, p. 201, Pl. XXIX, Fig. 2.

[3] Meek and Hayden, Final Rept. Nebraska, 1871, p. 153, Pl. VII, Figs. 3 to 3*d*.

Pichl[4] from the *Productus* limestones of the Salt Range. There are also several allied Russian species from the upper Carboniferous, such as *F. saraneana* Stuck.[5] and *F. eichwaldi* Stuck.,[6] and the author[7] has described a form allied to the latter species from the upper Carboniferous of Chitral. *F. laosensis* Mansuy,[8] from the Permo-Carboniferous of Indo-China, may also be compared.

Fenestella sp. ind.

Among the fragments of zoaria of *Fenestella* occurring in the collection there seems to be another species (7306, 7307) characterized by its finer mesh-work, 12 to 16 fenestrules occurring in a distance of 10 mm. The reverse face is longitudinally striated, but the poriferous face is unknown and the affinities of the species are therefore uncertain.

Polypora aff. *biseriata* Ulrich

A species of *Polypora* is represented by several poor and fragmentary specimens (7286, 7285, 7311, 7295, 7298). The one (7286) which has the celluliferous face of the zoarium best preserved shows also portions of the reverse face. The zoarium consists of subparallel, thick, straight branches, frequently bifurcating and bearing two rows of rather large alternating cells, with an additional one usually at the base of each dissepiment. Traces of a median line of small nodes can be occasionally detected. The reverse face is ornamented with 8 to 10 rather coarse longitudinal thread-like lines, and is flattened for most of its length, but seems to swell up in places into low, broad nodes. The dissepiments are short and thickened at their base and form oval fenestrules of subequal size longer than wide but narrower than the branches; about 7 occur in a length of 10 mm.

The relations of this imperfectly known species seem to be with *P. biseriata* Ulrich[9] and *P. varsoviensis* Prout,[10] both from the Warsaw Formation, Illinois.

Orbiculoidea saltensis sp. nov. (Plate XIII, Fig. 1)

Shell subcircular. Upper valve low, conical, with excentral apex situated at about one-third of the diameter from posterior margin. Surface ornamented with about fifteen coarse rounded subequidistant concentric liræ, mostly bearing small, low, closely placed, hollow tubercles, the whole crossed by very delicate radial striæ. Lower valve (incompletely known) flattened or gently concave, with hollow, low, conical apex and a small foramen at the end of a partly inclosed broad groove to posterior margin.

Dimensions—I (7335): Diameter, 20 mm.; height, c. 8 mm. II (7340): Diameter, c. 27 mm.; height, c. 9 mm.

Remarks—There are three specimens (7335, 7340, 7310) of this new species, one of which (7335) has the lower valve showing the posterior groove, though in a poor state of preservation. The other two are less perfect and only show the upper valve. The peculiar tuberculation of the concentric rugæ seems to be an original and definite character, but it is only well seen

[4] Waagen and Pichl, Salt-Range Foss. (Palæont. Ind., Ser. XII, 1885), p. 777; Pl. LXXXVII, Figs. 1 to 3.
[5] Stuckenberg, Mem. Com. Géol. Russ., vol. X, no. 3, 1895, p. 231, t. XX, Fig. 16.
[6] *Ibid.*, p. 234, t. XXII, Fig. 1.
[7] Reed, Upper Carb. Foss. Chitral (Palæont. Ind., n.s., vol. VI, mem. 4, 1925), p. 19, pl. II, Figs. 6, 6*a*, 7.
[8] Mansuy, Mem. Serv. Géol. Indo-Chine, vol. II, fasc. 4, 1913, p. 23, Pl. I, Figs. 2*a to c*.
[9] Ulrich, Geol. Surv. Illinois, vol. 8, 1890, p. 592, pl. LX, Figs. 4, 4*a* and 4*b*.
[10] *Ibid.*, p. 593, Pl. LX, Figs. 2, 2*a*, and 2*b*.

in two specimens, the third (7310) being much crushed and distorted. The relations of this species seem to be with *Orbiculoidea missouriensis* (Shumard)[11] of the upper Carboniferous rather than with *O. nitida* Phill.

Productus lineatus **Waagen** (Plate XIII, Fig. 9)

This species,[12] which is included by many authors in *Productus cora* D'Orb., is represented by one small complete specimen of a pedicle valve (7365) and several fragments of larger shells. The synonymy of this species has frequently been discussed,[13] but to the author[14] Waagen's type seems at any rate to mark a distinct variety of the form known as *Productus cora* in the lower Carboniferous of Europe.

Productus curvirostris **Schellwien var. nov.** ***barrealensis*** (Plate XIII, Figs. 4*a*, 4*b*)

Shell with strongly convex narrow, elongated pedicle-valve, having prominent incurved acutely pointed beak projecting behind and over short straight hinge-line. Ears small, triangular, gently convex, well marked off from body by impressed line. Surface of valve ornamented with few regularly distributed spinose tubercles, semirecumbent, widely spaced, and arranged in a roughly quincunx order, with weak concentric rugæ becoming more marked on the flanks and with fine, irregular, undulating concentric lamellose striæ over the whole valve.

Dimensions—(7315): Length, 16 mm.; width (cardinal), 10 mm.; height, c. 8 mm.

Remarks—This shell, which is represented by one well-preserved specimen of a pedicle-valve (7315) and by a fragment of another may be regarded as a variety of *Productus curvirostris* Schellw.[15] of the Permo-Carboniferous of Italy. Mansuy[16] has also recorded this species from Indo-China. It is undoubtedly allied to *Pr. aculeatus* Mart., but is sufficiently distinct, as Schellwien and others have pointed out.

Productus **cf.** ***juresanensis*** **Tschernyschew**

A fragment of a pedicle-valve of a species of *Productus* (7281) is too imperfect for a satisfactory determination, but it appears to possess the ornamentation of *Pr. juresanensis* Tschern.,[17] and it may be compared with it rather than with *Pr. nebrascensis* Owen,[18] which is closely allied and is also an upper Carboniferous species. *Pr. scabriculus* Mart. belongs to the same group.

Productus **(*****Marginifera*****) cf.** ***echinatus*** **Waagen**

One imperfect pedicle valve (7364) appears to possess the external characters of *Pr.* (*Marginifera*) *echinata* Waagen,[19] as figured by Waagen from

[11] Schuchert, Bull. 87 U. S. Geol. Surv., 1897, p. 280 (for synonymy and references).

[12] Waagen, Salt Range Foss. I (Palæont. Ind.), p. 673, Pl. LXVI, Figs. 1, 2; Pl. LXVII, Fig. 3.

[13] Hayasaka, Science Rept. Tohoku Imper. Univ., ser. 2, Geol., 1922, pp. 86–93.

[14] Reed, Up. Carb. Foss. Chitral, etc., Palæont. Ind., vol. VI, mem. no. 4, 1925, p. 28, Pl. III, Figs. 12 to 14*a*.

[15] Schellwien, Palæontographica, XXXIX, 1902, p. 26, t. III, Figs. 12 to 14. Gortani, Palæont. Ital., vol. XII, 1906, p. 23, t. II, Figs. 1 to 3; *id.*, Boll. Soc. Geol. Ital., vol. XXV, 1906, fasc. 2, p. 14, Fig. 7.

[16] Mansuy, Mem. Serv. Géol. Indo-Chine, vol. II, fasc. 4, 1913, p. 32, Pl. II, Figs. 9*a* to *c*; *ibid.*, vol. III, fasc. 3, 1914, p. 16, Pl. II, Figs. 10*a* to *c*.

[17] Tschernyschew, Mem. Com. Géol. Russ., vol. XVI, no. 2, 1902, p. 620, t. XLVII, Figs. 1, 2; t. LIII, Fig. 4.

[18] Schuchert, Bull. 87 U. S. Geol. Surv., 1897, p. 327 (for synonymy and references).

[19] Waagen, *op. cit.*, p. 727, Pl. LXXVIII, Fig. 1.

the lower *Productus* limestone of the Salt Range. The thin, recumbent spines on the surface, becoming more upstanding or tubercular posteriorly, and the transverse swollen shape of the valve are clearly preserved; the broad short beak, hollowed umbonal slopes, and hinge-line can also be distinguished. It had been labeled *Strophalosia* cf. *indica* Waag., but is totally different from that species.

Productus* (*Marginifera*) *spinulo-costatus* Abich var. nov. *peregrina (Plate XIII, Fig. 2)

There is one fairly perfect pedicle-valve (7374) which might be regarded as a variety of *Productus* (*Marg.*) *ornatus* Waag.,[20] but seems more allied to *Pr.* (*Marg.*) *spinulo-costatus* Abich,[21] of the Djulfa beds, and if better known we might consider it to be a distinct species. The shell is transversely semi-elliptical, with a straight hinge-line, equal to, or nearly equal to, its width; the pedicle-valve is strongly swollen, with a weak, broad median depression down the middle; the beak is broad, rounded, obtuse, swollen, and incurved and overhangs the hinge-line. The ears are small, triangular, depressed, and sharply marked off from the umbonal slopes, which descend steeply to them and are somewhat excavated. The surface of the valve is ornamented with weak, low, rounded, indistinct ribs, somewhat discontinuous, being mainly due to radially elongated recumbent stout spines arranged in a roughly quincunx fashion, but widely spaced; there are about eight such faint ribs on each side of the median depression, which bears only one short similar rib arising at about half the length of the valve; three to five small spinose tubercles form an irregular line along the junction of the ears with the body, and two to three more occur on the ears. Fine concentric striæ cross the valve, with a few stronger growth-lines becoming more marked on the flanks.

From typical examples of *Pr.* (*Marg.*) *ornatus* it differs by its more elongated recumbent spine bases, and thus more resembles the Armenian species, *Pr.* (*Marg.*) *spinulo-costatus*, which Frech[22] and Hayasaka[23] figure also from China. *Pr. walcottianus* Girty[24] may also be compared.

***Chonetes* cf. *pseudovariolata* Nikitin**

Two small specimens of *Chonetes* in rather a poor state of preservation seem to be comparable to *Ch. pseudovariolata* Nikitin,[25] of the Gshelian stage of Russia, rather than with *Ch. lissarensis* Diener,[26] of the Zewan beds of Kashmir; but such small and imperfectly known shells are almost impossible to determine specifically.

***Chonetes granulifer* Owen** (Plate XIII, Fig. 6)

One large specimen of a species of *Chonetes* (7319) shows the pedicle-valve with the shell broken away from most of the middle part and the outer surface only preserved on a small portion near the anterior margin. It is transversely semi-elliptical in shape, with the cardinal angles slightly

[20] Waagen. *op. cit.*, p. 721, Pl. LXXVII, Figs. 5 and 6.

[21] Frech and Arthaber, Palæoz. in Hocharmenien, Beitr. z. Palæont. u. Geol. Oesterr. Ung., Bd. XII, 1900, pp. 262–264, t. XX, Figs. 5, 7, 8, and 9; Diener, Palæont. Ind., n.s., vol. V, mem. 2, 1915, p. 82, Pl. VIII, Figs. 13, *a* to *d*, Pl. IX, Figs. 1 and 2.

[22] Frech in Richthofen's "China," Bd. V, 1911, p. 175, Pl. XXVII, Fig. 2.

[23] Hayasaka, Science Rept. Tohoku Imper. Univ. Ser. 2, Geol., 1922, p. 99, Pl. IV, Figs. 15 and 16.

[24] Girty, Prof. Paper 58, U. S. Geol. Surv., 1908, p. 269, Pl. XXI, Figs. 27, *a* and *b*.

[25] Nikitin, Mem. Com. Géol. Russ., vol. V, no. 5, 1890, p. 27, Pl. II, Figs. 1 to 4; Loczy, Beschr. Palæont. Stratigr. Result. Reise Graf. Bela Szechenyi in Ostasien (Budapest, 1898), p. 73, t. III, Figs. 8 to 13.

[26] Diener, Himal. Foss. (Palæont. Ind. Ser. XV), vol. I, pt. 4, 1897, p. 19, Pl. II, Figs. 4 and 6; *ibid.*, n.s., vol. V, mem. 2, 1915, p. 83, Pl. IX, Fig. 3.

pointed but not produced into ears. The cardinal margin shows seven to eight small, obliquely directed spine-bases, the largest being at the cardinal angle. The body is gently convex, and the valve is not definitely flattened or depressed in the middle, a sinus being completely wanting. The surface is covered with numerous fine, granulated, equal radial lines, fifty to sixty occurring on the margin in a space of 10 mm., apparently increasing by bifurcation and intercalation, and in all there must be at least 200 such lines around the whole margin of the valve. The interior shows a low, narrow median ridge extending from the beak for about one-third the length of the valve, and separating weakly impressed flabellate diductor scars, on each side and in front of which, to a distance of about three-fourths the radial diameter of the valve, there are coarse, rather closely set papillæ, somewhat irregularly arranged in radial lines; outside them there is a marginal band of smaller, more regular, closer, and more numerous papillæ (in both cases, of course, shown on the internal cast as punctæ).

This shell in some respects seems to resemble *Ch. variolata* D'Orb.,[27] and especially its variety *baroghilensis* Reed[28] from the upper Carboniferous of Chitral, in its internal character, but it has no definite median flattening or sinus. Many of the shells referred to *Ch. granulifer* Owen[29] bear a closer resemblance to our shell, though this specific name has been used in somewhat a wide sense and still requires a detailed diagnosis and strict limitation, but it is an indication of an upper Carboniferous horizon.

Camarophoria cf. *mutabilis* Tschernyschew?

Two crushed and imperfect valves (7327, 7352) of a rhynchonelloid shell having three to four ribs in the sinus and on the fold and four to five on each side seem to be comparable with the variable species *Camarophoria mutabilis* Tschern.,[30] typically occurring on the *Schwagerina* horizon of Russia and also recorded from Indo-China by Mansuy.[31]

Spirifer cf. *supramosquensis* Nikitin (Plate XIV, Fig. 1)

Stappenbeck[32] has already recorded *Spirifer supramosquensis* from this locality in Argentina. It is characteristic of the Gshelian, according to Nikitin.[33] There is one specimen (7316) in the present collection which seems indistinguishable from this species, and especially resembles the figure of the shell from the Urals referred by De Verneuil[34] to *Sp. crassus* De Kon., but considered by Nikitin to be identical with *Sp. supramosquensis*. The shells which Hayasaka[35] and Mansuy[36] respectively figure as *Sp. nikitini* Tschern. from the upper Carboniferous of Manchuria (in association with *Sp. supramosquensis*) and from the *Productus* limestone of Indo-China bear a considerable resemblance, and Hayasaka remarks on its likeness to the American *Sp. mexicanus* Shum. of the upper Carboniferous.

[27] D'Orbigny, Voyage dans l'Amerique Merid. III, pt. 4, 1842, p. 49, Pl. IV, Figs. 10 and 11. Kozlowski, Brach. Carb. Supér. Bolivie, Ann. Paléont. IX, 1914, p. 55, Pl. VIII, Fig. 16.

[28] Reed, Up. Carb. Foss. Chitral (Pal. Ind., n.s., vol. VI, mem. 4, 1925), p. 40, Pl. III, Figs. 1 to 4.

[29] Greene, Journ. Geol., vol. XVI, 1908, pp. 654–663, Pls. I–IV; Girty, Bull. 544, U. S. Geol. Surv., 1915, p. 59, Pl. VI, Figs. 12 to 133.

[30] Tschernyschew, *op. cit.*, p. 491, t. XLV, Figs. 1 to 15.

[31] Mansuy, *op. cit.*, vol. II, fasc. 4, p. 90, Pl. IX, Figs. 14*a* to *c*.

[32] Stappenbeck, Geol. Aufb. d. Vorkordillere (Geol. u. Palæont. Abh. N. F., Bd. IX, Heft 5, 1911), pp. 31–32.

[33] Nikitin, Mem. Com. Géol. Russ., vol. V, no. 5, 1890, pp. 66, 165, t. III, Figs. 1 to 3.

[34] De Verneuil, Géol. Russ. II, Palæont., p. 165, t. VI, Fig. 2.

[35] Hayasaka, *op. cit.*, 1922, p. 125, Pl. VI, Figs. 10 to 13.

[36] Mansuy, Mem. Serv. Géol. Indo-Chine, vol. 2, fasc. 4, 1913, p. 66, Pl. VI, Fig. 4.

Gortani[37] would regard *Sp. fritschi* Schellw. as only a variety of *Sp. supramosquensis*, and there are many closely allied species from the upper Carboniferous of Russia, such as *Sp. ussensis* Stuck.,[38] which are difficult to separate.

