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The Lateritic Soils of Western Queensland
Late Tertiary Limestones in Queensland and their Significance
The Evolution of the Barkly Tableland
Changes in the Valley of the Flinders River
The Climates of Queensland since Miocene Times

BY

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In recent years I have had considerable financial assistance in the field work from the University of Queensland and the research funds of the Commonwealth Council for Scientific and Industrial Research. I gratefully record these benefits.

STUDIES IN THE LATE GEOLOGICAL HISTORY OF QUEENSLAND.

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2. Late Tertiary Limestones in Queensland and their Significance (p. 23).

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4. Changes in the Valley of the Flinders River (p. 58).

5. The Climates of Queensland since Miocene Times (p. 62).

by

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(Plates I.-III.; text-figures 1-14.)

Explanation:

It has been my opportunity to travel the more sparsely settled parts of Western Queensland on many occasions during the past nine years. The geological and topographical features of those parts of the State still are only generally known. But, as may well be understood for such a vast area, the more one sees of a region in such a manner the less inclined one is to write about it. However, with other duties now arising that, for some time at least, may limit those opportunities, it has been thought advisable to assemble and place on record some of the ideas that slowly in this way have come to mind. As a first contribution these five studies are offered. They do not pretend to be a statement of late Tertiary events in Queensland; for very many aspects of which much is now known—the volcanic history, for example, and the features of the coast—are mentioned only slightly if at all. They are merely a plexus of four themes, distinct yet interwoven, the whole fabric of which is the subject of the final essay.

1. THE LATERITIC SOILS OF WESTERN QUEENSLAND.

Summary: The distribution of residuals of laterite clearly indicates that such soils once covered practically the whole of Queensland west of the Great Divide. The soil profiles vary slightly according to the parent rock; but an assemblage of three types characterised respectively by excess of iron oxide, kaolin and silica is common. There were at least two periods of laterite formation in Pliocene times. The soils seem to have been formed in warm climates of steady rainfall. A period of seasonal rains followed in which the lateritic plateau was deeply dissected and a series of derivative soils formed by physical and chemical agencies. The distribution of the residuals is related intimately to the physiographical peculiarities of the region and allows a reconstruction of the Miocene landscape. Some observations are offered on the origin of laterite soils.

It has been established by Woolnough (1927), Prescott (1931) and others that lateritic soils, no longer in the process of formation, are widespread in Australia, including considerable portions of Queensland. Bryan (1939) has discussed the age and origin of such fossil soils as they occur in south-eastern Queensland. The present note is to summarise the evidence for such soils in this State west of the Great Divide.

No group of soils has been discussed so diversely as the laterites. The meaning of the name laterite, what is a typical profile, is the presence of free alumina an essential, under what climatic conditions do such soils form, are they being formed to-day, is there a necessary topographic control—these and other matters have been debated intensively. In all this argument there is one point of general agreement: laterites are soils formed under conditions of very great leaching—that is to say in areas of high rainfall.

There is a progression in the compounds that, with increasing percolation, may be leached from the soil, the progression being: salt, gypsum, lime, clay, iron oxides and silica. It now seems to be generally accepted that the term laterite be applied to what is virtually the end point of this grade, that is to the soils that show considerable leaching of silica. A recent British definition (Imperial Bureau of Soil Science, 1932, p. 4) reads: " The word laterite is used throughout to denote a product of rock weathering formed *in situ*, by the leaching of the bases and much of the silica from the original rock, leaving a residue containing varying amounts of alumina uncombined with silica."

Mohr (1930, *fide* Pendleton 1936 *q.v.*) has shown that such a soil with silica depletion in the upper portions has typically three layers: an upper layer with a concentration of iron oxides; a middle layer mostly of kaolin; and a lower layer of cemented silicates. The second or kaolin-rich layer is typically spotted or mottled with iron oxides.

Accepting such a soil as a true laterite it may be claimed without hesitation that laterites are widespread in western Queensland. Little chemical investigation of soils has been made in this region, so that the relative amounts of free alumina (or its hydrates) in such profiles is not known. But the triune of ferruginous, kaolinic and siliceous deposits is so frequent and the horizons themselves are so typical in physical aspect that it is beyond suspicion that these are lateritic soils. Even when one or other of the horizons locally is missing from the sequence such variants clearly are due either to some subsequent, physical, surface change or to some controlling factor in the composition of the parent rock (*e.g.* low original silica and alumina values in a limestone), and not to any variation in the essential soil-forming process.

Although incomplete, since now they are being dismembered by erosion, there are great sheets of soils still *in situ* that here will be referred to as laterites. These together with their derivatives—soils formed either by subsequent chemical changes of the laterites or by transportation, by wind or water, of their component parts—will be called lateritic soils.

PREVIOUS RECOGNITION.

Over the Great Artesian Basin in western Queensland there are, in general, two types of soils—a pedocalcic group that grows rich Mitchell grass, and a series of lateritic soils that has other and a varied vegetation. Since these latter soils are not so well grassed, since also they frequently are red and have sand drifts upon them, the areas in which they occur are spoken of familiarly by the pastoralists as " desert." It is a curious but premeditated misuse of a technical term, awkward because true deserts occur within the limits of the State. It is thereby not implied that such areas are of little value. On the contrary they grow valuable fodder that is particularly useful and lasting in times of drought, so that the " desert " areas usually are desirable portions of a pastoral holding.

It was probably with this practice in mind that Daintree in 1872 (p. 277) used the name " Desert Sandstone " for such residuals. However by an unfortunate designation of a type section for the group (see below, p. 61) the name becomes ineligible in the sense for which clearly Daintree meant it. Nevertheless, such a picturesque term survived for generations of Queensland geologists, usually though not invariably for these old soils. That essentially they were soils was not generally recognised until relatively recently.

I do not propose to catalogue all references in Queensland literature to such soils. It may be noted, however, that since the time of Daintree there have been five stages in the history of their treatment in Queensland. At first they were regarded as a sedimentary series and described in purely general terms. Such was the treatment by Jackson (1902) and Danes (1910) each of whom was concerned with vast areas of this material. In spite of the fact that, in New South Wales, David had described laterites, as such, in 1889, the name does not appear to have been used in Queensland literature until 1913 when Marks (pp. 8-11) compared a dissected sheet of material in the Charters Towers region with the laterites of India. Marks, however, still regarded this as a sedimentary series, although not transported very far. Eight years later Saint-Smith (1921, p. 359), dealing with the same locality, showed that this lateritic material was not a transported sediment but was formed *in situ*. Subsequently Dunstan, to judge from conversations, was of the opinion that the laterites were formed from rocks of many different ages; although his only pertinent published statements (e.g. 1916, p. 165) are from earlier writings and are to the effect that the Desert Sandstone (in part) ranges from Tertiary to Jurassic. Finally Woolnough (1927) and Bryan (1939) have treated the Queensland lateritic deposits as soils with recognisable horizons and with definite stratigraphical, physiographical and climatic significance.

On sundry occasions one or other of the three soil horizons has been regarded as of igneous origin or relationship. By confusion with known basaltic red loams, particularly in the coastal regions, the deep red soils of the uppermost horizon of any laterite or red earth profile still are quite commonly believed to be " volcanic soils." Tenison-Woods (1889, p. 334), grouping many unrelated rocks as " Desert Sandstone," including much of what is now known to be exposed areas of mottled zone material, suggested that " the whole of these formations, except the conglomerate, are probably derived from volcanic ashes." After it had been shown that some surface quartzites in south-eastern Queensland were due to the metamorphism of sandstones by basalt flows, Dunstan (1916, p. 164) suggested a similar origin for the surface quartzites of western Queensland that here are placed as the silicified zone of the laterites. In each instance the assumption that all formations of that type have an igneous origin is unwarranted. Lateritic soils derived from igneous rocks are of course known. But relative to other laterites they are no more abundant than the proportion of igneous to non-igneous rock outcrops; and in western Queensland, where igneous rocks are few, such soils of igneous parentage are very rare.

SOME GENERAL ASPECTS.

Although many isolated residuals occur, some of considerable extent in intervening areas, the lateritic soils of western Queensland* may be grouped into four major regions thus (fig. 1):

(i.) *The Alice Tableland*—A plateau region a little over 1,000 feet above sea level, forming part of the Great Divide between latitude 20° 30′ and 24° S. This is the highest, the least dissected and the most sharply defined of the four.

(ii.) *The Central Region*—A long, broad belt of country aligned N.W.-S.E. through the central portion of the State, very considerably dissected by the rivers. This is the largest of the four regions.

(iii.) *The South Western Region*—This is adjacent to the central region and actually is an extension from it. However it is recorded as a separate division; for in the far south-west of the State the laterites have been so extremely dissected that several types of redistributed soils have been produced that are rare in the other regions. By the nature of the distinction the boundary between this and the previous region is indefinite.

(iv.) *The Gulf Region*—A belt extending around the margin of the Gulf of Carpentaria.

An important distinction between this group of regions and the rest of western Queensland should be emphasised. In those areas not included in these four Regions outcrops of pre-Tertiary rocks are very common; but in these major lateritic regions such exposures are extremely rare, being limited to a very few " windows " of the older beds through the varied capping of Tertiary sediments, lateritic soils and old alluvia.

A great variety of rocks may be traced upwards into these lateritic soils, the following being a selection. An old Pre-Cambrian schist series at Soldier's Cap in the Cloncurry region has a typical remnant upon it. Later Pre-Cambrian rocks (quartzites) underlie a lateritic mantle in a curious basin at the head of the Seymour River. Around the edge of the

* The term "western Queensland" is used throughout this paper to mean that portion of the State west of the Great Divide—the divide between the east coast waters and those of other systems.