Spirifer mexicanus* Shumard var. nov. *neotropica (Plate XIV, Figs. 3, 4)

There are two specimens (7325, 7366) of a species of *Spirifer* belonging to the *Sp. mexicanus* group which much resemble the varieties of *Sp. mexicanus* from Texas, figured by Girty,[39] and are distinguished by the more definitely demarcated but smooth channel in the median sinus of the pedicle-valve. This median channel in the sinus of one of our specimens is deep, narrow, devoid of ribs, and preserves an almost uniform width, but in the other (7366) is more open. The shell is longer, more oval, and narrower in shape than *Sp. supramosquensis*, being longer than wide, with a shorter hinge-line and smaller beak. The interior of part of the valve is seen in one specimen and shows rather coarse pitting toward the lateral margins on each side of the large median muscular area. There are seven to ten low, rounded, flattened, simple ribs of subequal size on each lateral lobe, and on the rounded slopes of the sinus there are three or four narrower equal similar ribs, and on the upper edge two much sharper ones. The cardinal ribs are very faint. Very fine radial lines and delicate concentric striation ornament the whole surface of the shell.

Dimensions—Length, c. 25 mm.; width, c. 30 mm.

Remarks—In spite of its more quadrate shape and simple ribs it seems probable that this shell is more allied to *Sp. mexicanus* than to *Sp. nikitini* Tschern.,[40] but it is certainly a new variety.

Spirifer wynnei* Waagen var. nov. *argentina (Plate XIV, Figs. 7*a*, 7*b*)

Shell transversely subelliptical, about twice as wide as long; hinge-line less than width of shell; cardinal angles rounded. Pedicle-valve convex, deeper than opposite valve; beak prominent, moderately high, somewhat incurved; hinge-area triangular, gently concave, inclined steeply to plane of valve, well-defined from lateral lobes by sharp edges; surface of valve crossed by shallow, broad, rounded median sinus, not sharply marked off from lateral lobes, increasing in width and depth anteriorly, with floor produced with broad, rounded, projecting tongue arching steeply upward, so as to be nearly at right angles to plane of valve; lateral lobes rounded, gently to strongly convex from side to side. Sinus holding nine to ten subequal, narrow, low, rounded ribs, which mostly divide at about half their length, making fifteen to eighteen on the anterior margin. Lateral lobes with ten to twelve similar, rather larger ribs, which bifurcate once at about half their length and sometimes again nearer margin, or rarely trifurcate, giving an appearance of fasciculation and numbering twenty-four to twenty-eight of subequal size on the margin, those near the cardinal edge becoming smaller and fainter. Brachial valve less convex and shallower than pedicle-valve, with low, broad, rounded median fold increasing in width anteriorly, not marked off from lateral lobes; beak small, slightly elevated, scarcely incurved; hinge-area narrow, with sharply defined edges, lying in plane of valve. Fold with five to seven narrow, low, rounded ribs, arising from the beak, and each bifurcating at about one-third to one-half its length, and

[37] Gortani, Palæont. Ital., vol. XII, 1906, p. 26, t. II, Figs. 15 to 18.

[38] Stuckenberg, Mem. Com. Géol. Russ., n.s., Liv. 23, 1905, pp. 44, 123, t. III, Fig. 17; t. V, Figs. 3 and 4; t. VII, Fig. 11.

[39] Girty, Prof. Paper 58, U. S. Geol. Surv., 1908, p. 360, Pl. XIII, Figs. 1 to 9.

[40] Tschernyschew, *op. cit.*, p. 542, t. XIII, Fig. 2.

some dividing a second time so as to form sixteen to eighteen ribs on the front margin. Lateral lobes with five to six similar but rather larger ribs on each side, which bifurcate soon after their origin and mostly again at about half their length or near the margin, so as to make about twenty to twenty-four in all on the margin, with a decided tendency to fasciculation. In both valves the ribs on the fold and in the sinus tend to be smaller than those on the lateral lobes.

Dimensions—(7309): Length of brachial valve, 31 mm.; width of brachial valve, 50 to 54 mm.; depth of conjoint valves, 26 mm.

Remarks—This form, which is represented by five imperfect specimens in different states of preservation, is undoubtedly closely allied to *Sp. wynnei* Waagen,[41] but it can hardly be considered identical with the Salt Range type-examples, though it may be regarded as a variety. The chief differences are in the tendency to fasciculation of the ribs and in the fact that they are smaller on the fold and sinus than on the lateral lobes. The rounded character and low elevation of the fold on the brachial valve and the sharply demarcated hinge-area on the pedicle-valve are features which distinguish it from another Salt Range species, *Sp. oldhamianus* Waag.;[42] the number of ribs is also less. The lower Carboniferous species *Sp. crassus* De Kon.[43] is perhaps allied to our shell, but it has a less marked median fold and sinus, and no tendency to fasciculation of the ribs. Some of the shells which from time to time have been referred to *Sp. striatus* Mart. show a marked resemblance in the ribbing, but differ by not possessing rounded cardinal angles, which is also one of the chief distinctions of our shell from the true *Sp. cameratus* Morton, though Derby[44] attributed some Brazilian shells of this shape to this species. The fine-ribbed specimens from the British lower Carboniferous which Davidson[45] at first referred to *Sp. duplicicosta* Phill. but subsequently[46] transferred to *Sp. striatus* are almost inseparable from our shells, but the present author does not agree with Davidson's views about the species. *Sp. volgensis* Stuck.[47] from the Russian upper Carboniferous may also be compared. Diener[48] has figured and described examples of *Sp. wynnei* from Chitichun, which much resemble our specimen. The species which Nikitin[49] described from the Gshelian of Russia as *Sp. poststriatus* was referred in 1889 by Tschernyschew to *Sp. wynnei* (but subsequently in 1902 to *Sp. cameratus*); it differs from our shell by having a more triangular shape and longer hinge-area, the latter extending to the cardinal angles instead of being considerably less than the width of the shell. The ribbing, however, of *Sp. poststriatus* is more like that of our shell than is that of *Sp. wynnei*, being subfasciculate. Undoubtedly our shell belongs to the same group as that containing *Sp. striatus*, *Sp. duplicicosta*, *Sp. cameratus*, *Sp. condor*, *Sp. fasciger*, *Sp. ravana*, and *Sp. marcoui*, all of which are recorded by Tschernyschew[50] from the upper Carboniferous of Russia. Hayasaka,[51] who describes *Sp. wynnei* from the upper Carboniferous of

[41] Waagen, Salt Range Foss., I, p. 517, Pl. XLIV, Figs. 6 and 7.

[42] *Ibid.*, I, p. 518, Pl. XLVI.

[43] De Koninck, Faune Calc. Belg., VI (Ann. Mus. R. Belg., XIV, 1887), p. 137, Pl. XXIII, Figs. 3 to 9.

[44] Derby, Bull. Cornell Univ., 1874, p. 12, Pl. I, Fig. 9 (non cet.).

[45] Davidson, Mon. Brit. Foss., Brach. II, p. 21, Pl. III, Figs. 7 to 9.

[46] *Ibid.*, p. 221.

[47] Stuckenberg, Mem. Com. Géol. Russ, n.s., Livr. 23, 1905, pp. 40, 122, t. III, Fig. 19.

[48] Diener, Himal. Foss., vol. 1, pt. 3 (Palæont. Ind. Ser. XV.) 1897, p. 44, Pl. VII, Figs. 1 to 4.

[49] Nikitin, *op. cit.*, 1890, pp. 64, 164, t. II, Figs. 16 to 19.

[50] Tschernyschew, *op. cit.*, 1902, pp. 133–146.

[51] Hayasaka, *op. cit.*, 1922, p. 127, Pl. VI, Figs. 15 and 16.

Manchuria, notes points of resemblance between it and *Sp. volgensis* Stuck. It is said also to occur in the "lower Permian" of Australia, according to Frech, and in the upper Carboniferous of California, and Schellwien[52] figures it from the Trogkofel beds of the Carnic Alps.

***Spirifer saltensis* sp. nov.** (Plate XIV, Figs. 8*a*, 8*b*)

Shell transversely elliptical, much compressed; cardinal angles strongly rounded; cardinal line less than width of shell. Pedicle-valve gently convex, most so posteriorly; beak small, pointed, elevated, incurved, with concave shoulders; hinge area small, triangular, nearly in plane of valves, with sharply defined edges. Surface of valve with weak, broad, shallow, but well-defined, rounded sinus holding four to five narrow, low, rounded, simple, equal ribs; lateral lobes covered with eight to nine much broader, low, rounded, flattened ribs, becoming narrower toward the cardinal angles, and each dividing near the margin into two, or usually three, much smaller ribs, giving a subfasciculate appearance. Brachial valve less convex than pedicle-valve, with a low, scarcely raised, but definite broad median fold, increasing rather rapidly in width and carrying a median weak, narrow, simple rib, and on each side of it a stronger but narrow, rounded, bifurcated rib, the division taking place at about the third of its length; lateral lobes with six to seven much broader, low, flattened ribs dividing into three smaller ones near the margin, and clearly forming fascicles; toward the cardinal margin all the ribs become very weak and faint.

Dimensions—(7296): Length, 20 mm.; width, 29 mm.; thickness, 10 mm.

Remarks—The relations of this shell, of which there is only one specimen which is fortunately nearly perfect, are undoubtedly with the *cameratus* group of species; the fasciculation of the ribs is a distinctive feature. The rounded elliptical shape of the shell and short hinge-line are unlike *Sp. fasciger* or its allies, although the ribbing especially recalls some forms attributed to *Sp. musakheylensis* Dav.,[53] which is often regarded as only a variety of *Sp. fasciger.*[54] But the elliptical shape, rounded cardinal angles, and short hinge-line are found combined with a similar division and subfasciculation of the ribs in some shells referred by Davidson[55] to *Sp. duplicicosta* Phill. from the British lower Carboniferous, and to *Sp. cameratus* Morton from Brazil,[56] of which species our shell might even be considered a variety.

***Spirifer barrealensis* sp. nov.** (Plate XIV, Fig. 2)

Shell transversely subtriangular. Pedicle-valve convex, with deep, well-defined median, subangular sinus, increasing slowly in width to front margin; hinge-line long, equal to width of valve; cardinal angles acute; beak high, prominent, acutely pointed, incurved; hinge-area high, triangular, concave, nearly in plane of valve. Surface of shell marked with five to six low, rounded, simple, weak ribs on each lateral lobe, becoming fainter and almost obsolete toward the cardinal angles; sinus with lateral slopes bearing a faint, low narrower rib on each side, arising at about half the length of the valve by the unequal division of the larger rib forming the edge of the sinus, the floor of

[52] Schellwien, Fauna d. Trogkofelsch., Abh. k. k. geol. Reichsanst., XVI, 1900, p. 75, t. X, Figs. 5 and 6.

[53] Diener, Himal. Foss., vol. I, pt. 4, p. 35, Pl. III, Figs. 3 and 4; Pl. IV, Figs. 1 and 2; Pl. V, Fig. 1.

[54] Reed, Upper Carb. Foss. Chitral, Palæont. Ind., n.s., vol. VI, mem. 4, 1925, p. 42 and references.

[55] Davidson, *op. cit.*, Pl. II, Fig. 11 (non cet.).

[56] Derby, *op. cit.*, p. 12, Pl. I, Figs. 3, 14 (non cet.).

the sinus being narrow, concave, and the width of a rib. Whole surface of valve covered with closely placed concentric lamellose striæ and growth-lines, and with very delicate radial striæ. Brachial valve unknown.

Dimensions—(7371): Length, c. 17.5 mm.; width, c. 32.0 mm.

Remarks—The affinities of this species seem to be with *Sp.* aff. *boonensis* Swallow, described by Girty[57] from Oklahoma. The one specimen in the present collection is crushed and imperfect, only the central portion and left lateral lobe of the pedicle-valve being preserved. *Sp. keilhavii* Von Buch[58] from the upper Carboniferous of the Urals, etc., is less like it.

Spirifer aff. rajah Salter (Plate XIV, Fig. 5)

There is one imperfect specimen (7317) of a pedicle-valve of a species of *Spirifer* which may be a variety of *Sp. barrealensis*, but it differs in being subquadrate in shape, in possessing more numerous and narrower ribs on the lateral folds, and by having on the steeply inclined, flattened slopes of the sinus two to three very faint and narrower ribs; the floor of the sinus is flattened, of nearly uniform width, and rather wider than one of the inner ribs on the lateral lobes, just as in *Sp. barrealensis*. The minute ornamentation is identical. In our specimen the anterior part of the shell is sharply bent under the posterior part, but the sinus, with its short projecting tongue, and the concentric lamellæ near the edge, are well preserved, and it is in this region that the ribbing is most clearly shown. The cardinal angles are obtusely angular, and the shell much resembles certain of the specimens figured by Broili[59] from Timor, which he refers to the Himalayan species *Sp. rajah* Salter. *Sp. samarensis* Stuck. is also allied.

***Spirifer* (*Martinia*) cf. *simensis* Tschernyschew** (Plate XIV, Fig. 6)

There are two specimens of pedicle-valves in the collection (7338, 7363) which seem comparable to, if not identical with, the shell figured and described by Tschernyschew[60] from the *Schwagerina* horizon in the Urals under the name *Martinia simensis*. Mansuy[61] has recorded this species from Tonkin.

Dimensions—(7363): Length, c. 15 mm.; width, c. 15 mm.

***Spirifer* (*Martiniopsis*) cf. *aschensis* Tschernyschew**

An imperfect pedicle-valve (7361) which shows the umbo, the median channel-like sinus, and the faint ribs on the lateral lobes, may be compared with Tschernyschew's *Martiniopsis aschensis*[62] rather than with any of the other closely allied species of the same subgenus described by the same author from the *Schwagerina* horizon in Russia.

***Spiriferina zewanensis* Diener** (Plate XIII, Fig. 3)

There is one nearly perfect but somewhat compressed specimen (7312) of a species of *Spiriferina* having the pedicle-valve in a good state of preservation and not crushed; the brachial valve is somewhat flattened by pressure, but it shows all essential characters, and the ornamentation of the surface

[57] Girty, Bull. 544, U. S. Geol. Surv., 1915, p. 91, Pl. XI, Fig. 5.
[58] Tschernyschew, *op. cit.*, p. 527, t. XL, Figs. 1 to 4.
[59] Broili, Palæont. Timor, VII, No. 12, 1916, p. 34, t. CXIX, Figs. 1 to 11, t. CXX, Figs. 1 to 6.
[60] Tschernyschew, *op. cit.*, p. 569, t. L, Figs. 1 to 3.
[61] Mansuy, *op. cit.*, vol. V, fasc. 4, 1916, p. 33, Pl. V, Fig. 10.
[62] Tschernyschew, *op. cit.*, p. 557, t. L, Fig. 4.

of both valves is beautifully preserved. In the pedicle-valve there are four (and a weaker fifth) strong angular folds on each side of the median sinus, which is broad, subangular, and rather rapidly increases in width anteriorly; the pair of folds bordering it are the strongest of the series, the others successively decreasing in size toward the cardinal region, a smooth triangular space devoid of ribs being left along the cardinal line. The beak is small, acute, elevated and slightly incurved, but not high, and the hinge-area is low and narrow. The brachial valve has a narrow, prominent median fold, rounded rather than subangular and very slowly increasing in width anteriorly; there are only three strong subangular folds on each side and traces of a fourth one. The cardinal angles of both valves are broken off, but seem to have been acute or subacute. The surface of both valves is covered with a series of strong, equidistant, regular, thick imbricating lamellæ about twenty to twenty-five in number, and the shell substance is coarsely punctate. A very delicate radial striation is also visible with a lens on the surface.

Dimensions—Length, 14 mm.; width (estim.), 28 mm.

Remarks—This shell is much like *Sp. octoplicata* Sow. as redefined by North, especially the mut. δ Vaughan,[63] but the species from the Zewan beds of Kashmir which Diener[64] first described as *Sp.* cf. *kentuckiensis* Shum., but subsequently as *Sp. zewanensis* sp. nov., seems to be indistinguishable from our specimen.

***Reticularia notica* sp. nov.** (Pl. XIII, Figs. 8*a*, 8*b*, 10)

Shell subcircular. Pedicle valve moderately convex; beak high, prominent, pointed, incurved, with umbonal slopes hollow; cardinal area concave, triangular, steeply inclined; hinge-line short, about half width of shell. Surface of valve marked with continuous median shallow sinus, scarcely increasing in width anteriorly. Ornamentation of shell consisting of numerous closely placed subequidistant concentric thin lamellæ with their edges provided with minute equidistant, rather widely spaced, small, short, simple, recumbent spines, not crossing the lamellæ but forming narrow fringes. Brachial valve unknown.