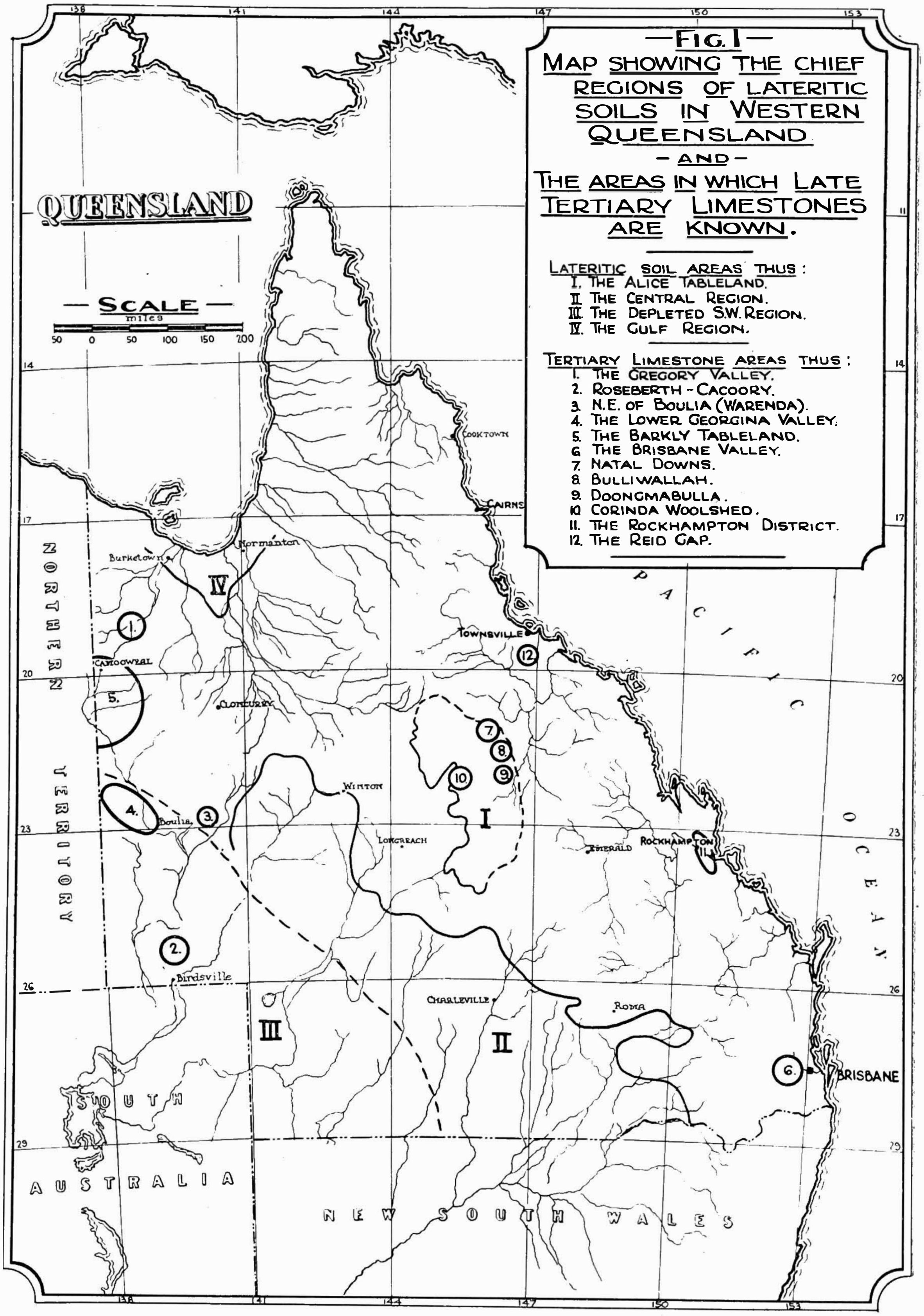
FIG. I
MAP SHOWING THE CHIEF REGIONS OF LATERITIC SOILS IN WESTERN QUEENSLAND
- AND -
THE AREAS IN WHICH LATE TERTIARY LIMESTONES ARE KNOWN.
LATERITIC SOIL AREAS THUS:
I. THE ALICE TABLELAND.
II THE CENTRAL REGION.
III THE DEPLETED S.W. REGION.
IV. THE GULF REGION.
TERTIARY LIMESTONE AREAS THUS:
1. THE GREGORY VALLEY.
2. ROSEBERTH - CACOORY.
3. N.E. OF BOULIA (WARENDA).
4. THE LOWER GEORGINA VALLEY.
5. THE BARKLY TABLELAND.
6. THE BRISBANE VALLEY.
7. NATAL DOWNS.
8. BULLIWALLAH.
9. DOONGMABULLA.
10. CORINDA WOOLSHED.
11. THE ROCKHAMPTON DISTRICT.
12. THE REID GAP.
QUEENSLAND
SCALE
miles
50 0 50 100 150 200
Cooktown
Cairns
Townsville
Normanton
Burketown
Camooweal
Cloncurry
Winton
Boulia
Longreach
Emerald
Rockhampton
Birdsville
Charleville
Roma
Brisbane
NORTHERN TERRITORY
SOUTH AUSTRALIA
NEW SOUTH WALES
PACIFIC OCEAN

σ

Barkly Tableland lateritic soils of several types occur *in situ* on Cambrian limestones. In the Alice Tableland the laterites occur continuously over a sedimentary succession that ranges from Carboniferous to Cretaceous. In the lower layers of a laterite-capped ridge, along the southern boundary between Warenda and Lucknow stations in the far west of Queensland, Lower Cretaceous (Albian) ammonites of the Tambo Series are abundant, converted into iron oxides. Some distance to the east of this locality, on Llanrheidol station (pl. 1, fig. 3), typical shales of the Winton Series (Upper Cretaceous) grade upwards into laterites. Early Tertiary beds (of the Eyrian Series) are affected in the far south-west, and late Tertiary beds (see below, p. 58) in the basin of the Flinders River.

THE INFLUENCE OF THE UNDERLYING ROCK.

In quite a number of relatively small areas where a variety of geological formations occurs the parent rock obviously has had a marked control upon the soil profile. Three examples will illustrate this:

1. In the fringe of dissected Cambrian limestones and associated sediments about the eastern edge of the Barkly Tableland, the lateritic soils *in situ* are now merely remnants upon the divides. As pointed out below (p. 46) in the region of Magenta Creek the limestones are somewhat argillaceous. Interbedded calcareous shales are abundant and there are some sandy beds. Nearby, in the basin of the west Thornton River (near Thortonia homestead), argillaceous types are rare. The limestones seem relatively pure, but for the presence of laminated cherts in several bands and certain slightly silicified replacements of fossils. There is a corresponding difference in the lateritic remnants that have been produced. In each region the old soil is a lime-depleted residue. Around Magenta Creek, where there was a richly argillaceous content in the rock, the remnants now consist mainly of kaolinic, mottled zone material, rather more ironstained than usual and with irregular, silicified patches at its base. Irregular blocks of quartzite have weathered out in places from this level and sometimes such large blocks remain, upon a divide, as the sole trace of the old soil. Occasionally large patches of slag-like, nodular limonite cap the mottled zone material. That is to say there was apparently in this region a lateritic soil with a threefold development of ferruginous, kaolinic and siliceous material.

In the Thornton basin, where argillaceous contamination of the parent limestone seems rare, the soil-remnants (see p. 46) consist of a mass of cellular and slightly silicified limonitic material at the base of which there is an accumulation, apparently by gravitational settlement, of the large insoluble plates of chert, still, for the most part, keeping horizontal and now loosely cemented with limonite. Apparently by the same soil forming process these two different calcareous suites have yielded different soil types, the limonitic layer being the only one common to the two.

2. The lateritic mantle of the Alice Tableland is developed in an area in which there is a sequence of sediments from Carboniferous to Cretaceous. These include arenaceous, argillaceous and calcareous deposits. Around Uanda, on the margin of the Tableland, the Blythesdale Series* of late Jurassic or early Cretaceous age contains numerous beds of conglomerates with quartz pebbles dominating. Quartz pebbles accordingly, as an insoluble

*A paper is in preparation on the geology of the Alice Tableland. The series names here quoted are used necessarily in advance of the descriptions that will, in that way, be given.

ingredient, are found scattered through all three zones of the lateritic soil which form the plateau immediately to the north. The plateau surface, upon which the ferruginous horizon is well developed, has a screen of quartz pebbles weathered from the soil. In the creek sections, where the mottled zone is well exposed, this material also has quartz pebbles through it. The few exposures of quartzites that were seen (representing the silicified lower layers) also are conglomeratic.

In great contrast to this are the laterites, further to the east, on the eastern side of Lake Buchanan, where the underlying beds appear to be the calcareous shales and mudstones of the Cunno Series. No silicified material has been noticed here; but the ferruginous and kaolinic material, where they were examined at the southern end of the Salt Mountain, are free from arenaceous particles. The mottled zone consists of a remarkably fine and soft, white material with few, large, red, mottled patches.

In other regions of the Tableland a sandy type of mottled zone material, accordingly, has been taken as evidence of unexposed arenaceous rocks below.

The Uanda occurrence is reminiscent of the Glendower section described below (p. 58) where a pebbly and sandy laterite is to be seen developed directly from an arenaceous series of sediments. Reference may be made also to the Charters Towers occurrence described by Saint-Smith (1921) where, developing from a granodiorite, a lateritic soil contains quartz crystals, quartz veins and other relics of the parent rock.

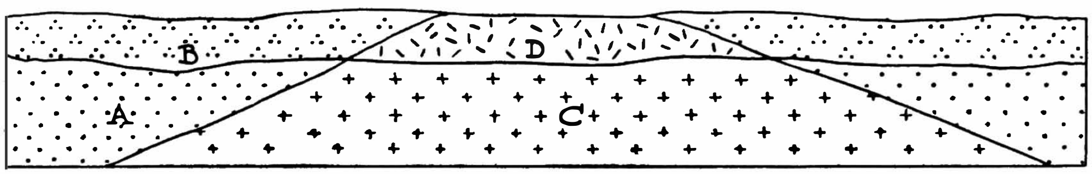

FIG. 2 - DIAGRAMMATIC VIEW OF A SCARP ON CURRAWINYA.

A, SANDSTONE ; B, QUARTZITE ("BILLY") ; C, GRANITE ; D, ALTERED GRANITE.

3. A third and most interesting occurrence has been noted on Currawinya* where several inliers of granite and slate occur through the Cretaceous shales. At one of these, four miles from Currawinya on the road to Boorara, there is a scarp in which a cupola of granite is encompassed by Tertiary sandstones (fig. 2). The fresh granite is a very coarse rock with pink felspar crystals, up to 3 inches in length, showing very marked twinning. Both granite and sandstone have been altered by laterite action, but all except the lowest of the affected layers have been stripped by erosion. The sandstone has been cemented by silica to form a thick, uniform bed of quartzite (perhaps 10 feet thick). The granite has been leached in such a way that the pink felspar crystals have been altered to a cream-coloured, silicified kaolin that shows no trace of the cleavage or twinning. But for the colour and the absence of these felspar structures the rock is a replica of the

* Near the New South Wales border in longitude 144° 30′ E. The latitudes and longitudes of localities mentioned in this paper but not shown on the maps will be found in the appendix.

fresh granite below and retains the usual structures—graphic, gneissic, etc. Although thus the sandstone and the granite have been altered dissimilarly, the zone of alteration is approximately the same depth in each and there is quite a sharp gradation from altered to unaltered rock.

The alteration of the granite and sandstone, although at first sight so markedly different, is comparable. Two changes seem to have taken place. In the first aqueous action the cement was washed from between the grains of the sandstone, while the felspars of the granite were altered to kaolin. Subsequently both rocks were silicified, the silica filling the interstices in the now porous sandstone and impregnating the kaolin of the altered granite.

THE SOIL HORIZONS.

A complete profile of a laterite soil, as developed in western Queensland, has four stages. At the top is the deep red, ferruginous zone. Below it, with a transitional passage, is the mottled zone of white, kaolinic material with red patches. Downwards the ferruginous mottlings become more scattered until sometimes, by gradation, the soil passes into a layer without mottlings in which often the form of the original rock is little changed. Marbut (1932, p. 75) calls this the " gray layer "; Green (1933, pl. VIII.) in his translation of Vageler's work, refers to it as the " decomposition zone." Neither term is appropriate; for with us the beds are rarely grey, being more commonly white or slightly brownish, while actually any horizon of a soil is a decomposition zone. Essentially this material is bleached by the removal of much if not all of the iron. The terms " leached " and " bleached " already are used in technical senses in soil descriptions, so that the name " pallid zone " is introduced for it.

The pallid zone is not always present. Sometimes the mottled zone is the first true soil horizon above the parent rock.

The silicified material sometimes forms a basal horizon. Frequently, however, there are silicified regions in the three other zones. Accordingly in this review the silicified portions are not referred to as a zone or horizon.

1. THE FERRUGINOUS ZONE:

The material of this zone is the least coherent and most easily transported portion, and no deep sections have been examined in it. The scarps that frequently are seen are in the lower horizons, particularly in the second or mottled zone; and from there, by the erosion that has formed the scarps much, sometimes all, of the upper or ferruginous zone has been stripped. For such reasons figures are not available of the average or the maximum thickness of such material. However, from surface outcrops, it is clear that all the variants listed and figured by Bryan (1939) in the red earths of south-eastern Queensland can be matched in the western province.

Red loams, sometimes sandy, sometimes not (depending essentially upon the parent rock), and without any marked concentration of limonitic nodules are common. Occasionally, on the top of plateau residuals, as at Palardo, they are cultivated. The striking, thick, red caps to some residuals —Donor's Hill for instance—above a mottled zone base are of this type. Great sheets of red loams, forming plains many miles across, are common features in western Queensland—as about Talwood and Ambathalla. They contain scattered, small limonitic nodules, and the surface, by erosional concentration, often is strewn with a black screen of them. In other regions, near Nindigully for instance, there are equally large sheets in which the nodules are uniformly larger (like marbles) and are packed in the loam to that degree typical of the Nodular Zone described by Bryan (1939, p. 24). A well section near Mirrica Spring in the very far west (within the Simpson Desert) shows such a nodular zone grading downwards into mottled zone material.

A cellular type in which the nodules are loosely held by a morsel of ferruginous cement but in which there is little of the loamy material is a common variant. I have seen it only in regions where evidently the ferruginous zone has been leached and the clay particles removed. It occurs in this way as a thin capping to the mottled zone in regions of scarps (such as at Grey Rock east of Aramac) or in creek sections (as at Mirtna). Among the coastal forms it corresponds to the cellular type figured by Bryan (1939, pl. 2, fig. 3) from Scarborough where again there has been leaching (at the base of seacliffs).

Often in front of the scarps much of the red earth has been transported and redeposited at lower levels. This is abundantly seen about the Alice Tableland. It is evident, for example, on the stepped eastern scarp about the Aramac-Clermont road; while, over great distances, the plains immediately fronting the long western scarp of this Tableland often are bordered by a belt (two or three miles wide) of these obviously descended soils. The great, red earth plains, such as those in the Talwood, Nindigully and Ambathalla districts just referred to, may be to some extent of this type. It is very noticeable in such regions that there is a reversal in soil levels. The red earths cover the plains whereas the hills are scarped plateaux of mottled zone material. Two explanations come to mind—either there has been stripping, as indicated above, after the soils have been dissected, or else there has been faulting. The matter is complicated in that creek sections in such regions (for instance at St. George) sometimes expose the mottled zone. The possibility of faulting is discussed below.

2. THE MOTTLED ZONE:

The mesas and buttes that make such striking landscapes in western Queensland are for the most part residuals of soils of the mottled zone. In a full section of a lateritic soil (see Bryan, 1939, pl. 1, fig. 1) there is a gradation from the uniformly ferruginous horizon to the mottled zone, since the top of the latter has abundant small and close ferruginous patches as compared with the larger and more widely spaced ferruginous mottlings of the main mass lower down. In most of the mesas and buttes of western Queensland the top few feet (see pl. I, fig. 3) form steep, cliffed masses, reddish or brown in colour, sharply contrasted with the lighter coloured, easier graded slopes below. This top layer corresponds with the transitional zone between the ferruginous and the mottled horizons. Masses from the upper layer, dismembered by vertical joints, form a talus on the lower slopes.

The material lower in these residuals varies in this great province, yet it remains sufficiently uniform to accord with all the physical criteria of the soils of this horizon. Generally it is white, kaolinic material with irregular mottlings of red. Often it is a hard, resistant substance. In texture the white mass may be wonderfully smooth (as at the Salt Mountain, east of Lake Buchanan) or it may be coarse from sand grains, as frequently it is, such characters, as in the ferruginous horizon, being no doubt an inheritance from the parent rock. Commonly in this zone occur those curious, vermicular cavities that have been recorded in the lateritic soils of many countries.

The red mottlings may be much less in amount than the white kaolinic material and discontinuous, as usually happens, or they may increase to form an irregular, three-dimensional lattice with the white material as the nuclei. Such a type is well seen in the section at the head of Rosedale Creek that is described below.

The depth of the mottled zone varies considerably, due maybe in part to different climatic conditions of formation and certainly in part to differences in the parent rock. Around Grey Rock east of Aramac, where the zone is formed in a tight shale, a thickness of 12 feet is about the maximum, notwithstanding that elsewhere in this same lateritic tableland sections from 20 to 30 feet are to be seen in the mottled zone. In the Central Region cliffs of the mesas are commonly 50 feet high. The lower layers in the sections are sometimes in the pallid zone. Talus deposits usually make it difficult to record the true thickness of the mottled zone in such exposures.

Two most curious variants due to leaching have been noticed in the Alice Tableland and seem to be something new to the literature on the laterites. Where the top of the plateau has been swept of the upper soil horizon and where there is little sand or vegetation to mask the surface, a concentration of limonitic material frequently is to be seen as circular rims, two to six feet across, within which the material is softer, whiter and more porous (see pl. II, fig. 1). The red mottlings frequently disappear entirely from these central areas.

From such a stage two peculiar types develop. In one, in which the cores seem subsequently to have been impregnated slightly with silica, the ferruginous rim disappears and the white, leached and cemented axes remain as columns (pl. II, fig. 2). Such a soil is well seen at old Barcoorah and it forms much of the mottled zone in the section at Glendower that is described in study No. 4.

In the other type, where there has been no subsequent cementing, the reverse happens and the cones weather away to leave hollow shafts or pits (pl. II, fig. 3). The most striking of these that I have seen are at Rangers' Valley, where they occur over considerable areas within the plateau and also in vertical section on the scarp. The mottled zone here is about 10 to 12 feet thick, formed in a tight shale. Below is a sandstone that has been affected but little by the soil processes. On the surface there are many of the uneroded pans. But there are numerous groups in which the soft cores have been removed leaving most regular conical pits with very smooth sides bottoming on the sandstone bed 10 to 12 feet below. A group of three of these is illustrated on plate II. Near the head of Rosedale Creek they occur almost as strikingly but with no apparent relationship to any lower sandstone bed. One most informative section was noticed there and is illustrated diagrammatically in text fig. 3. The scarp cut by the creek has cleanly bisected one such partly formed pit. The whole structure is bounded by a thin but very well defined conical crack. In the lower part of the cone, which is about 10 feet deep and 3 feet in diameter at the top, the centre is the ordinary mottled zone material indistinguishable from the mass outside the cone. From the surface to a depth of three feet the cone is empty and with smooth sides. But between this and the normal mottled zone material is an irregular pad, up to one foot thick, of the bleached and leached material. The cone had not quite reached its apex at the bottom of the section. Clearly the cones, as defined within the crack, first developed, then within them leaching has taken place downwards while, concurrently, much of this softer leached substance has been removed by erosion.