Dimensions—Length, 15 to 16 mm.; width, 14 to 15 mm.

Remarks—This species, of which there is one broken example (7326) of a pedicle valve having the surface beautifully preserved and showing the ornamentation, and three other decorticated and poor specimens (7376, 7345, 7372) can not be referred to *Ret. lineata* Mart., because of the median sinus and the character of the marginal spinose fringes. But as often remarked, *R. lineata* has been made to include a variety of forms. It is more like *Ret. setigera* Hall and Whitfield[65] in the ornamentation and in the median sinus and shape we may also compare *R. orientalis* Mansuy,[66] and *Ret. rostrata* Kut.[67] *R. waageni* Loczy,[68] from southern China and especially *Squamularia guadelupensis* Shum.[69] from Texas, may also be compared.

[63] North, Quart. Journ. Géol. Soc., vol. LXXVI, pt. 2, 1920, p. 217, Pl. XIII, Fig. 9.

[64] Diener, Himal. Foss., vol. I, pt. 2, 1899, p. 61, Pl. V, Figs. 11 and 12; *id.* Anthrac. Foss. Kashmir, etc. (Palæont. Ind., vol. VI, mem. 2, 1915), p. 90, Pl. IX, Fig. 12.

[65] Hall and Whitfield, Explor. 40th Parallel, p. 270, Pl. VI, Figs. 17 and 18.

[66] Mansuy, *op. cit.*, vol. II, fasc. 4, p. 81, Pl. IX, Fig. 2.

[67] Tschernyschew, *op. cit.*, p. 575, t. XX, Figs. 14 to 18.

[68] Loczy, Beschr. Wiss. Ergeb. Pal. Stratigr. Result. Reise des Grafen Bela Szechenyi. (Budapest, 1898), p. 110, t. IV, Figs. 1 and 2.

[69] Girty, *op. cit.*, 1908, pp. 367 to 369, Pl. XIV, Figs. 2 and 3.

Ambocœlia plano-convexa **Shumard**

This well-known brachiopod, which occurs in the upper Carboniferous of America,[70] Asia,[71] and Europe[72] and was recorded by Derby[73] from the coal measures of Brazil and by Kozlowski[74] from the upper Carboniferous of Bolivia, is represented by one pedicle-valve in the collection, measuring about 7.5 mm. in width and about 5 mm. in length.

Athyris **(*Spirigerella*) ? sp.**

There is one fragmentary specimen of a broadly subcircular pedicle-valve with a weak anterior, broad, median sinus, and strong concentric growth-ridges which seems to belong to some species of *Athyris* or *Seminula* and may perhaps be compared with *Spirigerella grandis* Waag.[75] and the allied species from the *Productus* limestones. We may also compare some of the shells from the upper Carboniferous of Bolivia figured by Kozlowski[76] under the name *Seminula argentea* (Shepard), for the genus of our specimen is uncertain.

Hemiptychina **cf.** ***sublævis*** **Waagen** (Plate XIII, Fig. 5)

A small oval terebratuloid shell (7300 showing only the pedicle-valve has the external appearance and shape of *Hemiptychina sublævis* Waag.,[77] but its identification is somewhat uncertain. It measures about 6.5 mm. in length.

Pseudamusium stappenbecki **sp. nov.** (Plate XIII, Figs. 11 and 13)

Shell obliquely subelliptical, longer than high, transverse, bilaterally asymmetrical, having an oblique axis and anterior swing; gently biconvex, compressed. Right valve with body gently convex, more or less flattened; beak pointed, with its edges meeting at a right angle or more than a right angle, situated excentrally at about one-third the length of the valve from posterior end; anterior end of valve rounded, projecting in front, strongly arched forward above, curving back sharply below into inferior margin, which makes a wider, gentler curve and passes obliquely up into shorter, more semicircular posterior margin; junction of body above with posterior ear straight; junction of body with anterior ear slightly concave. Anterior ear large, narrow, long, acutely triangular, depressed, sharply marked off from body, rounded in front, without byssal slit; surface marked with four to five broad, low radial folds. Posterior ear small. short, depressed, smooth, weakly but distinctly marked off from body, with obtuse posterior angle, higher than long, extending a short distance down posterior margin of body. Surface of body marked with very faint, low, wide, flattened radial ribs of subsequal size, separated by incised lines and only distinct toward the margins; a few closely placed fine raised radial lines are present on anterior and posterior upper margins of body near junctions with ears; strong concentric striæ and growth-ridges at unequal distances apart cover the whole surface of both valves. Left valve similar to right valve, but with the fine radial lines extending over more of the surface of the body.

Dimensions—Length (oblique), 25 mm.; height, 22 mm.

[70] Girty, Bull. 544 U. S. Geol. Surv. 1915, p. 94 and refs.
[71] Mansuy, *op. cit.*, vol. II, fasc. 4, 1913, p. 82, Pl. IX, Fig. 4.
[72] Tschernyschew, *op. cit.*, p. 575, t. XX, Fig. 1.
[73] Derby, Bull. Cornell Univ., 1874, p. 19, Pl. VIII, Figs. 12, 16, 18, Pl. IX, Fig. 7.
[74] Kozlowski, *op. cit.*, 1914, p. 76, Text-Fig. 19, Pl. I, Fig. 5, Pl. X, Figs. 1 to 14.
[75] Waagen, *op. cit.*, p. 461, Pl. XXVI, Figs. 1 to 7 (especially Figs. 3 and 4).
[76] Kozlowski, *op. cit.*, 1914, p. 79, Pl. XI, Figs. 1 to 46.
[77] Waagen, *op. cit.*, p. 364, Pl. XXVII, Figs. 1 to 3; Diener, Palæont. Ind., ser. XV, Vol. I, Pl. V, 1903, p. 40, Pl. II, Figs. 3 *a* to *d*.

Remarks—This species is represented by several fairly perfect specimens, but the radial ribbing is only seen in those having the shell more or less preserved, most of the specimens being casts in which the concentric lines and ridges are more conspicuous.

The right valves (7287, 7290, 7303) are more complete than any of the left valves (7301?, 7302, 7291, 7289, 7284), but there seems to be little or no difference in their characters. The generic reference of this shell is to *Pseudamusium* as defined by Wheelton Hind, and it seems allied especially to *Ps. anisotum* Phill.[78] and to *Pecten sibiricus* De Vern.,[79] which Hind considers to be probably identical.

Diener[80] has figured an unnamed species of "*Aviculopecten*" from the Zewan beds which seems rather to resemble the Argentine shell. The well-known Russian species *Av. sericeus* De Vern.[81] is less oblique and less transverse, and the same differences are noticeable in the Amazonian upper Carboniferous shell which Katzer[82] has figured as *Euchondria neglecta* Geinitz. But Herrick's species *Crenipecten foerstii*[83] of the Pottsville fauna closely resembles our species in character.

Pseudamusium cf. ellipticum (Phillips) (Plate XIII, Fig. 12)

There seems to be another species of *Pseudamusium* in the collection which is only represented by one good example of a left valve (7304), and it differs from the foregoing in its shape and apparently in its ornamentation. It is not oblique and is higher than long, being a bilaterally symmetrical oval shell like a *Pecten;* the sides of the beak which is central in position, meet at about 75°; the anterior ear is shorter broader, and more equilaterally triangular than in *Ps. stappenbecki* and shows concentric lines instead of radial ribs. The long, straight shoulders of the body descend nearly to the middle of the valve. The surface is gently convex, and though the shell is mostly missing, there is a regular fine radial lineation visible over the whole surface, passing into broad, flattened ribs near the margins, which are more distinct than in the previous species, and the concentric ridges and striæ are less well developed.

This shell seems to resemble *Ps. fibrillosum* (Salt.) of the Coal Measures of England, as described by Wheelton Hind,[84] but still more *Ps. ellipticum* Phill.[85] of the Carboniferous limestone of Great Britain and Ireland.

Dimensions—(7304): Height, 25 mm.; length, 19 mm.

Pseudamusium cf. fibrillosum (Salter)

There is one left valve (7324) of a species of *Pseudamusium* which seems more like *Ps. fibrillosum* (Salt.)[85] as described by Wheelton Hind than *Ps. anisotum*, *Ps. ellipticum*, or *Ps. redesdalense* Wh. Hind. It has the upright oval shape and vertical axis of *Ps. ellipticum* and *Ps. fibrillosum*, but the finer ornamentation of the latter without any wide, flat ribs.

***Aviculopecten barrealensis* sp. nov.** (Plate XIII, Fig. 14)

Shell obliquely oval, gently convex. Body subtriangular, rounded; beak subanterior, small, with sides meeting at about 90°. Anterior margin of shell short, strongly arched, sweeping down and back obliquely into well-

[78] Wheelton Hind, Brit. Carb. Lamellibr., vol. II, 1903, p. 104, Pl. XXI, Figs. 13 to 20.
[79] De Verneuil, Géol. Russ., II, Palæont., p. 329, Pl. XXI. Fig. 7.
[80] Diener, Himal. Foss., vol. I, pt. 2, 1899 (Palæont. Ind.), p. 16, Pl. I, Fig. 3.
[81] Stuckenberg, Mem. Com. Géol. Russ., vol. XVI, no. 1, 1898, p. 200, t. I, Fig. 22.
[82] Katzer, Grundzüge d. Geol. d. unter. Amazonasgebietes (Leipzig, 1903), p. 185, t. VIII, Fig. 6.
[83] Morningstar, Geol. Surv. Ohio, Ser. 4, Bull. 25, 1922, p. 230, Pl. XIII, Figs. 7, 8.
[84] Wheelton Hind, *op. cit.*, p. 106, Pl. XVI, Figs. 16 to 22.
[85] *Ibid.*, p. 103, Pl. XX, Figs 11 to 18.

arched inferior margin which curves up sharply behind with short rounded projecting posterior end. Ears well marked off from body, flattened depressed; anterior ear rather large, triangular, projecting, with rounded anterior margin; [posterior ear larger (?), triangular, with acute (?) posterior angle]. Surface of valve covered with fine, regular, straight, mostly equidistant, threadlike, raised radiating ribs, of equal strength, thirty to thirty-three in number, less than half being primary and continuous from beak to margin, the rest arising by intercalation mostly at about one-fourth the length of the others; interspaces wide, flat, all of them as well as the ribs being crossed by rather closer, finer, regular, threadlike raised lines which are equidistant in the lower half of the shell, but become more and more crowded and numerous toward the beak. Anterior ear with concentric growth-lines.

Dimensions—(7362): Length (oblique), 11.5 mm.; height, 9.0 mm.

Remarks—Only one specimen (7362) occurs in the collection, but it is a nearly perfect left valve. The surface of this shell is divided up into numerous oblong cancellæ by the crossing of the radial and concentric lines, as in *A. forbesii* McCoy,[86] which it also much resembles in shape, but this Argentine species differs by the ribs being of equal strength, and the obliquity of the shell is more marked and the body narrower and not suborbicular. *Ps. radialis* (Phill.) as figured by Waagen[87] from the Salt Range has a somewhat similar ornamentation.

Nuculana (*Leda*) cf. *bellistriata* Stevens (Plate XIII, Fig. 7)

One small right valve of a species of *Nuculana* occurs in the collection (7339), but it is only an internal cast and does not show the dentition. It seems somewhat like *N. bellistriata* Stevens,[88] from the Pennsylvanian of the United States, but is shorter and blunter behind. Probably it is a new species.

Dimensions—Length, 10 mm.; height, 7 mm.

Euomphalus subcircularis Mansuy (Plate XV, Figs. 1, 2, 4)

There is a species of *Euomphalus* rather abundantly represented in the collection and including several well-preserved specimens which seems absolutely indistinguishable from Mansuy's *E. subcircularis*[89] from the Carboniferous of Chouei Tang, Yunnan. Apparently this is the shell which Stappenbeck mentions from Barreal as resembling *E. parvus* Waag.,[90] but as being much larger.

The specimens average about 25 to 30 mm. in diameter, and some of them (7322) are well preserved and show both the apical and basal surfaces. In all respects they agree with Mansuy's figures and description, which need not be repeated.

Pleurotomaria advena sp. nov. (Plate XV, Fig. 5)

Shell low, conical, heliciform, height and diameter being about equal, basal whorl occupying about half the height; apical angle about 130°; whorls rounded, five to six in number, rapidly decreasing in size to apex. Basal whorl large, rounded below, more or less flattened above, rising at an angle of 45° to 60° from the periphery, which is obtuse; slit-band promi-

[86] Wheelton Hind, *op. cit.*, p. 83, Pl. XVIII, Figs. 3 to 7.
[87] Waagen, *op. cit.*, p. 280, Pl. XXIII, Fig. 5.
[88] Girty, Bull. 544, U. S. Geol. Surv., 1915, p. 122, Pl. XIV, Figs. 1 to 9; Jakowlew, Mem. Com. Géol. Russ., n.s., Livr. 4, 1903, p. 10.
[89] Mansuy, *op. cit.*, vol. I, fasc. 2, 1912, p. 105, Pl. XIX, Figs. 3*a* to *d*.
[90] Waagen, *op. cit.*, p. 89, pl. IX, Fig. 2.

nent, situated slightly above the periphery, narrow, concave, deep, with sharp raised edges. Upper whorls rounded. Sutures not deeply sunken, with slit-band on upper whorls situated on or slightly above them. Base of shell convex, rounded; umbilicus small, closed, depressed; lip of mouth somewhat thickened. Shell ornamented with revolving liræ crossed by finer spiral lines which at their intersection form small pustules or nodules giving a moniliform character to the liræ; on apical surface of each whorl above the slit-band there are five to seven of such equidistant revolving liræ of equal strength, closely nodulated, mostly with finer, similarly nodulated liræ between them; below the slit-band on the basal whorl are more numerous and more closely placed finer nodulated liræ, with the closely placed spiral lines bending back to meet the slit-band at an angle of about 20°.

Dimensions—Height, c. 30 mm.; basal diameter, c. 35 mm.

Remarks—There is one specimen (7355) somewhat crushed but showing well the basal whorl, slit-band, and ornamentation. Another (7360) shows the spire and upper whorls better. The species seems to be allied to *Pl. punjabica* Waag.[91] of the upper *Productus* limestone of the Salt Range, but differs in the upper whorls being more rounded, in the slit-band being sutural, and in the more marked nodulation of the revolving liræ. We may perhaps also compare *Pl. timorensis* Wanner[92] from the Permo-Carboniferous of Timor and *Ptychomphalus venustus* Mansuy[93] from the corresponding beds of Indo-China, especially with regard to the shape of the shell and its ornamentation.

Pleurotomaria argentina sp. nov. (Plate XV, Figs. 3*a*, 3*b*, 3*c*)

Shell conical, subtrochiform; apical angle 75°; whorls five to six in number, bluntly angulated at periphery, slowly decreasing in size. Basal whorl large, fully half the total height of the shell, with swollen, convex rounded base, subangular periphery bearing a prominent, well-defined, sunken, narrow slit-band having sharply raised edges, and with a somewhat flattened apical face sloping up to suture-line. Upper whorls with prominent suture-band situated a little distance above suture-line, which is not sunken. Surface of whorls marked with regular revolving liræ, numbering six to seven on apical face, equidistant and bearing regular sharp, equidistant, small spinose tubercles; below the slit-band on the upper whorls are one to three similar liræ. Lower surface of basal whorl with several similar equidistant liræ immediately below slit-band, but nearer umbilicus they become finer and less distinct or obsolete, fine spiral growth-lines being here specially developed. Umbilicus sunken, closed. Mouth large, subcircular.

Dimensions—(7334): Height, c. 27 mm.; diameter, c. 24 mm.

Remarks—This species is closely allied to *Pl.* (*Phanerotrema*) *grayvillensis* Norw. and Pratt, as described by Girty[94] from the Pennsylvanian of Oklahoma, differing chiefly in the absence of strong spiral lines crossing the revolving liræ, and of the transverse ridges below the suture-lines on the apical surface of the whorls.