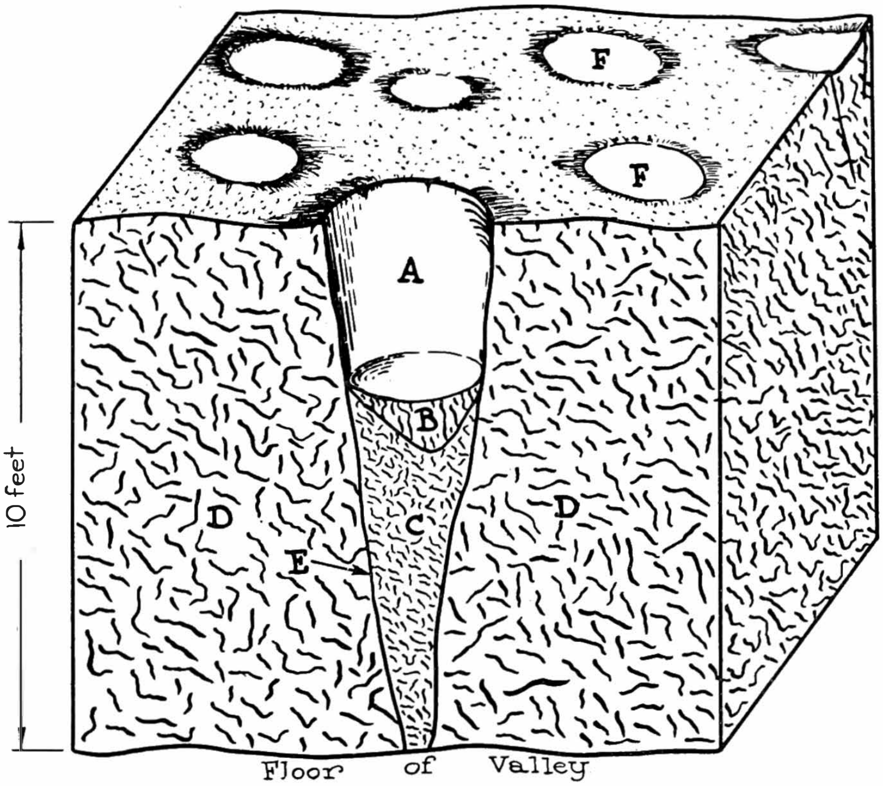

FIG. 3.- BLOCK DIAGRAM OF A DEVELOPING CONICAL SHAFT IN THE LATERITES (MOTTLED ZONE) NEAR THE HEAD OF ROSEDALE CREEK.

A = THE EMPTY UPPER PORTION.
B = LEACHED MOTTLED ZONE MATERIAL.
C = NORMAL MOTTLED ZONE MATERIAL.
D = MOTTLED ZONE MATERIAL, IDENTICAL WITH "C".
E = BOUNDING CRACK.
F = UNERODED CONES IN SURFACE SECTION.

It is likely that such structures are present throughout the mottled zone of the Alice Tableland. The circular pans are almost invariably seen where the surface of the tableland is bare, mottled zone material. Where, as more commonly happens, the mottled zone has a veneer of sand carrying a grassy or spinifex vegetation, circular or subcircular ungrassed plots up to six or eight feet in diameter are scattered profusely through the grassy mat. This is seen most strikingly in an aerial view and probably reflects a **foundation** of these curious pans.

I do not remember having seen such structures in the other three provinces. But I have not returned to those regions since I have examined the cones in the Alice Tableland; so that a search for them is warranted in those districts also. In a modified way small, packed cones or prisms may be characteristic generally of the mottled zone. I have noticed recently, in the Brisbane district, that horizontal platforms carved in this zone (as quarry floors or wave-cut platforms) show the iron oxides as an irregular reticulum, with intercepts on the average about six to twelve inches long, and with white, kaolinic material in the centres.

Some of the native wells in the Alice Tableland are partly excavated cones of this type. One of these is to be seen close to the Jericho road about two miles N.E. of Rosedale homestead. Here the bare top of the mottled zone is crowded with the circular pans, some of them being shallowly, but naturally, delved. The " well " is the deepest of these, about three feet across and three feet deep. When I saw it in June, 1940, there was one foot of water in it. There had been no rain since March. The depth to the water possibly represents ordinary evaporation over that period, so that this would appear to be in the nature of a storage tank rather than a spring-filled hole. Three miles away from this well, on either side, are permanent waterholes; so that I am inclined to believe that this is but a naturally eroded cone used by the aboriginals, rather than a structure dug by these pleasantly lethargic people.

3. THE PALLID ZONE:

Although for descriptive purposes it is advisable to recognise this zone, it must be emphasised that there is no clear-cut demarcation of it from the mottled zone above. Usually the junction is irregular and ill-defined.

In three of the major regions (the Alice Tableland, the Central Region and the Gulf Region) the upper portions of the lateritic profile commonly are exposed so that the pallid zone is only occasionally seen. In the South-Western Region, due to erosion, the soil profiles more frequently begin well down in the mottled zone; and in this Region the material of the pallid zone commonly outcrops.

Two different types of material may be grouped in this zone. In one it is a kaolinic substance, little different from the mottled zone above except for the absence of the ferruginous mottlings. In the other it is a material essentially similar to the parent rock but for the depletion of lime and iron oxides. There is often a gradation, the latter type merging upwards either into the former or directly into the mottled zone.

Interesting sections are to be seen near Ulcanbah. Here the creeks have cut down through the laterite scarps and exposed the unaltered, typical, fine, dark brown, calcareous sandstones of the Cunno Series (Jurassic). At the base of some of the scarps the rock is a fine-grained, cream-coloured sandstone with no lime left and very little iron. Essentially it is a fine sandstone (or siltstone) with a kaolin cement, entirely different from the ordinary weathered product of Cunno sandstones in non-lateritic areas. Similar kaolinic sandstones of low density, derived from Cretaceous and Tertiary sediments, occur widespread in the South-Western Region where they are associated with beds of white kaolin and flinty, kaolinised mudstones.

The light-coloured (often pure white) sandstone and clays low down in the plateau residuals on the opal fields in the Central and South-Western Region are largely of this material.

In the Central and South-Western Regions the material of the pallid zone sometimes has vermicular hoies. Also occasionally a curious concretionary structure develops in these deposits the nodules being, on the average, about 1 cm. in diameter; thcugh this seems to be more common across the border in South Australia (around Blanchewater, for instance). It suggests a gradual accumulation of kaolin around nuclei.

4. SILICIFIED MATERIAL:

Silicified material occurs in many forms and is most irregular in its distribution. Frequently all that has happened is that, by percolation, there has been a slight dissemination of silica, modestly indurating the rock or soil. Commonly under such conditions the originally more leached portions only of the mottled zone are affected and such indurated fractions may weather out in characteristic shapes. The cores of the cones at old Barcoorah (see above p. 10 and pl. II, fig. 2) are an example. Frequently, as about Augathella and Lisgool, large irregular masses are affected in this way. More intensive silicification of this type, in a sandy laterite, leads to the production, within the mottled zone, of irregular nodules of quartzite, usually termed "billy."* They may be of very large size, as shown on pl. II, fig. 4, which is a photograph of a group of these boulders, weathered from the soil, on the Augathella-Charleville road. Such nodules have an irregular, dimpled surface, very smooth and with a distinct polish. There is also quite a characteristic appearance on freshly broken surfaces.

If the lower horizons are not sandy, but clayey only, such silicification produces a smooth, hard, indurated clay, locally called porcellanite.

Sometimes great sheets of billy are formed by the uniform cementation of a lower horizon. The best examples of this are those already noted (p. 7) around Currawinya. There a sheet of billy caps an extensive plateau marked on some maps as Hood's Range. This type is most common in the South Western Region. It is rare elsewhere. One possible example on the Alice Tableland, south of Annievale, will illustrate the irregularity of the effect. There, in a belt of porous sandstones of the Blythesdale Series, the rock is exposed in numerous creek sections. Billy is extremely rare, except in one place, a mile south of Annievale, where the whole of a large hill is a massive billy.

In the far south-west, where concretionary structures have been noted in the pallid zone a nodular billy is very common and appears to be such material silicified.

A special type is that of the opal deposits of western Queensland —and the adjacent portions of the other States. Such deposits occur sometimes in the mottled zone and, frequently, as Jackson (1902, p. 10) has noted, in the bleached rock (pallid zone) below. It may occur as veins or as replacements of material. The noble opal that is so characteristic of

* This term is used frequently in local geological conversation but rarely has appeared in literature. The earliest Queensland reference was by Dunstan (1900, p. 5). Unfortunately two types of quartzites are grouped under the name—some formed by the metamorphism of sandstones by basalts, and these quartzites of lateritic origin. It would seem that in the type area (Clermont) both kinds are present.

these regions seems to be largely a replacement of calcite by silica. Frequently the noble opal reproduces the granular form of a massive calcite with the cleavage lines indicated. In New South Wales (White Cliffs) and South Australia (Stuart's Range), where the basement rocks are marine Cretaceous shales, the noble opal replaces the calcareous fossils, calcareous bands and concretions of these series, the matrix being usually bleached, kaolin-rich material suggestive of the pallid zone.

Between Bulgroo and Windorah a scarp shows an excellent section of a mottled, nodular laterite, passing upwards into a highly ferruginous billy, and seems to represent a silicification of the transition belt from the mottled to the ferruginous zone.