Pleurotomaria barrealensis sp. nov. (Plate XVI, Figs. 1*a*, 1*b*)

Shell subturbinate, composed of four to five rounded whorls, rather rapidly decreasing in size to apex; apical angle about 80°. Basal whorl

[91] Waagen, *op. cit.*, p. 115, Pl. XI, Figs. 3 and 4.
[92] Wanner, Palæont. Timor, Lief. XI, Abh. XVIII, 1922, p. 20, t. 151, Figs. 9*a* and *b*.
[93] Mansuy, *op. cit.*, vol. II, fasc. 4, 1913, p. 102, Pl. XI, Fig. 3.
[94] Girty, Bull. 544 U. S. Geol. Surv., 1915, p. 149, Pl. XXIII, Figs. 2 to 8.

large, rounded-subquadrate in section, being somewhat flattened on outer face; slit-band narrow, inconspicuous, situated at junction of outer face with convex apical face; inferior surface of basal whorl rounded, but not strongly convex, somewhat flattened; umbilicus sunken, small; mouth transversely oval, wider than high, with thickened inner lip. Upper whorls with more or less flattened vertical outer face below the slit-band, which is situated in about the middle of each whorl. Inferior surface of basal whorl crossed by strong subequidistant, sublamellose, spiral growth-lines and by numerous rather closely placed, subequidistant, thick, thread-like, smooth revolving liræ, not tuberculated; outer face of basal whorl ornamented with similar more widely spaced revolving liræ; apical face (not well preserved) ornamented with similar revolving liræ.

Dimensions—Height, c. 55 mm.; diameter at base, c. 55 mm.

Remarks—There is only one specimen (7323) of this shell, but it is nearly complete, though the surface ornamentation is destroyed, except on the basal whorl, and the slit-band is nowhere distinct. We may compare this species with *Pl. orientalis* Roemer, as figured by Fliegel[95] from the upper Carboniferous of Padang, Sumatra, and with *Pl.* cf. *punjabica* Waag. as figured by Diener[96] from the *Productus* shales of the Himalayas.

Metoptoma ? sp.

One much-crushed subcircular shell (7318) may possibly be referred to the genus *Metoptoma*, for apparently it had a low capuliform shape with an elevated submarginal apex scarcely overhanging the posterior margin. The surface of the shell seems to have been gently convex, very obliquely conical, and there are traces of two to three small, short marginal radial folds in the median line on the anterior edge. On one part of the central preumbonal region regular fine, equidistant, incised radial lines are visible, and a few concentric growth-striæ and ridges sweep around the margins and pass beneath the umbo.

Dimensions—Diameter, 22 to 25 mm.; height, + 4 mm.

Orthoceras sp.

One small fragment of a subcylindrical shell with a circular cross-section is probably referable to a species of *Orthoceras*. The specimen is only 10.5 mm. in length and shows five to six horizontal septa in that distance. The siphuncle is central and circular and measures one-sixth to one-seventh of the diameter. The walls of the cameræ seem to be unusually thick. The external surface of the shell seems to be smooth, except for very delicate concentric striæ. The affinities of this fragment are not clearly determinable, owing to the poorness of the specimen. Another fragment (7354) of apparently the same species consists of one broken, isolated camera; the septa are seen to be deeply concave and the siphuncle apparently expands in the upper part of each chamber. If the thickness of the walls of the chambers as seen in the other specimen is due to a marginal infilling we may perhaps compare *Pseudorthoceras knoxense* Girty[97] from the Pennsylvanian of America, which also agrees in its slow rate of tapering, central siphuncle, distance apart of the septa, and circular section. The rate of tapering, central siphuncle, circular section, and distance apart of the septa in our specimens also suggest a comparison with *Orth. punjabiense* Waag.[98] from the middle *Productus* limestone of Musakheyl.

[95] Fliegel, Palæontographica, Bd. XLVIII, Lief. 3, 1901, p. 113, t. VIII. Figs. 7 and 8.
[96] Diener, Palæont. Ind., ser. XV, Vol. I, pt. 5, 1903, p. 100, Pl. V, Figs. 1 to 3.
[97] Girty, Bull. 544 U. S. Geol. Surv., p. 227, Pl. XXVII, Figs. 1 to 6
[98] Waagen, *op. cit.*, p. 71, Pl. VI, Fig. 11.

COMPOSITION AND CORRELATION OF THE FAUNA

The following is a list of the species in the present collection which have been identified and described above:

* *Fenestella* aff. *perelegans* Meek.
  sp. ind.
Polypora aff. *biseriata* Ulr.
Orbiculoidea saltensis sp. nov.
*†*Productus lineatus* Waag.
* *curvirostris* Schellw. var. nov. *barrealensis.*
* cf. *juresanensis* Tschern.
* (*Marginifera*) cf. *echinata* Waag.
* (*Marginifera*) *spinulo-costatus* Abich var. nov. *peregrina.*
**Chonetes* cf. *pseudovariolata* Nik.
  granulifer Owen.
**Camarophoria* cf. *mutabilis* Tschern.
**Spirifer* cf. *supramosquensis* Nik.
* *wynnei* Waag. var. nov. *argentina.*
  saltensis sp. nov.
  barrealensis sp. nov.
  mexicanus Shum. var. nov. *neotropica.*
* aff. *rajah* Salt.
* (*Martinia*) cf. *simensis* Tschern.
* (*Martiniopsis*) cf. *aschensis* Tschern.
**Spiriferina zewanensis* Diener.
Reticularia notica sp. nov.
*†*Ambocœlia plano-convexa* Shum.
Athyris (*Spirigerella*) ? sp.
**Hemiptychina* cf. *sublævis* Waag.
Pseudamusium stappenbecki sp. nov.
  cf. *ellipticum* (Phill.).
  cf. *fibrillosum* (Salt.).
Aviculopecten barrealensis sp. nov.
Nuculana (*Leda*) cf. *bellistriata* Stevens.
Euomphalus subcircularis Mansuy.
Pleurotomaria advena sp. nov.
  argentina sp. nov.
  barrealensis sp. nov.
Metoptoma ? sp.
Orthoceras sp.

With regard to the two horizons in the shales from which Doctor Du Toit's specimens were collected the following lists indicate the distribution of the species:

Lower horizon (7281–7313).
Polypora aff. *biseriata.*
Fenestella sp. ind.
Productus cf. *juresanensis.*
Spirifer wynnei var. *argentina.*
  saltensis.
Spiriferina zewanensis.
Hemiptychina cf. *sublævis.*
Pseudamusium stappenbecki.
  cf. *ellipticum.*

Upper horizon (7314–7376).

Fenestella aff. *perelegans.*
Orbiculoidea saltensis.
Productus lineatus.
curvirostris var. *barrealensis.*
(*Marginifera*) cf. *echinata.*
(*Marginifera*) *spinulo-costatus* var. *peregrina.*
Chonetes cf. *pseudovariolata.*
granulifer Owen.
Camarophoria cf. *mutabilis.*
Spirifer cf. *supramosquensis.*
barrealensis.
mexicanus var. *neotropica.*
(*Martinia*) cf. *simensis.*
(*Martinia*) cf. *aschensis.*
Reticularia notica.
Pseudamusium cf. *fibrillosum.*
Aviculopecten barrealensis.
Nuculana cf. *bellistriata.*
Euomphalus subcircularis.
Pleurotomaria advena.
argentina.
barrealensis.
Metoptoma ? sp.
Orthoceras sp.

The species marked with an asterisk (*) in the above list occur either in the Carboniferous of Russia or parts of Asia, though several are represented here by varieties. In many cases we have not been able to feel sure that the other species are identical, owing to the paucity or poor preservation of the specimens in the present collection, so that they can only be compared with already described forms. A few are, however, identified without hesitation; such are *Productus lineatus*, *Chonetes granulifer*, *Ambocœlia planoconvexa*, *Spiriferina zewanensis*, and *Euomphalus subcircularis.*

The species marked with a dagger (†) have been recorded by previous geologists from South America, but these are very few, and the remainder show little affinity. The fauna, in fact, of this Argentine locality is quite distinct from that of Brazil or Bolivia, and does not show any striking resemblance to any occurring in North America, except perhaps to the Guadelupian type.

Derby,[99] in 1894, gave a list of the Amazonian upper Carboniferous fauna, but without any figures or descriptions. Many had been described in his earlier paper on the Brazilian Carboniferous fossils from Itaituba. The most complete list of the upper Carboniferous fossils from the Amazon region, with descriptions and figures of several of the species, was given by Katzer,[100] in 1903. Among the species occurring in this area and the present collection from Barreal

[99] Derby, Journal of Geology, vol. II, 1894, p. 480.

[100] Katzer, Grundzüge d. Geol. d. unter Amazonasgebietes (Leipzig, 1903), pp. 142–188, 263–268, t. IV–VIII.

are: *Productus lineatus* and *Ambocœlia plano-convexa*, while probably some of the shells referred to *Sp. condor* by Katzer (*e.g.*, *op. cit.*, t. V, Fig. 1) should be identified with *Sp.* cf. *supramosquensis*, and *Pr. nebraskensis* may be the same as the shell compared with *Pr. juresanensis*. But the Amazonian fauna, which is a large one, consists mainly of species not recognized at Barreal. Katzer (*op. cit.*, pp. 246–253) has discussed the relations of this fauna with that of other regions and has referred to the literature on the subject.

The relations of the Argentine fauna to that of the upper Carboniferous of Bolivia, of which the brachiopods alone have been adequately studied, is not close, as is seen by Kozlowski's[101] memoir. But *Ambocœlia plano-convexa* and *Productus lineatus* (= *cora* (pars) Kozl.) are species which the two faunas have in common.

Meyer,[102] in 1914, described marine upper Carboniferous faunas from Peru and Bolivia and discussed their occurrence generally in South America, referring to Stappenbeck's discovery of such at Barreal, but without giving any further particulars. Of the Argentine species, *Productus cora* (including *Pr. lineatus*) alone is mentioned as occurring in Bolivia, but in Peru we note, in addition to this species, *Ambocœlia plano-convexa*. Reviewing the evidence, Meyer assigns all the faunas to the upper Carboniferous and not to the Permian. Douglas[103] in 1914 briefly described a similar fauna of the Titicaca district, ascribing it to the upper Carboniferous or Permo-Carboniferous, and he recognized that a few forms were related to "Permian" forms from the Salt Range. None of the Argentine species appear to occur. In a subsequent paper[104] he records the occurrence of lower Carboniferous fossiliferous beds in southern Peru, but the fauna is quite distinct from that of Barreal.

There is not any very close resemblance with the fauna of any part of the *Productus* limestones of Asia, though a few species are apparently identical and several are allied or comparable. Hayasaka,[105] however, has described a small fauna of brachiopods from the upper Carboniferous of the coal-bearing series of Hon-kei-ko, Manchuria, which includes the following species occurring at Barreal: *Camarophoria* cf. *mutabilis*, *Spirifer supramosquensis*, *Sp. wynnei*, and some other allied species of *Spirifer*.

If we accept Holland's correlation of the *Productus* limestones[106] we only find *Spiriferina zewanensis* of the Zewan beds as a Permian form, though *Pleurotomaria advena* is more allied to an upper *Produc-*

[101] Kozlowski, Brach. Carb. Supér. Bolivie, Annales de Paléont. IX, 1914, pp. 1 to 100 Pls. I to XI.

[102] Meyer, Neues Jahrb. f. Mineral. etc., Beil. Bd. XXXVII, 1914, pp. 590–651, t. XIII, XIV.

[103] Douglas, Quart. Journ. Geol. Soc., vol. LXX, 1914, pp. 30–37, Pls. VIII, IX.

[104] *Ibid.*, vol. LXXVI, 1920, p. 41.

[105] Hayasaka, *op. cit.*, 1922, pp. 117–137.

[106] Holland, Mem. Geol. Surv. India, vol. LI, pt. 1, 1926, p. 22.

tus limestone species than to any other. *Productus lineatus* and *Ambocœlia planoconvexa*, though occurring in the Zewan beds, are abundant also on lower horizons and in the so-called upper Carboniferous of Russia and America. *Chonetes granulifer* is typically a Pennsylvanian species; and the species *Sp. supramosquensis* is characteristic of the Gshelian, which occurs immediately above the Moscovian and is therefore well below the Permian. If we look at the rest of the species from Barreal, we observe that nearly all are closely allied to or comparable with established species from either the lower Carboniferous of Europe or the middle or upper Carboniferous of Russia or North America, and that none are limited to undisputed Permian beds. Thus among the new forms, *Spirifer saltensis* shows close affinities with some examples of *Sp. duplicicosta* of the lower Carboniferous; *Sp. barrealensis* is especially allied to *Sp. boonensis; Reticularia notica* is related to *R. setigera* of the lower Carboniferous; *Pseudamusium stappenbecki* has affinities with upper Carboniferous species; *Pleurotomaria argentina* closely resembles a species from the Pennsylvanian of the United States, and *Pl. barrealensis* is like an upper Carboniferous form from Sumatra.

Thus the weight of evidence from the fossils leads us without hesitation to refer this fauna from Barreal to the *Carboniferous*, and it seems that it should not be placed at the top of that formation, but probably *toward the base of the upper division.* It is interesting to note that Holland (*op. cit.*) places the glacial boulder bed of the Salt Range in the Carboniferous, for the tillite of Barreal is stated to pass up into and even include some of the beds from which the present collection of fossils was obtained.

TRIASSIC FOSSILS FROM RÍO CLARO, PARANÁ, BRAZIL

The following species have been determined provisionally from the material forwarded by Doctor Du Toit, but it is intended to publish full descriptions and figures elsewhere at some later date. The fossils from the upper zone have presented difficulties in their identification owing to their occurrence in the form of casts.

LOWER HORIZON—ZONE 1:

Pachycardia aff. *rugosa* Hauer.
Anodontophora aff. *trapezoidalis* Mansuy.
Trigonodus aff. *rablensis* (Gredler).
Radiolaria (not determinable).

UPPER HORIZON—ZONE 2:

Pachycardia neotropica sp. nov.
Myophoria (*Myophoriopis*) aff. *carinata* Bittn.
aff. *lineata* Münst.
Megalodus ? *neotropicus* sp. nov. cf. *triqueter* (Wulf).
Gonodon (*Schäfhautlia*) *paranaense* sp. nov.
Modiola aff. *subcarinata* Bittn.

Solenomorpha in the sense used by Holdhaus is not represented in the collection, nor are there any species common to the two zones. Permian forms are absent, the fossils from both horizons displaying undoubted Triassic characters suggestive of the upper rather than the lower Trias.

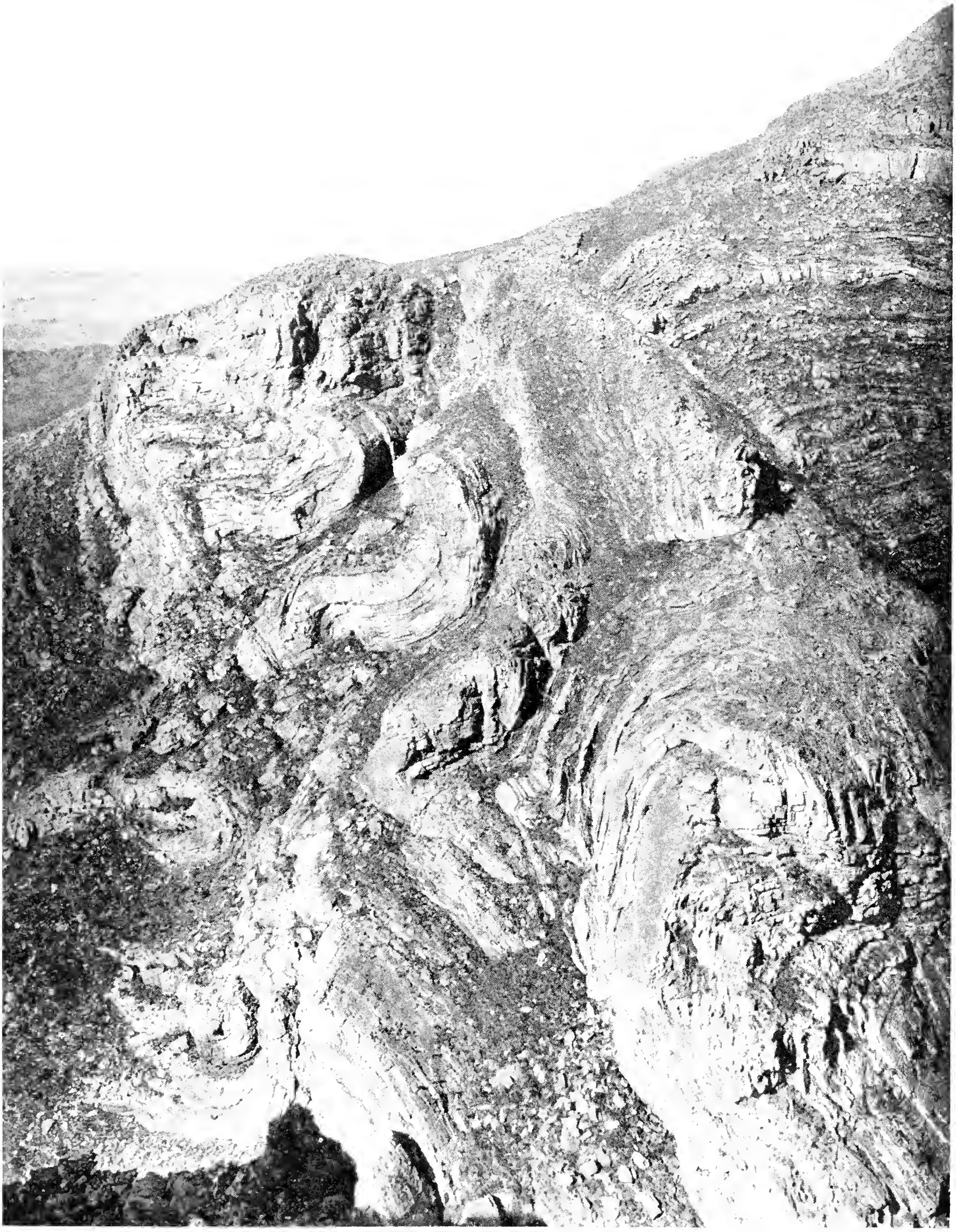
INDEX

Authorities Cited in the Text

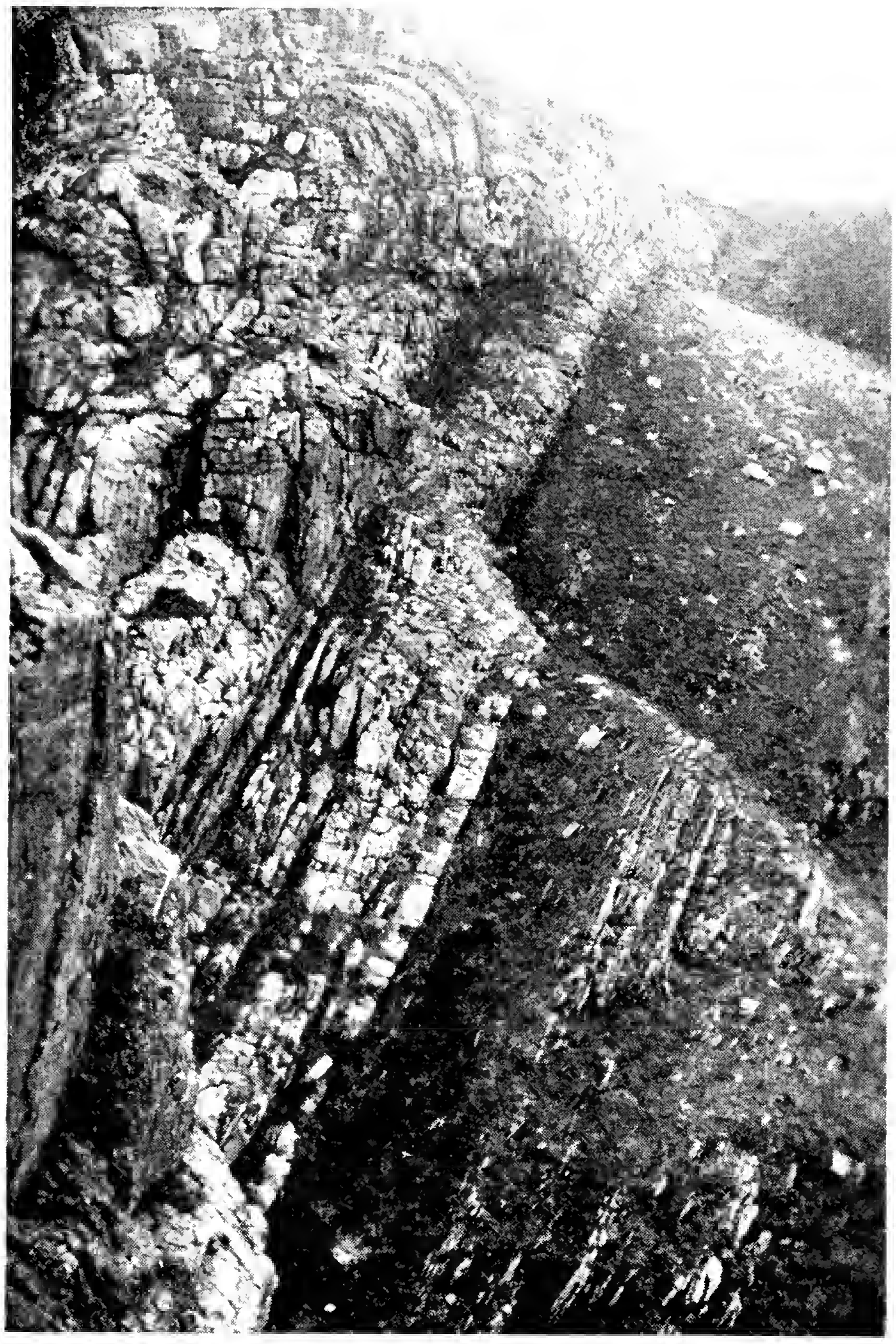
Fossils Described in Appendix

General

PLATES

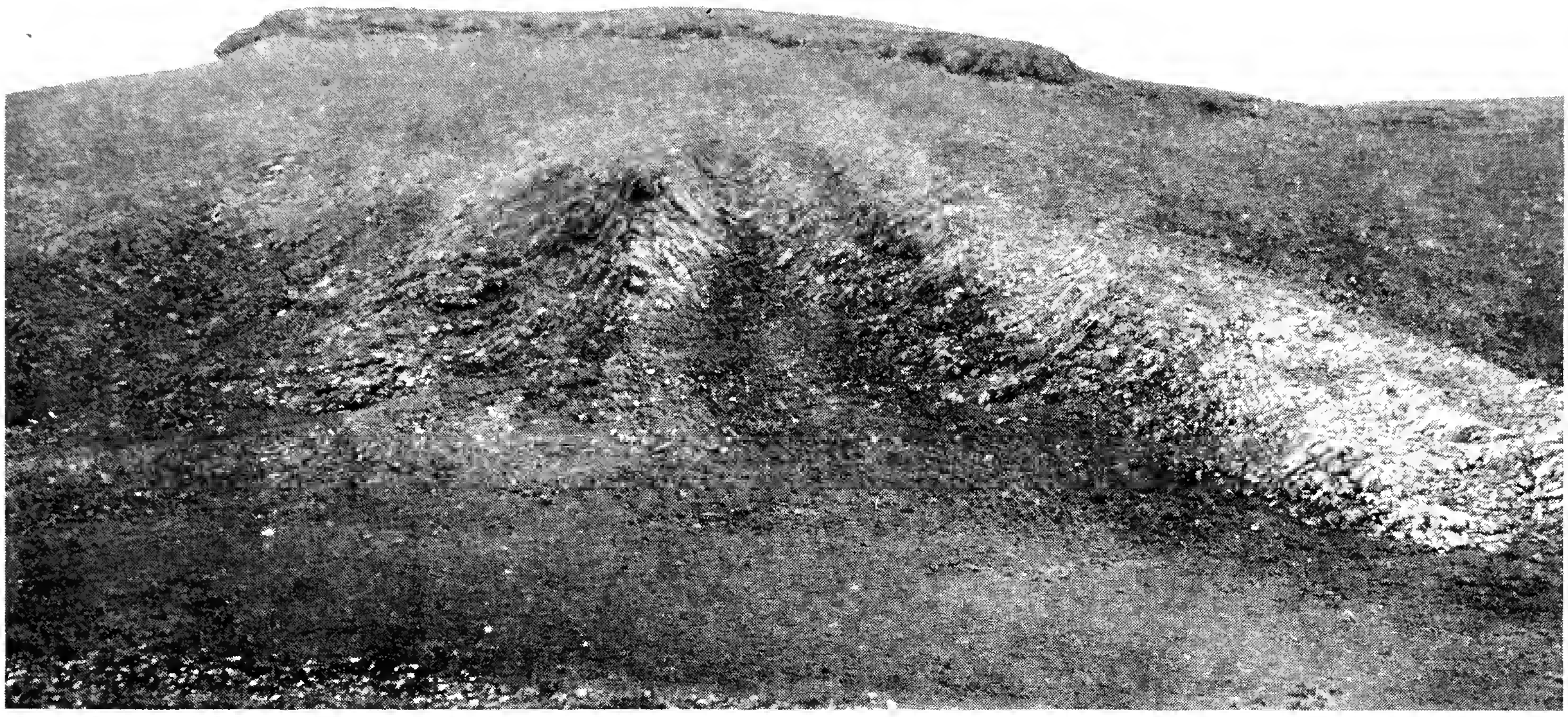


Folded Devonian quartzites north of the Cerro Napostá Grande, looking east
From a photograph by Dr. R. Beder

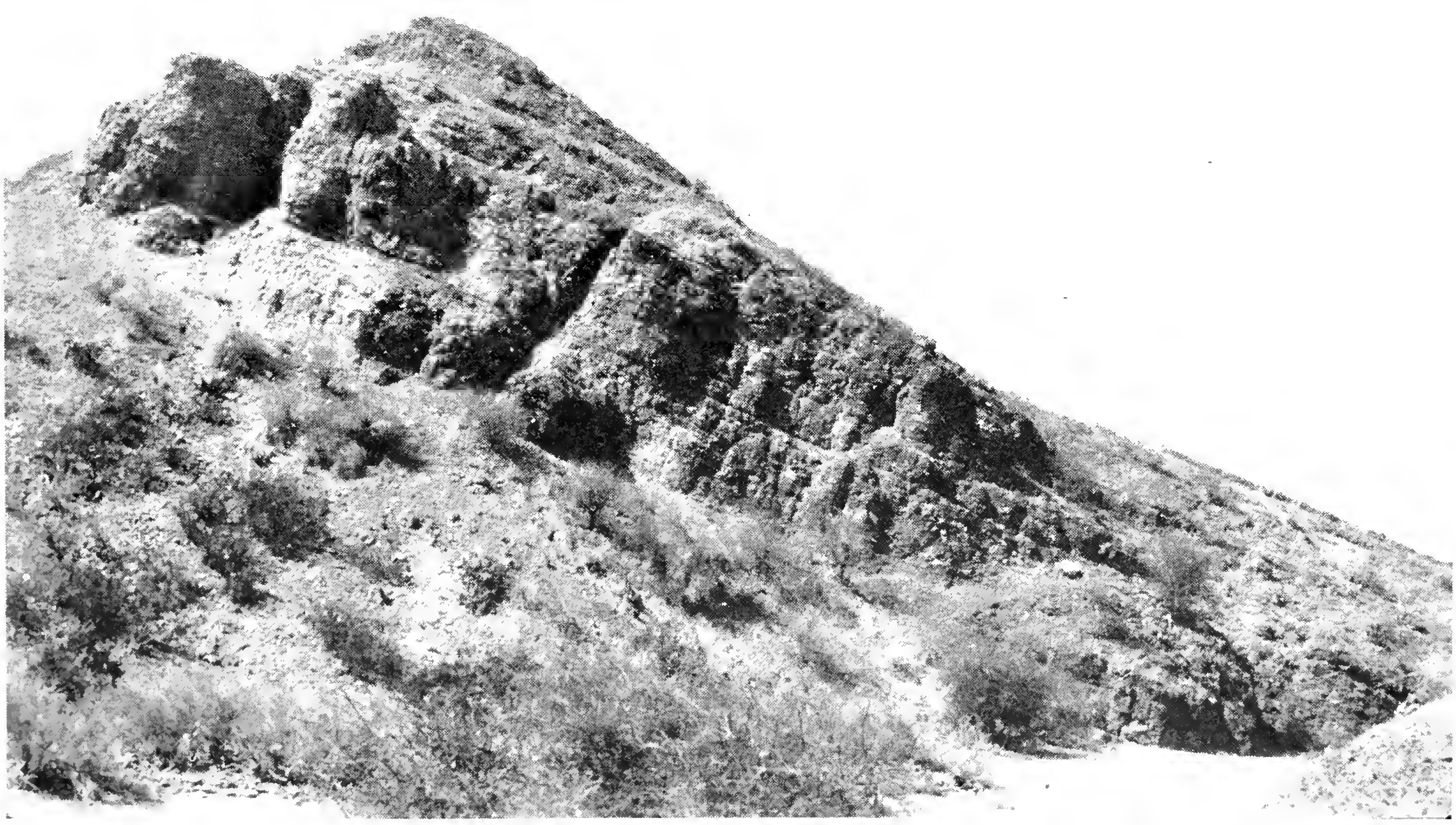


A—Shale band in quartzites of the Sierra de la Ventana gorge below the Tres Picos

B—Cleavage in tillite, railway cutting a little northeast of Sierra de la Ventana station



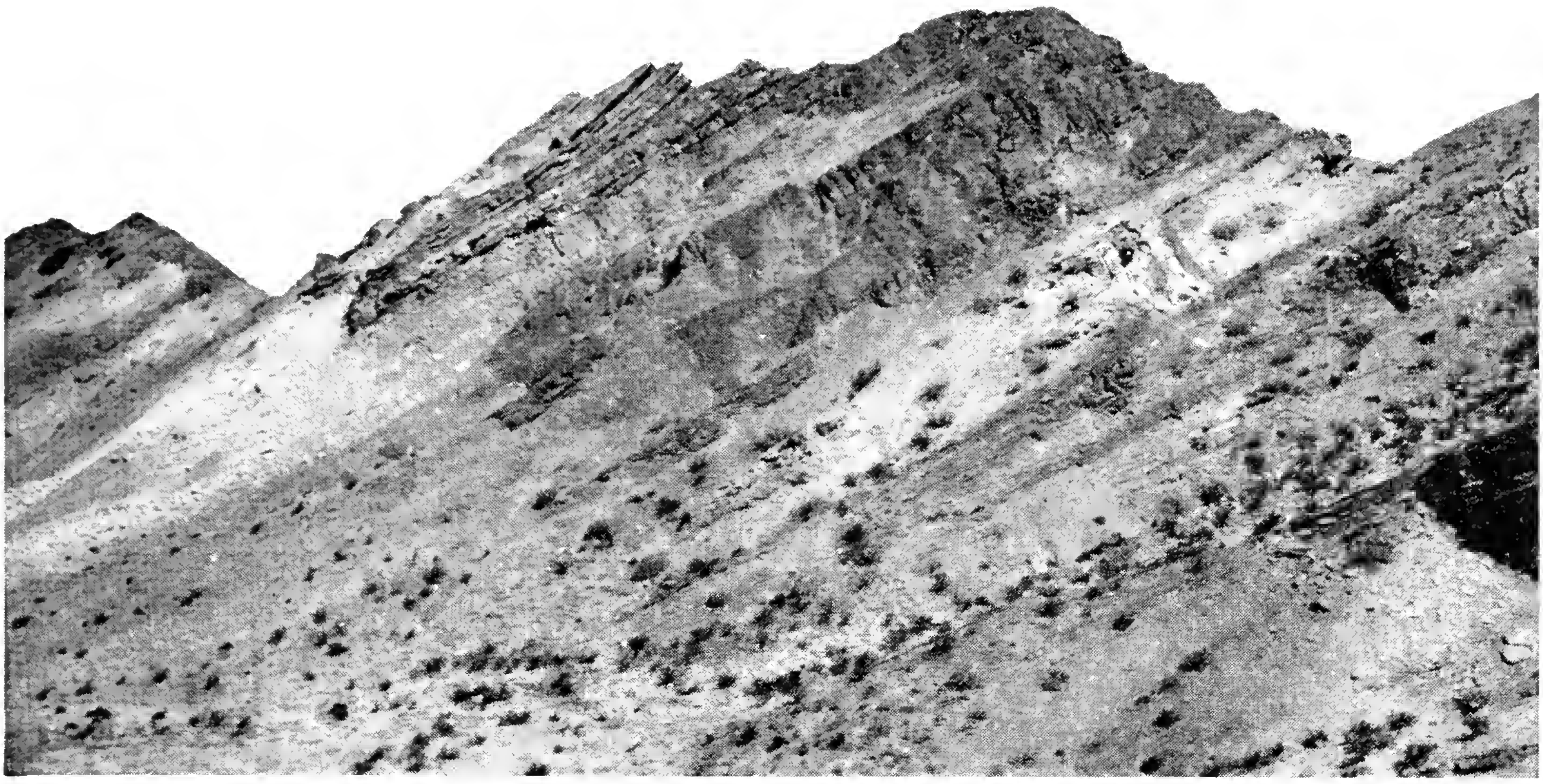
A—Tertiary "high-level gravels" on folded Devonian beds, west side of the Arroyo San Bernardino, Sierra de la Ventana