Thus the silicified material does not form a restricted zone but may be irregularly and sporadically developed through the whole section. As noted below this possibly is to be explained in terms of a repetition of the soil process. The cemented sheets below the mottled zone, as at Currawinya, may represent the early lateritic process, while the irregular cementation in the upper horizons may be due to the resumed action.

SECONDARY SOILS.

According to the degree of local erosion the exposed soil may be any one of these horizons. But in addition to soils *in situ* there are many secondary types, some of which are important in that they cover large areas. The following eight forms may be listed:

1. *Redistributed Red Loams:*

These already have been discussed in some detail. It is possible that, in the Central Region, they cover vast areas.

2. *Leached Red Loams:*

A leaching of the red loams to leave a little-cemented, cellular and nodular deposit is occasionally seen.

3. *Leached material of the Mottled Zone:*

This occurs discontinuously, as the cores of the large cones but sometimes continuous beds of white, porous clays of low density are exposed. One such may be seen in a creek crossing on the main road 19 miles west of Pentland. Here there is a bed of white, leached material of low density resting upon a bed of uniformally brown material that possibly stores the iron oxides removed from the upper bed.

4. *Sands accumulated in place:*

Where the laterites are of the sandy type the removal of kaolin by ordinary weathering leaves masses of sand upon the surface—red sands upon the ferruginous horizons, pink or cream-coloured drifts on the lower zones. These may form on either the soils *in situ* or the transported members.

5. *Redistributed Sands:*

Beyond the region of static or primarily transported soils sand drifts may occur by the concentrating action of wind or water. There may be considerable local accumulation in this way, as at Adelong, or they may be regional. Of the latter, two important types need to be mentioned.

The Alice River, a tributary of the Barcoo, widely dissects the Alice Tableland. Douglas Ponds Creek, arising also in the Tableland, joins the Barcoo below Blackall. After they issue from the scarped southern front, they have first a zone of primarily transported red loams in their basins, and then a series of isolated sand drifts that converge fanwise down their converging valleys (and that of the Barcoo) towards Isisford. These sands are present as red or pink drifts of great size as far as 70 miles from the nearest point of the scarp. Their relation to the main lateritic mass is most interestingly to be seen from the air. Mr. S. L. Everist informs me that on the great drifts about Blackall the sands grade downwards usually into deeper red types but sometimes into yellow sands, and that they rest on other alluvial types, frequently gravels. Also they are found under the latest alluvium.

The sands in the enormous red sandhills of the Simpson Desert in the extreme south-west of the State are, in all appearance, so markedly similar to the red sands of the Alice and Adelong regions, and to those extracted from the red loams *in situ*, that it is inevitable to suggest that they had a similar derivation but have been wind-piled. Two matters are pertinent. In this region the foundation rocks (of the Eyrian Series—of Tertiary age) are largely arenaceous, and the ferruginous layer has completely gone from the residuals. The sandhills may represent the arenaceous particles from this totally dismembered sheet, just as the widespread old, red alluvium may contain much of the argillaceous fraction.

On the fringe of the Simpson Desert cream-coloured sandhills occur, usually of a coarser sand. Maybe these are later additions derived from the lower zones of the laterites.

6. *Gibber Plains:*

In the Central Region, but far more abundantly in the South-Western Region, the surface is often strewn thickly with nodules ("Gibbers") of billy, packed so thickly that really little soft soil remains between. Sturt's Stony Desert in the far south-west of the State is of this type. Locally these fragments are called "gidgea stones." Clearly they are strewn remnants of once widespread deposits—both nodular and continuous—of a siliceous zone. Usually they are roughly graded. An average of two to three inches is common; but in some regions—near Birdsville for instance—they may increase to nine to twelve inches.

As mentioned above the greatest uneroded sheets of siliceous material are to be seen near Currawinya. Not far west from here there is a very rugged region in the neighbourhood of the Macintyre Gap where great dismembered blocks of billy thickly strew the surface for miles. Here apparently is a transition from the continuous sheets into the gibber plains.

7. *Claypans:*

In the region of the more eroded laterites claypans are abundant. These are perfecty flat crusts of clay in depressions. They would appear to be the concentrated outwashed clay fractions from various types of lateritic soils, primary and secondary. The greatest is the Bilpamorea Claypan north of Birdsville, 28 miles long and 10 miles wide. This, from its huge size, is abnormal. The vast majority are only of the order of 100 yards across.

8. *A Grey Type:*

Over large areas of the Alice Tableland a grey soil is spread. On its surface small, pink, sand-drifts occur by superficial leaching. It represents some redistributed soil type about the origin of which I am not yet certain.

KUNKARS AND RELATED SOILS.

Laterites with lime accumulations have long been known from India under the name of Kunkar. Since in the soil process under which a laterite is formed lime is very early removed, such soils represent later accumulations of lime—probably in an arid phase. In western Queensland not only lime but gypsum, magnesia and salt have been found in lateritic soils. But these are discussed in a later study of this series (No. 5).

ADULTERATED SOILS.

Hybrid soils are common in western Queensland due to material from the disintegrating laterites mingling with other superficial deposits. Three examples will suffice.

1. In the headwaters of the Maranoa and the Warrego Rivers the laterites are present as small and rare residuals, so that generally the rocks (a sequence of quasi-horizontal lacustrine, Mesozoic series) are very well exposed. One of these rock groups, the Attica Series, consists of very friable sandstones that seldom outcrop, the surface being a mass of deep, loose, white sand. It is very noticeable that where a small, lateritic residual occurs in this belt the sandy soil for some distance all about it becomes deep red in colour. There has been a contamination of the normal sand with red material outwashed from the hill.

2. Throughout the South-Western Region the oldest Pleistocene alluvium is a widespread mantle of red silts. It covers enormous areas far from the present watercourses and has been modified by the development within it of thick, lime pans. Occasionally, as at Urimbin and Bransby, the present streams have cut deep sections through it and shown a sandy, typically alluvial profile. Since in this Region the laterites have been the most dissected with the ferruginous layer entirely stripped, these red silts seem to have preserved some of this denuded upper loam as a contamination that has given the red colour to the series. As pointed out elsewhere (p. 64) this is the earlier and more extensive of the two Pleistocene alluvia. Thus it gives evidence of the earliest and most intensive denudation of the laterites before the ferruginous layer had entirely gone.

3. The pedocalcic soils in western Queensland, when remote from any lateritic region, are greyish-brown or olive-grey in colour. Beyond the western edge of the Alice Tableland such soils develop directly from the Cretaceous clays. But within a mile or two of the laterites, the soils change suddenly in hue and become chestnut-coloured. This happens so frequently (it may be seen particularly well near Corinda Homestead) that obviously it is due to an admixture of lateritic loam with the calcareous soils.

A somewhat similar admixture is evident in the Goondiwindi district. These red loams, to casual appearances pedalferic, develop gilgai, the surface depressions characteristic of the pedocalcic soils.

Generally through almost the whole of the southern half of the Central Region, the pedocalcic soils show this adulteration. They are almost invariably chestnut-coloured and on more than one occasion have been regarded as normal Chestnut Earths. But their colour is due to this contamination. Throughout this Region lateritic residuals are frequent. Where the north-western mail 'planes cross, the Warrego Range sharply marks the junction between the Central Region, with its frequent lateritic residuals, and the Barcoo River basin that is free from them. The Warrego Range is merely the last scarp of these soils. Viewed from the air the change is most abrupt across this range—from the chestnut-coloured downs in the south (in the region of residuals) to the ashy grey downs in the north (where there are no such remnants). It is far too abrupt to be due to anything but a contamination in the southern sector.

THE AGE OF THE LATERITES.

Little direct evidence for the age of the laterites may be quoted from western Queensland. They are later than certain Tertiary sediments; but the precise portion of the Tertiary sequence represented by these sediments has not been determined by fossil evidence.

Laterites are such specialised soils that Woolnough's claim (1927, p. 26) that such deposits in the several Australian States were contemporaneous may be regarded as valid. Woolnough suggested, from such evidence as then was available, a Miocene age. Bryan (1939, p. 28), with Hills' later palaeontological work (1934) as a basis, was able to indicate Pliocene as more likely than Miocene. That position may be accepted. It is a moot point whether the late "fossil" laterites throughout the world may not be equivalent in age. A Pliocene age has been claimed by Li (1936) for similar soils in China. However, Harrassowitz (1926, p. 416) places the late Tertiary German "laterites" as Upper Miocene; although from his descriptions it is doubtful whether such soils strictly are comparable with those that here are described.

Four distinct criteria in western Queensland indicate that there were at least two periods of lateritic action—that may be placed provisionally as early and late Pliocene.

1. In the Flinders valley (see below, study No. 4) a late Tertiary sedimentary series that contains boulders of "billy," such as is formed in a laterite, is itself converted into a lateritic soil, of which the mottled zone has been preserved *in situ*.

2. The silicification of the laterites has affected even the base of the ferruginous zone as noted above (p. 14) near Bulgroo. This can hardly be explained other than as a silicification later than the laterite; and at the moment one is at a loss to find cause for a subsequent release of silica other than a recurrence of conditions.

3. At several places in the Central Region, between Winton and Boulia, the eroded plateaux of mottled zone show two levels of the upper more ferruginous crust. This is shown on plate I, fig. 4. Sometimes (not illustrated in this photograph) they occur on the same slope.

4. It has been noticed within the Alice Tableland that several water-courses cut completely through the mottled zone to the rock below and yet have, in their bed, normal mottled zone material. Such is seen for

instance in the Alice River at Texas and in Corinda Creek at old Barcoorah. It is difficult to see how mottled zone material could be transported and still retain its coarse mottling. It is suggested that these rivers cut their valleys after laterites were first formed and subsequently lateritic processes recurred, converting to laterites the alluvium that meanwhile had been deposited.