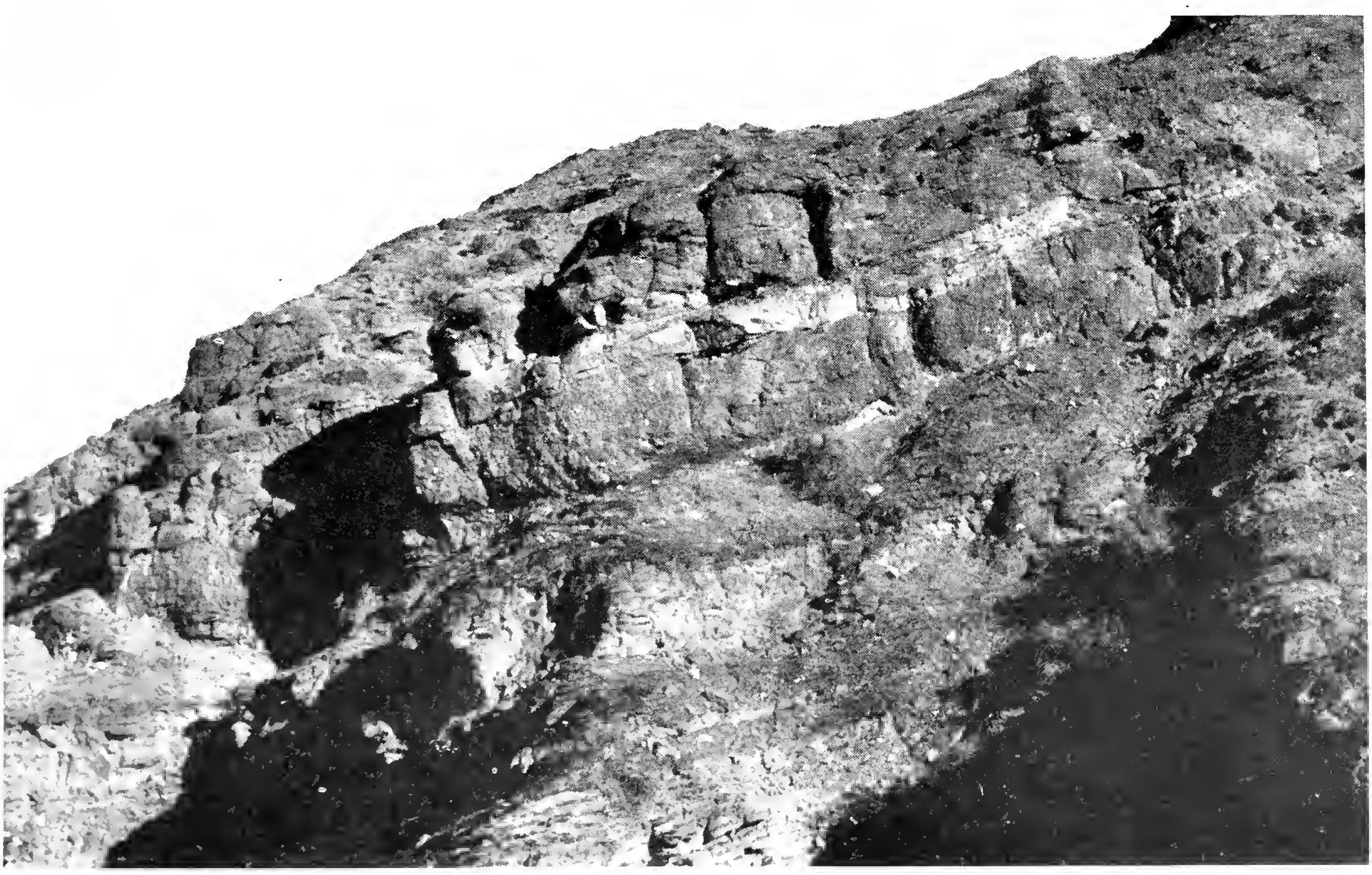
B—Lower glacial zone, immediately to the north of the Río Grande, Sierra Chica de Zonda, San Juan

A—Glaciated surface of Ordovician limestone beneath lowest glacial zone, a little north of the Río Grande, Sierra Chica de Zonda, San Juan; the hammer indicates the direction of the glacial striae

B—The lowest glacial zone, resting on tilted Palaeozoics, followed by plant-bearing shales crowned with sandstones, a little north of the Río Grande, Sierra Chica de Zonda, San Juan

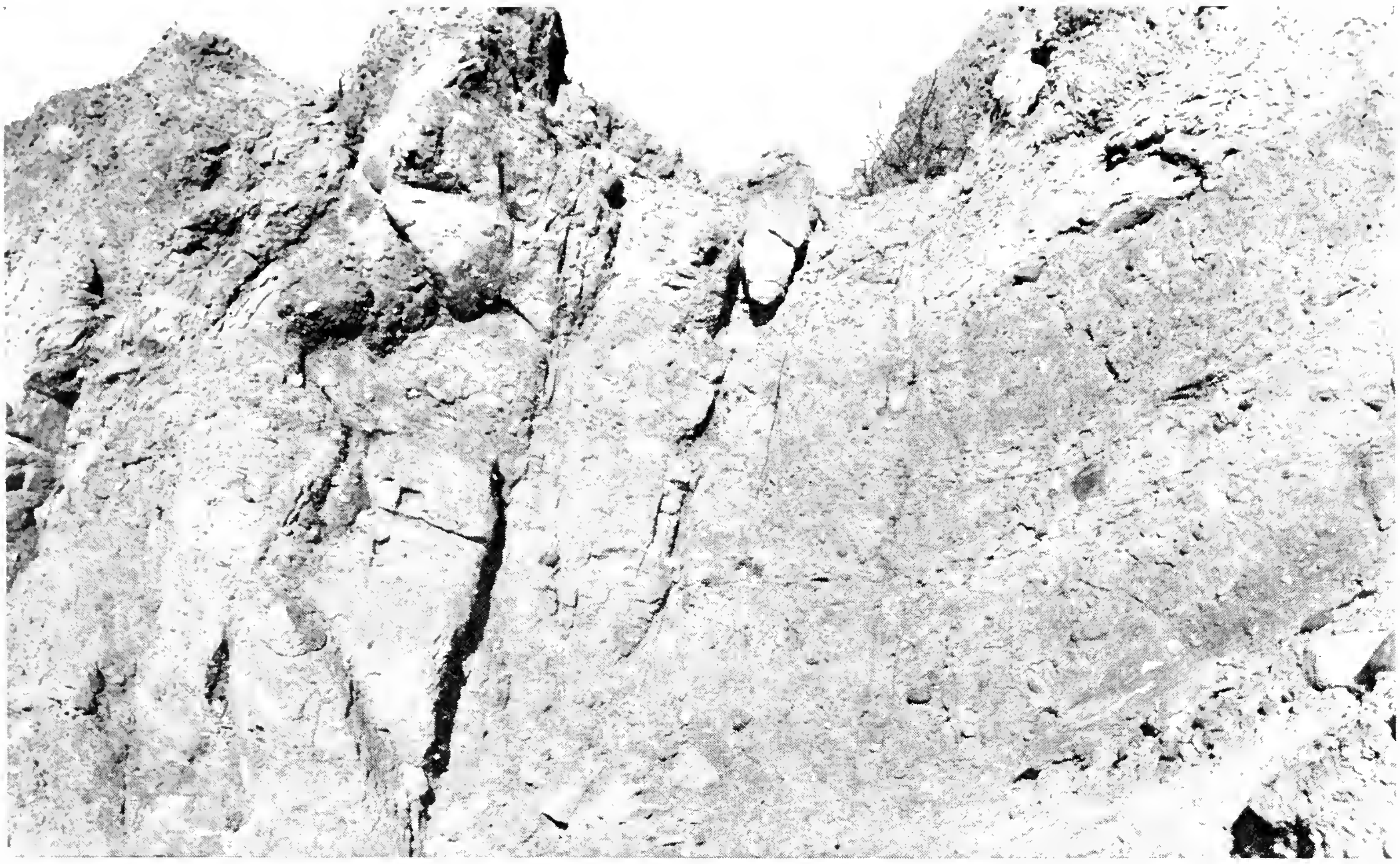


A—Second glacial zone, a little north of the Río Grande, Sierra Chica de Zonda, San Juan. The dark tillite forms the central peak and is sandwiched between well-stratified beds; the third glacial zone forms the point on the extreme left



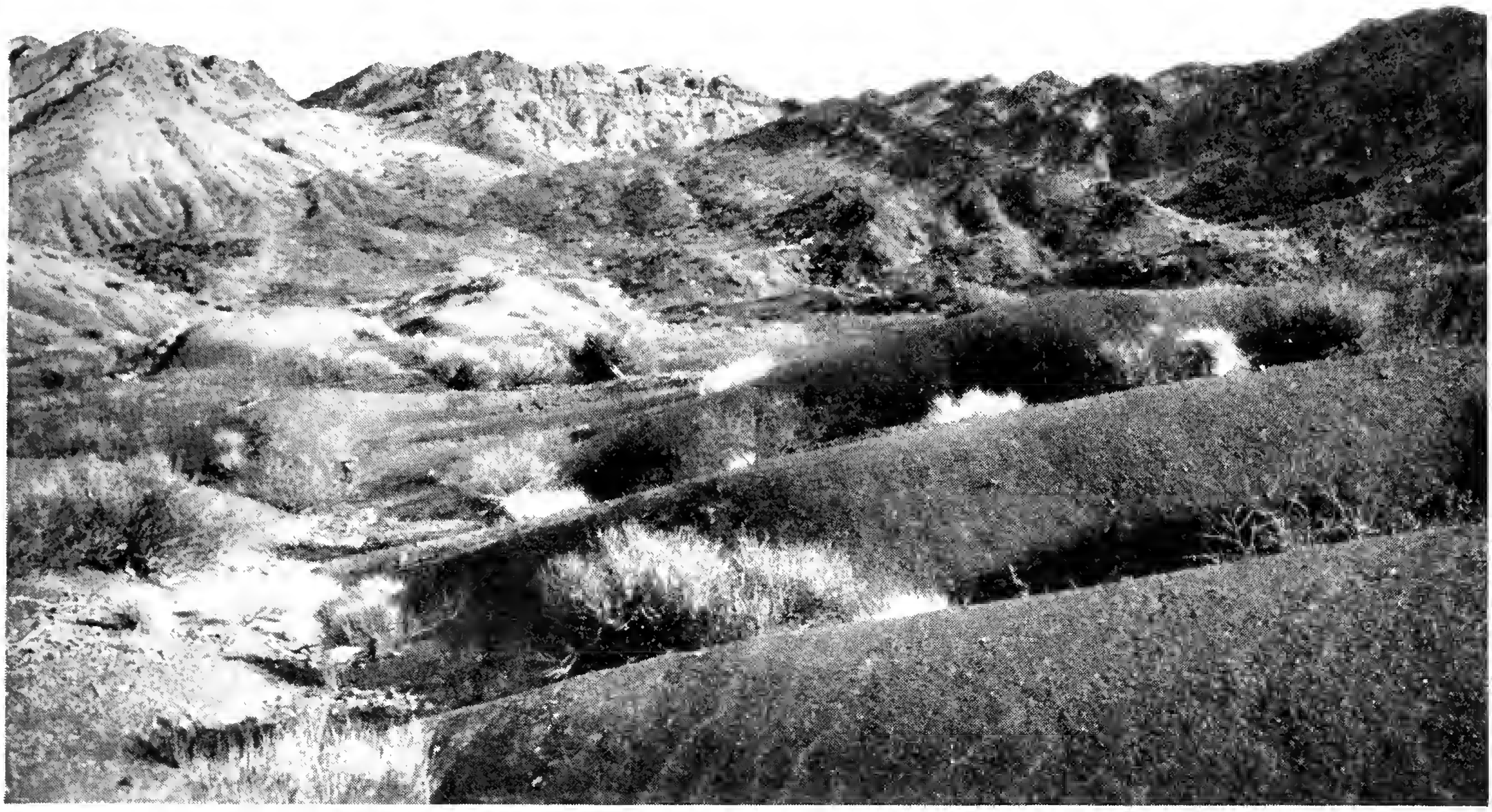
B—Second glacial zone, Arroyo de Jejenes, San Juan. Below are sandstones, followed by the glacials with lens of sandy material and overlain by sandstones which form the summit of the cliff

The second glacial zone, Arroyo de Jejenes, San Juan, showing lenticular band of sandy material



A—The second glacial zone, Arroyo de Jejenes, San Juan, showing practically unstratified tillite

B—Dome in Paganzo beds, followed by tilted Calchaqueños and overlain by horizontal Quaternary gravels; west of Carpinteria, San Juan

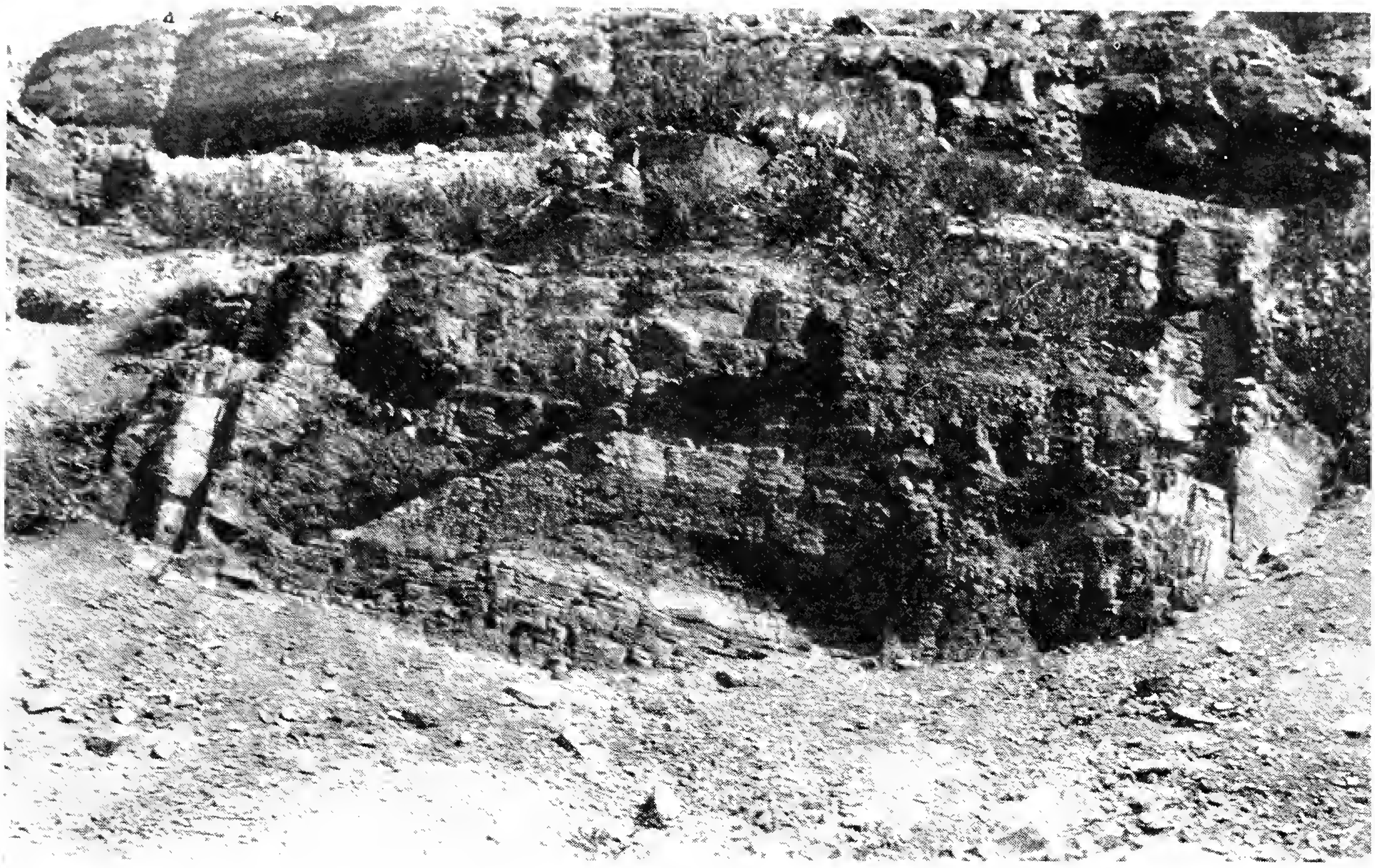


A—Dome in Carboniferous beds near Quebrada del Salto, Barreal, San Juan, showing in foreground boulder shales and fossiliferous shales, followed by sandstones forming the hills in the background

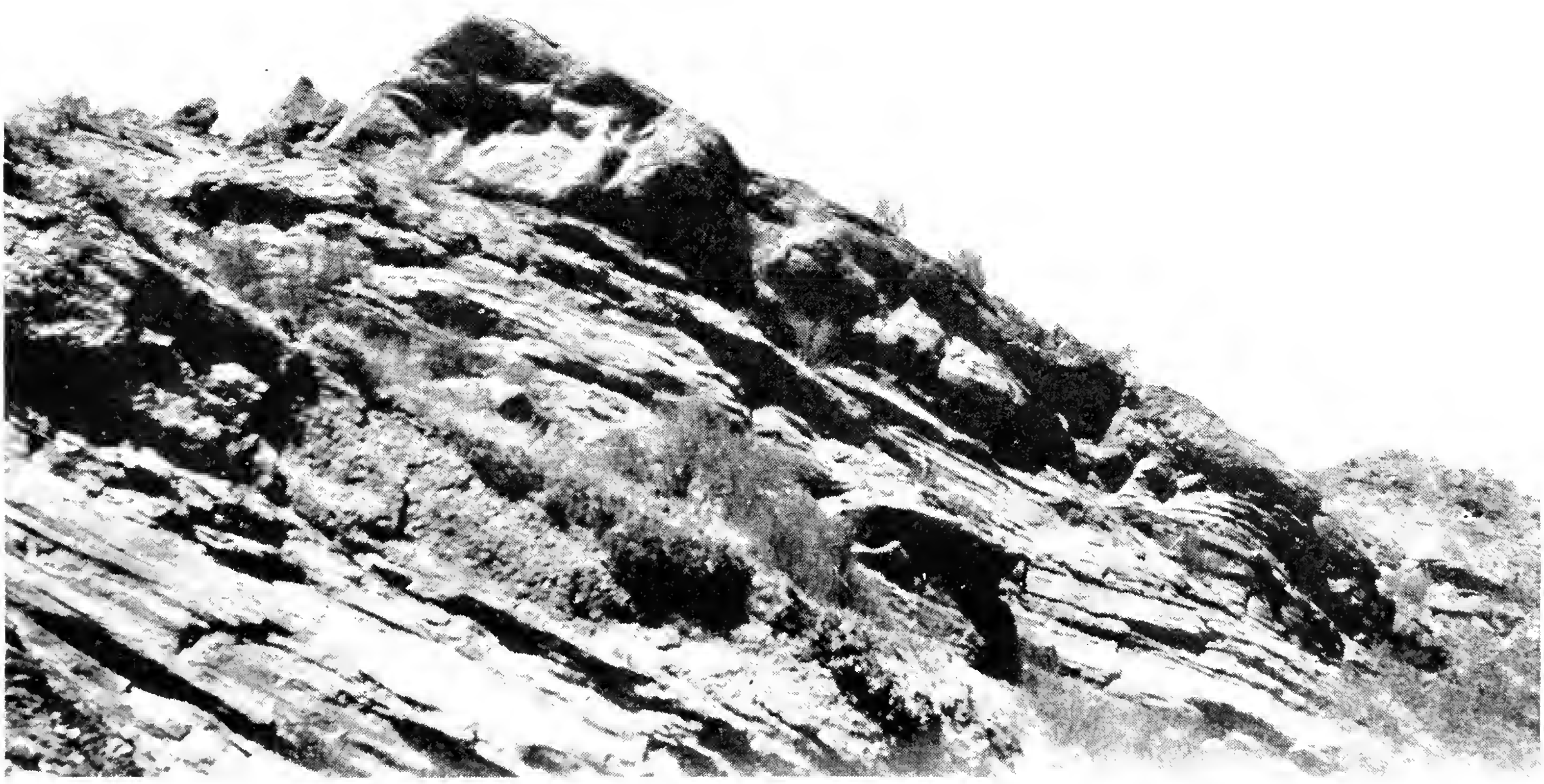
B—Plant-bearing Paganzo beds, Bajo de Velis, Sierra de San Luiz. The range in the background is made of crystalline rocks

A—Triassic plant-bearing strata of Stage IV, Quebrada del Jarillal, Barreal; on extreme right beds of Stage V

B—Triassic beds of Stage IV, overlain by the red conglomeratic strata of Stage V, Quebrada del Salto, Barreal, San Juan

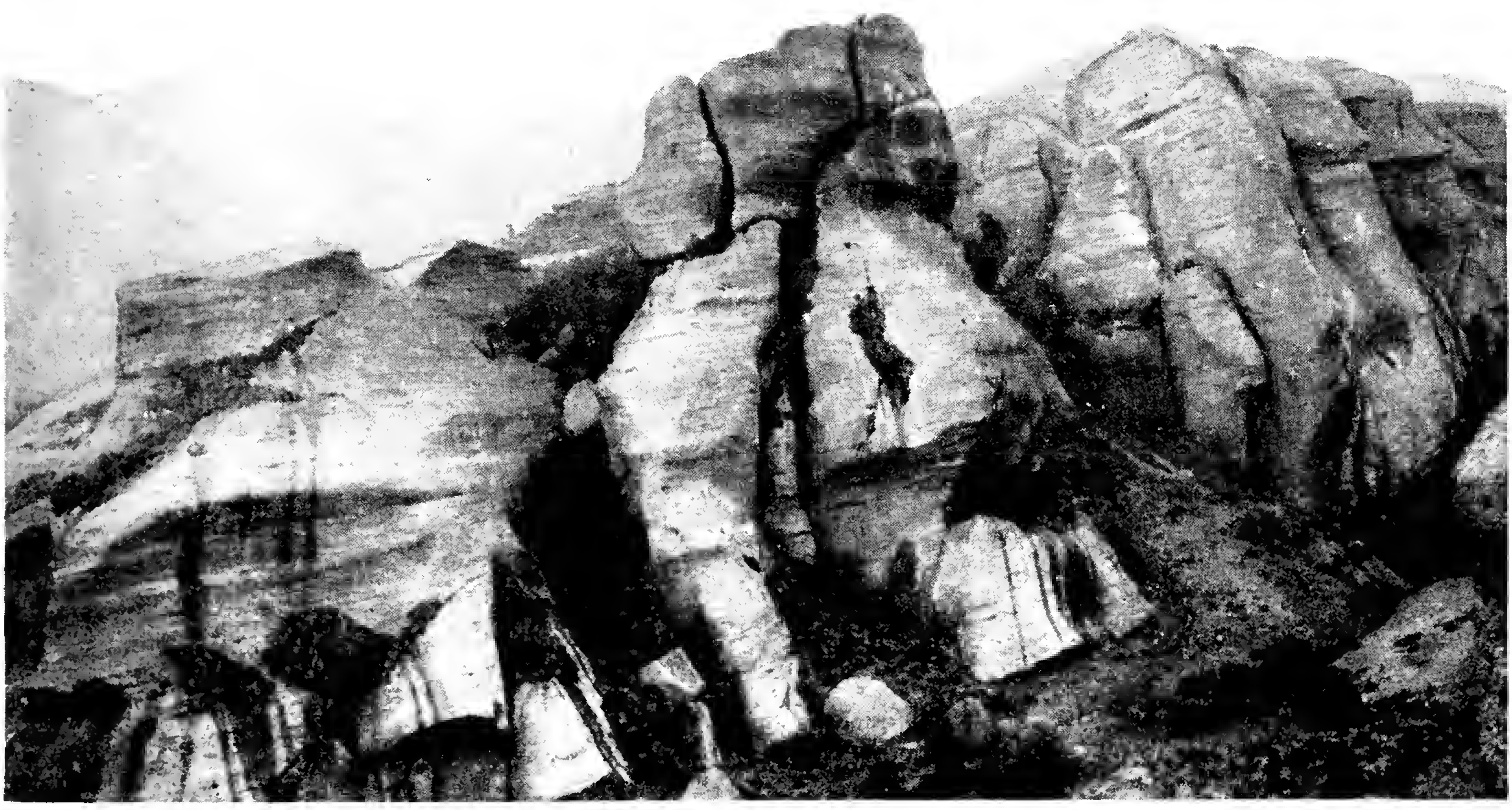


A—Tree trunks standing erect in Triassic volcanic ash, Paramillo de Uspallata



B—Tilted sandstones and conglomerates of the coal-bearing section of Stage IV, Carrizal, near Marayes, Sierra de la Huerta, San Juan

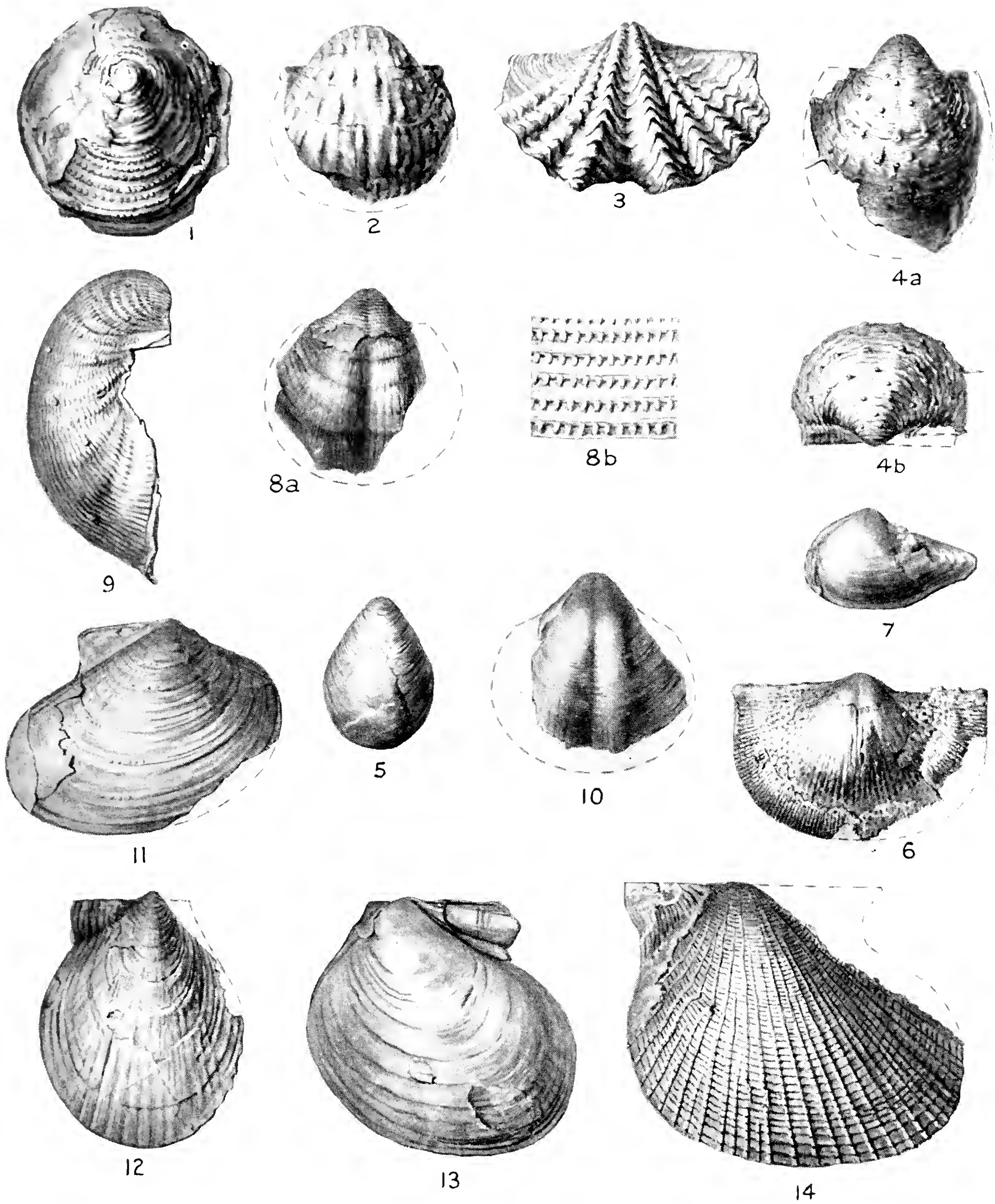
A—Red Triassic conglomerates, Saldan, north of Córdoba



B—Triassic conglomeratic sandstones, Los Terrones, near Capilla del Monte, Sierra de Córdoba

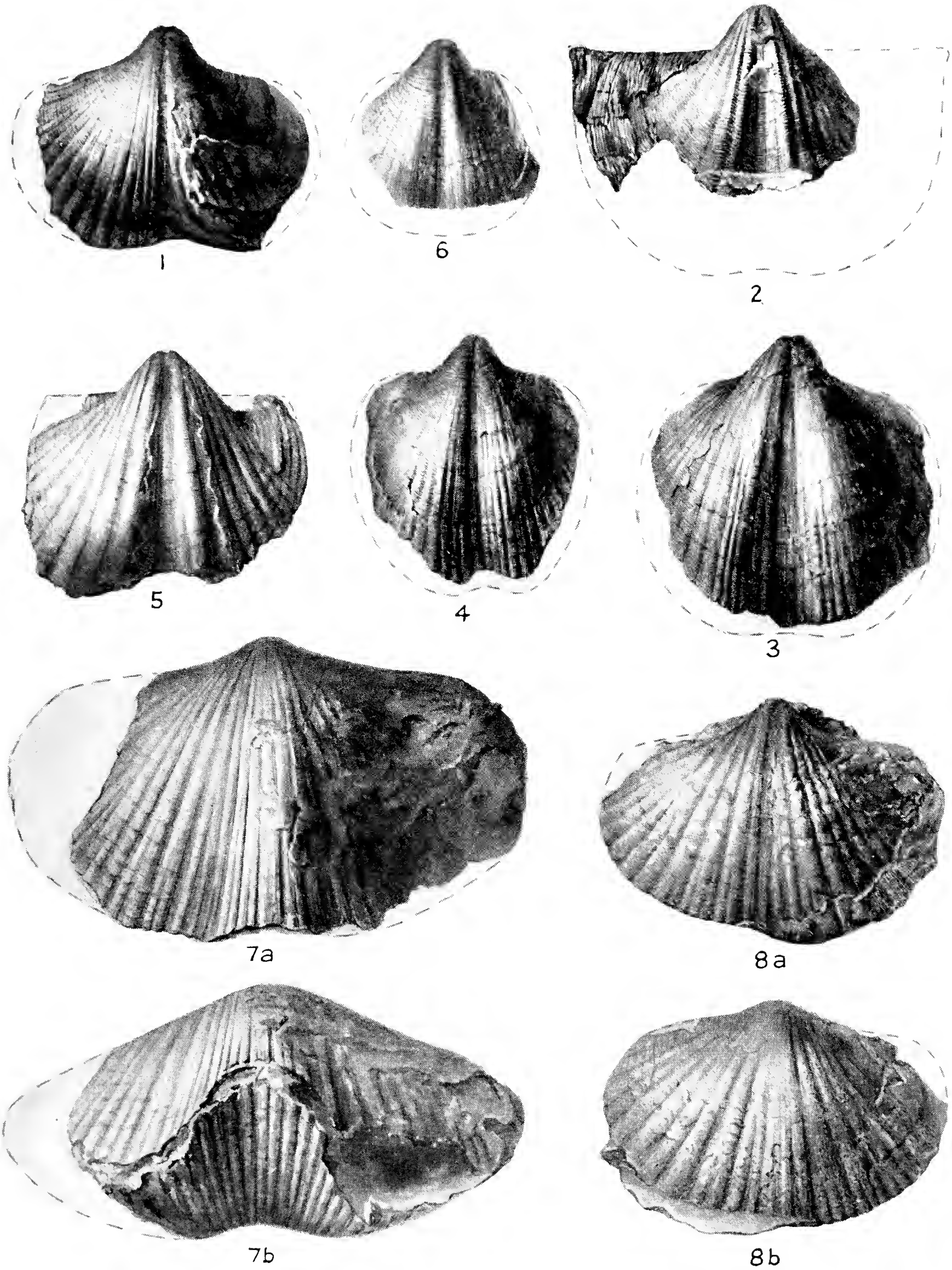
A—Devonian Furnas sandstone, showing current-bedding. East of Ponta Grossa, Paraná

B—Rio do Rasto "millet-seed" sandstones, municipal quarry, Taquara, near Porto Alegre. The marked dip from left to right is due to false bedding, the formation being actually horizontal



Carboniferous Fossils, Barreal, Argentina

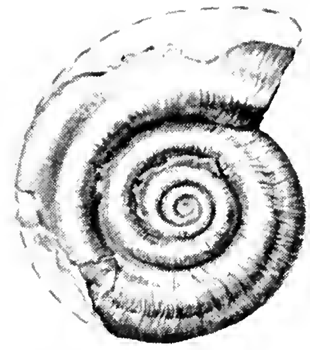
(1) *Orbiculoidea saltensis* sp. nov. (7335), upper valve. × 1.5. (2) *Productus* (*Marginifera*) *spinulo-costatus* Abich var. nov. *peregrina* (7374), pedicle-valve. × 1.25. (3) *Spiriferina zewanensis* Diener (7312), pedicle-valve. × 1.5. (4*a*, 4*b*) *Productus curvirostris* Schellwien var. nov. *barrealensis* (7315), pedicle-valve. *a*, top view; *b*, front view. × 2. (5) *Hemiptychina* cf. *sublævis* Waagen (7300), pedicle-valve. × 3. (6) *Chonetes granulifer* Owen (7319), pedicle-valve (shell partly wanting). × 1.5. (7) *Nuculana* (*Leda*) cf. *bellistriata* Stevens (7339), internal cast. × 2. (8*a*, 8*b*) *Reticularia notica* sp. nov. (7326); *a*, pedicle-valve. × 1.5; *b*, portion of shell. × 8. (9) *Productus lineatus* Waagen (7365), side view, pedicle-valve. × 2. (10) *Reticularia notica* sp. nov. (7445), pedicle-valve. × 1.5. (11) *Pseudamusium stappenbecki* sp. nov. (7291), left valve. × 1.5. (12) *Pseudamusium* cf. *ellipticum* (Phillips) (7304), left valve. × 1.5. (13) *Pseudamusium stappenbecki* sp. nov. (7290), right valve. × 1.5. (14) *Aviculopecten barrealensis* sp. nov. (7362), left valve. × 4.