It is difficult to assess the relative intensity of the soil processes of these two (or even more) phases. In a second such activity the great lateritic sheets already in existence would be modified only in degree; and in them the most noticeable effect would be in the irregularity of the silicification. The most obvious results would be seen in the sediments laid down since the earlier phase. Such are the changes that are noticeable in the arenaceous beds on the Flinders River, the old alluvium of the Alice, and in the many limestones laid down in an arid interval since the first laterites were formed.

ORIGIN OF THE LATERITES.

Notwithstanding all argument about the origin of laterites some essential features of the soil themselves generally have been neglected in such discussion. The soils, as they are present in western Queensland, have two contrasted parts—the upper or ferruginous zone and the lower layers. The upper zone can be matched in many soils. The mottled zone is distinct from all others.

The descent and concentration of iron oxides is a feature of pedalferic soils generally, and a nodular development of the limonitic fractions occurs through a fairly wide pedogenic range. Types in which the iron oxides are distributed through a uniformly reddish soil depend not only upon climatic conditions but also upon the solubility of the parent rock. Thus a terra rossa will form upon such a relatively soluble rock as a limestone under far less humid condition than a red loam will develop upon a basalt. The ferruginous zone of a lateritic soil is but the extreme type of a soil sequence in which there is even some silica depletion.

But the mottled zone introduces another conception that seems very largely to have escaped attention. In other pedalfers there is no new development of iron concentration below the base of the ferruginous zone. Usually here begins the unaltered rock. With soils such as the western Queensland laterites there is a very thick zone in which, peculiar among soil types, there is an upwards concentration of the iron. In a thick section the unaltered rock is succeeded vertically by a leached type, still retaining the rock structures, but with the lime and iron removed and the kaolin amassed. Gradually upwards succeeds the mottled zone, the mottlings being at first large and widely spaced, progressively becoming smaller and more crowded until the zone merges into the upper ferruginous horizon.

That is to say, laterites such as these have an upper portion, due to the *downwards* concentration of iron oxides, and a lower, due to the increase *upwards* of such material. In such manner they appear to be unique among soils. It is yet to be proved that such a soil, with a lower mottled layer, is in process of formation to-day.

Some special set of conditions clearly is needed for them to form, apart from the extensive plainland foundation that generally is regarded as a pre-requisite. The Queensland evidence gives a clue to what these conditions are. It may be assumed that, for such thick pedalfers to form upon a varied assemblage of rocks, heavy rainfall conditions are necessary. Under such conditions the ferruginous zone would develop. But there is evidence (p. 40) that, in Queensland, before such humid conditions began there was an arid period. Not only that, but there is evidence, already stated, of two periods of laterite formation, each preceded by an arid phase. If these arid phases *immediately* antedated the rains, then during such a prelude the water-table would be deep. With the onset of the newer rainy conditions that water-table would rise. Thus there is postulated two movements of water—a downwards movement by normal percolation producing the upper ferruginous horizon, and a gradual rise of the water-table which, it is now suggested, has intensified the features of the mottled zone. The junction of the two horizons may have represented the ultimate level of the water-table.

A study of present pH values will give no clue to these things, for these are fossil soils. A large series of complete analyses of properly sampled layers through a thick profile would help greatly, but I am not aware than this has ever been done.

The mottled zone material in the scarp at the head of Rosedale Creek gives some indication of how the iron movement through the mottled zone may have occurred. There the material is a red lattice with white nuclei, an inch or two inches in diameter. But between the white and the red portion is a yellow zone, one-tenth of an inch wide. The core of each of the white nuclei has one of those curious vermicular tubes, now partly filled with clay minerals. Such tubes allow easy percolation; and the zonal arrangement about them gives evidence of an outward movement of the iron salts and a peripheral concentration, in the manner of the production of the first of a series of liesegang rings. Vermicular tubes are not necessary for such a beginning. Joint planes are other and, no doubt, more usual conduits.

And so it is suggested that, as the water-table rose and reducing conditions supervened, the iron was concentrated in upwardly growing nuclei. Mohr (1930) already has suggested that there has been some upward movement of iron oxides and alumina in the final growth stages of lateritic soils. The large conical structures described above from the Alice Tableland may be further evidence of this upward action; for they on a grand scale show a peripheral concentration of the iron oxides and they expand upwards.

The ferruginous zone is a normal illuvium. It would appear now that the mottled and the pallid zones together form a special type of illuvial division in which kaolin and silica have been accumulated by the usual downwards movement as well as, originally, some of the iron; but eventually the iron has been concentrated by upward percolation.* The term *reluvial horizon* is suggested for this.

There are details in the development yet to be filled in. It is likely that the kaolin concentration in the lower layers has developed to a great extent, if not entirely, before the rise of the water-table. Such a kaolinic concentration would be necessary, almost, to retard the rise of the water-table and allow gradually the iron concentrations. More attention should be given to this. The irregularity in silica precipitation in the lower layers also needs further observation, while a study of such pH or other chemical conditions that could concentrate iron in such a manner would be most helpful.

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* Since (*v. supra*) it is clear that there were two phases of lateritic action some of the iron oxides in the mottled zone may be due to limited percolations in the second period.

There is one important corollary to this notion. The presence or absence of a reluvial horizon and its relative thickness when developed depend upon the position of the water-table when the necessary rainfall conditions began. If the water-table, real or perched, was high originally, then a ferruginous zone could develop without a mottled zone below. With some reservation due to the type of parent rock the deeper the water-table originally the thicker the mottled zone. It is to be noted that in Queensland the greatest development of the pallid zone and the silicified material is in the South Western Region that is now the most arid portion of the State and presumably was the most arid in the time immediately preceding the formation of the laterite. Such local variations adequately may explain the variants in the red earths noted by Bryan in south-eastern Queensland.

Thus in this conception the same climatic conditions could produce either a soil with a ferruginous zone only or one with the addition of the mottled and other zones, the prime determining factor for the profile variations being the position originally of the water-table. If so, then all such variants might legitimately be termed laterites, some descriptive adjectives being used to qualify the several types. In this way might be reconciled many of the diverse usages to-day of the term laterite

There has been discussion about whether steady or seasonal rainfall is necessary to form laterites. Possibly it does not matter. Either might be effective. From the evidence on the Barkly Tableland (p. 56) it seems that in Queensland steady rain fell; but that after the laterite formed a change took place and seasonal rains developed sufficent not only to dismember the laterites but to erode the rocks below.

THE POSSIBILITY OF FAULTING.

Ball (1926, p. 164 and sections) has suggested that some of the scarps of what are mottled zone material in the Central Region may be fault scarps. Although thereabouts there is commonly a reversal of soil levels—the mottled zone forming the hills and scarps with the ferruginous loams covering the plains in front of them—faulting *per se* need not necessarily be invoked. The scarps about the Alice Tableland are very prominent and there is abundant evidence that these are purely erosional and not tectonic features. The same is true for very many of the scarps in the Central Region, where mesas, widely separated by the alluvial plains of a watercourse, are at apparently the same level. Jackson's map (1902) of the " Desert Sandstone," which is in effect a map of the reluvial residuals and is still the best published map of these deposits, clearly shows that these residuals occupy the areas between watercourses and are, generally, merely the remnants of a once continuous sheet dismembered by the present streams.

Nevertheless faulting may have occurred in some regions. Sometimes the scarps present not a level skyline but are sharply, even repeatedly, stepped, suggesting a series of minor step or even trough faults. Such a skyline may be seen, in western view, on the main road 20 miles west of Adavale.

The most pertinent evidence noticed was at Currawinya in the neighbourhood of the granite scarp described above (p. 7). On the low ground in front of this scarp there are numerous mound springs, leakages from the Artesian Basin, that must have burst out abruptly; for often they bear great blocks of rock brought up from below. Some of these have fragments of the normal granite; but one, perhaps a quarter of a mile from the face of the scarp, has brought up fragments of that curious porcellanised granite that outcrops only at the crest of the scarp. It is indicated therefore that this very special superficial rock here is at a lower level and a fault is suggested.

Faulting of a post-lateritic period thus probably has affected western Queensland but possibly it is not common, most of the scarps being essentially erosional features.

FORMER EXTENT AND SUBSEQUENT DENUDATION.

In the far north of Queensland, in the Cape York Peinsula, the laterites are extensively developed west of the Great Divide as Jackson's work (1903) shows. The ferruginous zone is well developed in this region. To the south, in that more rugged and elevated country in the quadrangle between Cooktown, Croydon, Hughenden and Townsville, there does not appear to be any extensive sheets of laterites.* Still further on, from Hughenden to Yalleroi, the Great Divide is virtually the only moderately elevated Alice Tableland, the most uniform of all the major lateritic regions. Southwards and south-east from here the Divide once more is in high country and the laterites are only tiny remnants due no doubt to the greater erosional activity in this more steeply graded area. I have not found them much over 2,000 feet above sea level,** but whether they have been stripped from the higher ground or whether they never occurred in the higher parts it is yet not possible to say.

Coming down from the high land to the Central Region in the basin of the Maranoa River, the main sheets of the laterites, in between the watercourses, begin at heights of from 1,300 to 1,400 feet above sea level. Then, as the country slopes very gradually to the south-west, the mean height above datum of the residuals also declines. At first, the residuals are of mottled zone material with great sheets of the ferruginous horizon, most probably redistributed, on the lower lands. Occasional gibber patches occur but of no great extent. Then gradually there is a change. The residuals merge to pallid zone material or even to the little altered rock. The plains change from pure, but probably transported, ferruginous material to the red silts in which loams of the ferruginous zone are mixed with the oldest alluvium. The gibber plains become very extensive. All this suggests erosion to lower levels. The change is so important but so gradual (marking the merge from the Central to the South-Western Region) that, at my suggestion, Blake (1938) placed the line on his recent vegetation map of western Queensland.

Thus the country so flat now had probable even more gentle grades immediately before the lateritic action began and was apparently the perfect plain with a slope so gentle that run-off was very slow.