Carboniferous Fossils, Barreal, Argentina

(1) *Spirifer* cf. *supramosquensis* Nikitin (7316), pedicle-valve. × 1.25. (2) *Spirifer barrealensis* sp. nov. (7371), pedicle-valve. × 1.5. (3) *Spirifer mexicanus* Shumard var. nov. *neotropica* (7366), pedicle-valve. × 1.25. (4) *Spirifer mexicanus* Shumard var. nov. *neotropica* (7375), pedicle-valve. × 1.25. (5) *Spirifer* aff. *rajah* Salter (7317), pedicle-valve (anterior part bent underneath). × 1.5. (6) *Spirifer* (*Martinia*) cf. *simensis* Tschernyschew (7363), pedicle-valve. × 1.5. (*7a*, *7b*) *Spirifer Wynnei* Waagen var. nov. *argentina* (7309), *a* brachial valve, × 1.25; *b* front view. × 1.25. (*8a*, *8b*) *Spirifer saltensis* sp. nov. (7296); *a*, pedicle-valve. × 1.5; *b*, brachial valve. × 1.5.

1



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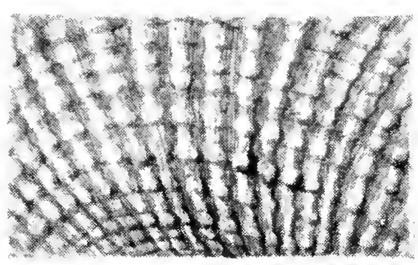

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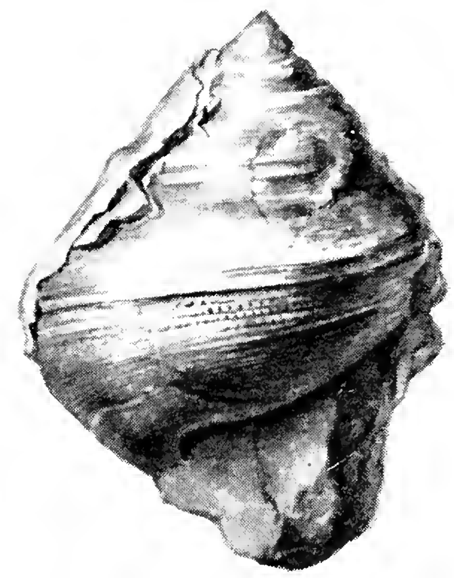

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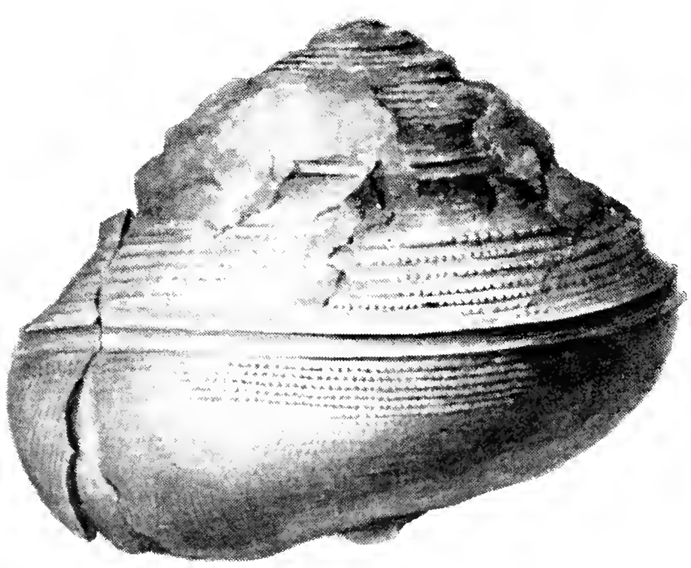
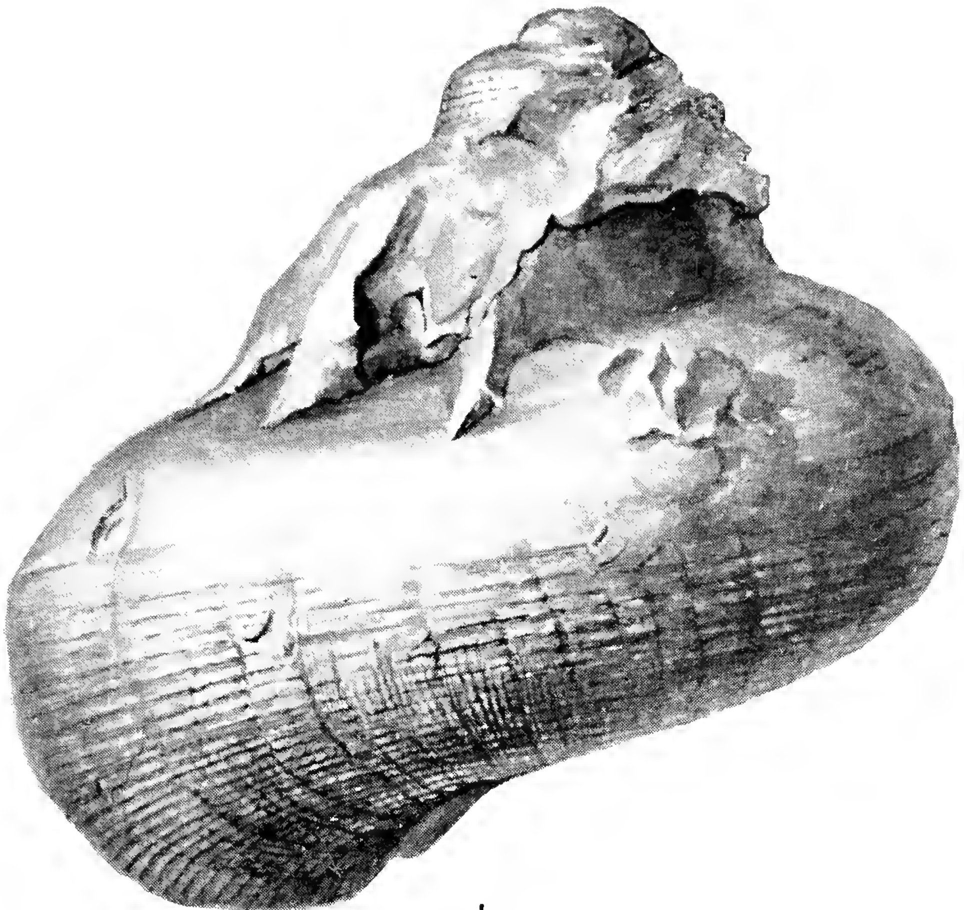


5

Carboniferous Fossils, Barreal, Argentina

(1) *Euomphalus subcircularis* Mansuy (7328), base. × 1. (2) *Euomphalus subcircularis* (7344) apical surface. × 1.25. (3*a*, 3*b*, 3*c*) *Pleurotomaria argentina* sp. nov. (7334); *a*, *b*, side-views. × 1.5; *c*, portion of base. × 6. (4) *Euomphalus subcircularis* (7322), apical surface. × 1.25. (5) *Pleurotomaria advena* sp. nov. (7355). × 1.5.



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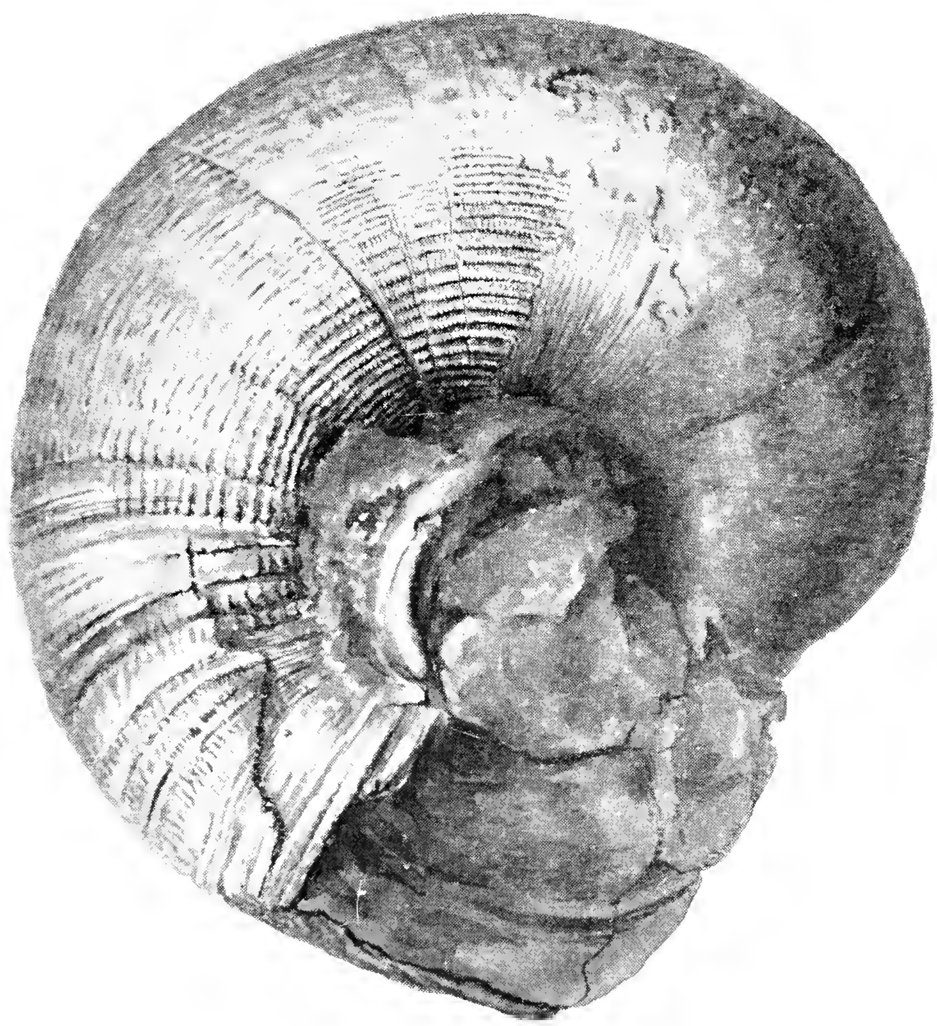
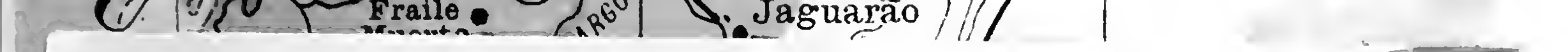
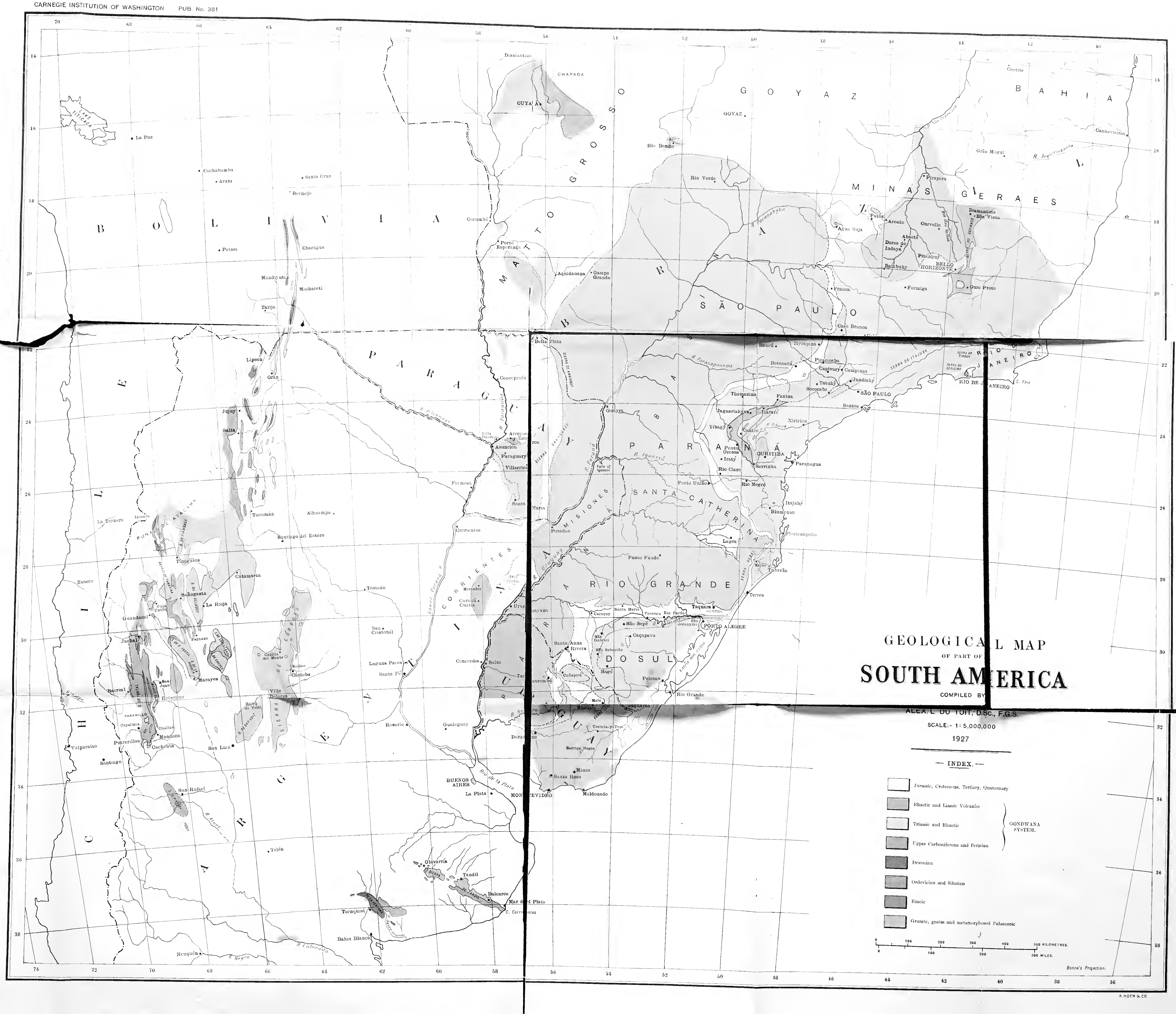


1b

Carboniferous Fossils, Barreal, Argentina

Pleurotomaria barrealensis sp. nov. (7323); *a*, side view. × 1.5; *b*, base, × 1.5.


Fraile
Jaguarão


GEOLOGICAL MAP
OF PART OF
SOUTH AMERICA
COMPILED BY
ALEX. L. DU TOIT, D.Sc., F.G.S.
SCALE:- 1: 5,000,000
1927
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Rhaetic and Liassic Volcanics
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500 KILOMETRES.
300 MILES.
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A. HOEN & CO.
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