Between the Alice Tableland, or the Gulf Region, and the Central Region there is the wide, inter-regional area, the major portion of the basins of the Thompson and the Flinders Rivers, where now there is virtually no laterite. The residuals of mottled zone material are few and very scattered. But some are present and, on the divides, screenings of gibbers are common. Apparently once the laterites extended across this region but now have been almost entirely stripped. The basement is of exposed Cretaceous rocks producing uncontaminated soils. It seems necessary to postulate that the plain upon which the laterites of western Queensland formed had here a

* To judge from published reports. I have seen very little of this region.

** This region, in the Buckland Tableland, rises to 4,000 feet.

slighter elevation than the surrounding regions; and by later base-levelment of the rivers the superficial deposits have been stripped to the rock foundations.

Thus the surface of western Queensland upon which the laterites began to form was (apart from the tableland residuals) not markedly different from at present. Its great plains had even a slighter grade, with some modification as in the Thompson and Flinders basin; and along the eastern edge the highlands rose to heights comparable with those at present.

APPENDIX.

The longitudes and latitudes of localities mentioned in the text but not shown on the accompanying maps are approximately as follows:

Adavale	144° 36′ E.; 25° 55′ S.
Adelong	145° 28′ E.; 22° 28′ S.
Ambathalla	145° 19′ E.; 25° 56′ S.
Annievale	145° 52′ E.; 22° S.
Aramac	145° 15′ E.; 22° 58′ S.
Blackall	145° 27′ E.; 24° 27′ S.
Bulgroo	143° 40′ E.; 25° 48′ S.
Bransby	142° 5′ E.; 28° 14′ S.
Corinda	145° 22′ E.; 22° 4′ S.
Cunnamulla	145° 37′ E.; 28° 4′ S.
Currawinya	144° 30′ E.; 28° 50′ S.
Donor's Hill	140° 37′ E.; 18° 42′ S.
Eulo	145° E.; 28° 10′ S.
Glendower	144° 29′ E.; 20° 44′ S.
Goondiwindi	150° 19′ E.; 28° 32′ S.
Grey Rock	145° 40′ E.; 23° S.
Isisford	144° 25′ E.; 24° 16′ S.
Kynuna	141° 55′ E.; 21° 35′ S.
Lake Buchanan	145° 55′ E.; 21° 30′ S.
Lisgool	146° 13′ E.; 24° 15′ S.
Llanrheidol	141° 37′ E.; 22° 18′ S.
Macintyre Gap	143° 55′ E.; 28° 20′ S.
Mirrica Spring	138° 30′ E.; 23° 48′ S.
Mirtna	146° 14′ E.; 21° 16′ S.
Nindigully	148° 49′ E.; 28° 21′ S.
Old Barcoorah	145° 21′ E.; 22° 40′ S.
Palardo	149° 49′ E.; 26° 39′ S.
Pentland	145° 25′ E.; 20° 31′ S.
Rangers' Valley	145° 46′ E.; 23° S.
Rosedale Creek	146° 7′ E.; 23° 9′ S.
St. George	148° 33′ E.; 28° 5′ S.
Texas	145° 52′ E.; 23° 5′ S.
Uanda	144° 53′ E.; 21° 35′ S.
Urimbin	143° 52′ E.; 28° 21′ S.
Windorah	142° 37′ E.; 25° 27′ S.
Yalleroi	145° 48′ E.; 24° 5′ S.

EXPLANATION OF PLATES.

PLATE I.

Figs. 1-3. Dissected lateritic residuals on Llanrheidol and Cawnpore Stations.

1. View showing several residuals.
2. A valley in the upper portion of the mottled zone.
3. The hill at Llanrheidol homestead, showing the breaking away into columns, of the transitional material between the mottled and ferruginous zones.

Fig. 4. View near Tranby, showing two levels of hard, surface capping (transitional material from the mottled to the ferruginous zone). (S. T. Blake, photo.)

PLATE II.

Fig. 1. Surface of the plateau at Rangers' Valley, showing the surface "pans" in the mottled zone.

Fig. 2. At old Barcoorah. Columns of silicified, kaolinic material without ferruginous mottling—apparently the hardened cores of pans similar to those of fig. 1.

Fig. 3. Vertical view of three conical pits at Rangers' Valley, from which the unsilicified cores of the pans have been eroded.

Fig. 4. Blocks of "billy" weathered from the surrounding soil on the Charleville-Augathella road.

PLATE III.

Three views near Llanrheidol. (F. C. Johnson, photos.)

Fig. 1. The upper portion of a mottled zone remnant.

Fig. 2. Similar to fig. 1, showing, beyond the scarp, the plains of Winton Series shales on which these remnants are developed at this locality.

Fig. 3. An indurated (? slightly silicified) remnant of the mottled zone.

Plate I.

Plate II.

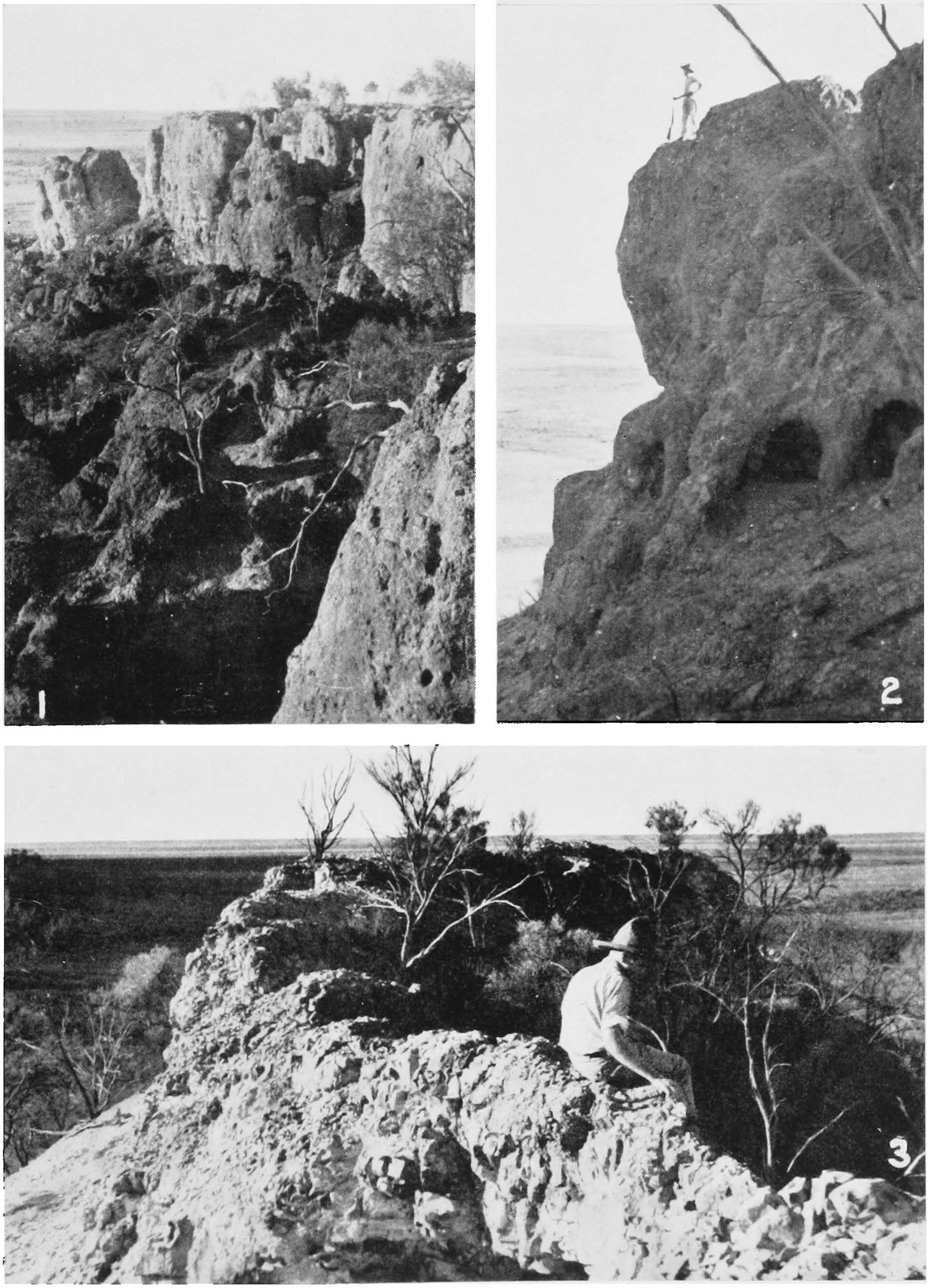

Plate III.

2. LATE TERTIARY LIMESTONES IN QUEENSLAND AND THEIR SIGNIFICANCE.

Summary: Limestones of non-marine origin (some of them aqueous sediments, others terrestrial deposits) were formed in widely separated regions in Queensland on at least three occasions between Middle Miocene and Pleistocene times. It is suggested that they are deposits formed under arid or semi-arid conditions in inter-pluvial epochs.

In isolated areas, widely scattered in Queensland, there are deposits of white, non-crystalline limestone, non-marine in origin and often highly silicified, few of which have been recorded in literature. Often there is clear evidence of a late Tertiary age for these deposits. Such limestones occur in the following regions:

1. Near the north-eastern edge of the Barkly Tableland, in the basin of the Gregory River;
2. North of Birdsville, between Roseberth and Cacoory (and isolated outcrops further north);
3. North-east of Boulia, between the Hamilton and the Burke Rivers;
4. In the southern portion of the Georgina River basin, chiefly in the valley of Pituri Creek;
5. Over the surface of the Barkly Tableland;
6. In the valley of the Brisbane River, chiefly around Ipswich and Pine Mountain;
7. On Natal Downs, 100 miles south of Charters Towers;
8. On Bulliwallah, 57 miles south-east of Natal Downs;
9. At Doongmabulla in the valley of the Carmichael River (a western tributary of the Belyando);
10. At Corinda Woolshed, 66 miles north of Aramac;
11. In the Yaamba-Rockhampton-Bajool-Raglan area;
12. South of Townsville, in and about the Reid Gap.

These localities are shown on the accompanying map (fig. 1). There must be very many others; but those that I have listed are such that I have seen on various occasions when travelling through the State. Such limestones are not restricted to Queensland. I have noticed similar outcrops, for instance, in South Australia and the Northern Territory.

The Brisbane Valley deposits have been described by several authors, Cameron (1923) grouping them, with other associated rocks, as the Silkstone Series. Jones (1927, pp. 28-30) has summarised the data on this series. The deposits in and about the Gregory River have been discussed to some extent by Cameron (1901), Ball (1911), Danes (1916) and others. Dunstan (1920, p. 47) referred in passing to limestone and chalcedony near Boulia, and Rands (1899, p. 22) briefly mentioned those at Natal Downs. The remaining deposits seem hitherto to have passed unnoticed.

The characteristics and associations of the limestones in these twelve regions are as follows:

THE GREGORY RIVER VALLEY.

The great terrain of Cambrian limestones that outcrop in the basin of the Georgina River extends north-easterly into the basins of the Gregory and the O'Shanassy Rivers and of Lawn Hill and Widdallion Creeks. There are outliers amid Pre-Cambrian rocks still further to the north-east, the chief of these being the great mass which Ball (1911, p. 14) called the "Dentalium Plateau,"* upon which the homestead of Lawn Hill station is situated. Such Cambrian limestones, massive and compact, lie horizontally or almost so, and often are channelled by the weather into "karst" surfaces.

In the neighbourhood of Riversleigh limestones of late Tertiary age, often crowded with fossils, rest and abut upon the Cambrian limestones and form a zone up to three miles wide between them and the late Pre-Cambrian quartzites still further to the east. Topographically these later limestones are indistinguishable from the older (Cambrian) limestones that here contain *Orthotheca*, *Lingulella*, *Protospongia*, echinoderm ossicles and fragments of trilobites. They too are very massive and compact, and their surfaces are channelled with "karst" structures to much the same degree as the Cambrian limestones. They have been eroded by the Gregory and its tributaries to great scarps such as those of the Tarpeian Rock (opposite Riversleigh homestead) and the other scarps immediately adjacent.

Daneš (1911, p. 80) hinted that the limestones of the adjacent Barkly Tableland may represent more than one geological period; but it seems to have escaped notice hitherto that the limestones in the Gregory basin include both an early (Cambrian) and a late (Tertiary) series. For instance, Ball (1911, pl. 10) figures the chert-bearing limestones, that here are typical of the Cambrian group, as part of the post-Tertiary series. The topographic unity of the limestones has obscured this twofold development.

The most abundant fossils in the late limestones are fresh water and land gastropods some of which were identified provisionally by Etheridge (1901) as *Isodora* and *Helix* (*Thersites* and *Chlorites*). They are almost always present, often in crowded masses. The best preserved and most abundant of such gastropods were noticed on the hills about a mile east of Riversleigh homestead. North-west from Riversleigh, near where Verdon Creek issues from the limestones, vertebrate fossils occur as well as the gastropods.† Large bones are very abundant but difficult to extract from the massive limestone. This bone horizon can be traced for some considerable distance, perhaps half a mile, along the scarp. Reptilian (crocodilian) and mammalian bones are abundant, as noted by Danes (1916, p. 30), and I have found some well preserved teeth of *Neoceratodus*.

How much further north they extend I am unable to say. Daintree (1872, p. 278) recorded *Tellina* "in a bed of horizontal limestone at the head of the Gregory." The exact locality is not known and the specimen has not been preserved. Ball (1911, p. 18) noticed that "the limestones along Louie Creek on certain horizons contain small shells, possibly *Tellina*, ... but I was unable to detach any completely for determination."

* The specimens of the so-called *Dentalium* that I have seen in these beds are species of *Orthotheca*. A Middle Cambrian trilobite (*Nepea sp.*) has been found also near Lawn Hill homestead.

† These bones, as well as the mollusca, were first recorded by Cameron, 1901, p. 190.

I did not see these shells when at Louie Creek. No marine limestones later than Cambrian are known otherwise in this region; and it may be that these small lamellibranchs are really non-marine forms. The Louie Creek limestones are on the eastern edge of the main mass. It is a matter worth enquiry whether such beds represent a northern continuation of the late limestone.

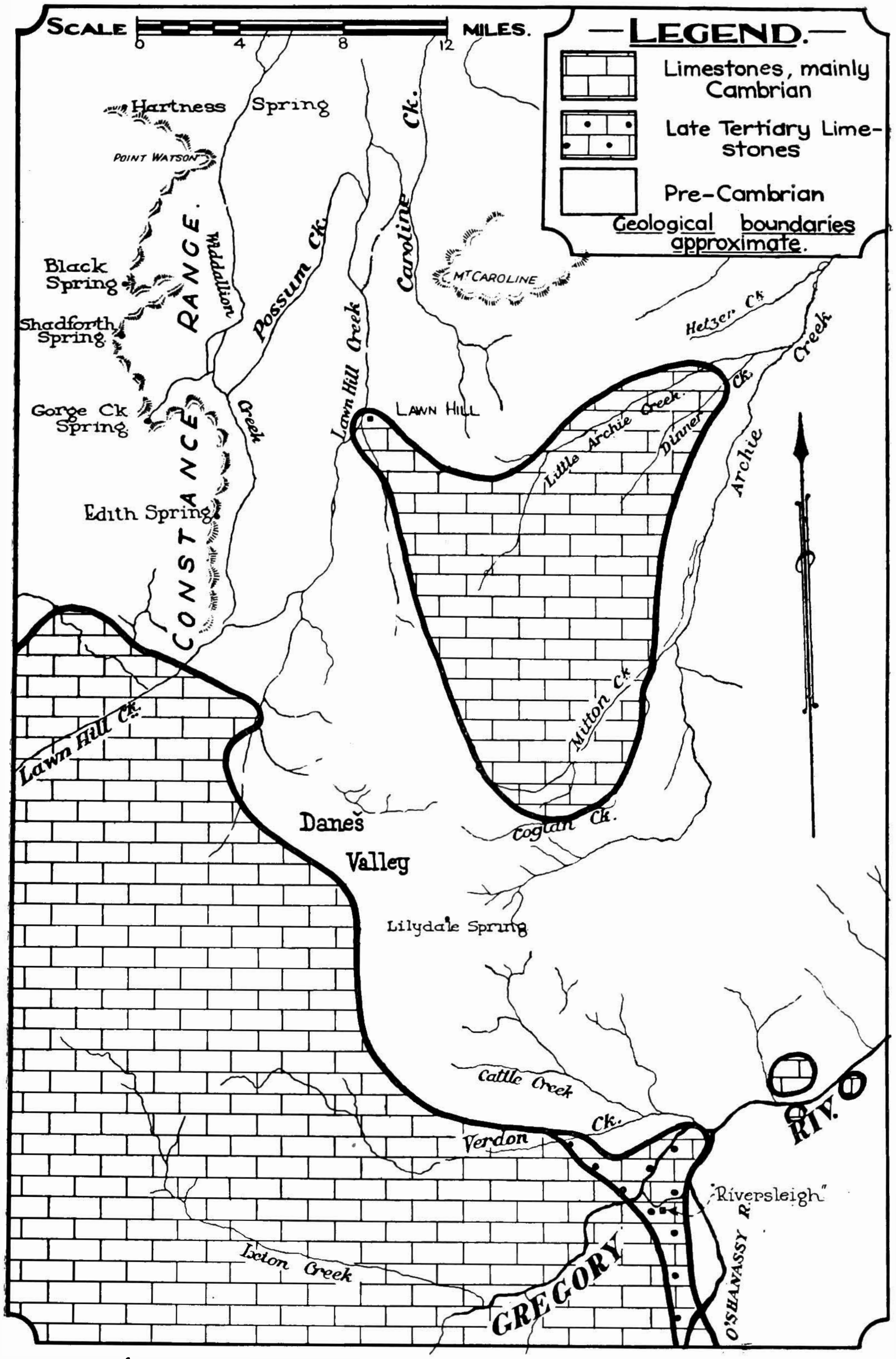

FIG. 4.—GEOLOGICAL SKETCH MAP OF THE RIVERSLEIGH - LAWN HILL REGION.

In appearance, on freshly broken surfaces, the late limestones vary considerably. Most of them, like those one mile east of Riversleigh house, are white and smooth on such fresh surfaces; but the limestone of the bone bed is mostly brown in colour and crystalline. Usually on such fresh surfaces the limestone has a brecciated appearance. In places, it has been moderately silicified, with thin bands of chalcedony running through the mass and with a certain amount of replacement of both matrix and fossil shells by silica. The bone bed in one place on the crest of the ridge has the surface replaced largely by iron oxides.

Perhaps the most instructive section of these limestones is to be seen in the region of the bone bed (fig. 3). Here the scarp of the late limestone runs N.W.-S.E. fronting the old alluvial plain of Verdon Creek. Immediately behind there is a valley, subparallel to the scarp, carved by a tributary of the creek. On the western side of the valley the limestones yield Cambrian fossils. On the eastern side occurs the bone bed with its associated gastropods. Both limestones are horizontal and the junction between the two is on the eastern side of the valley. Near the base of the latter series, in places, the bed consists of ferruginous-calcareous-argillaceous material with angular fragments of limonite and chert. Within it are what appear to have been once vertical fissures now filled with angular chert rubble. This deposit is very similar to certain surface material among the Cambrian limestones south-west of Thorntonia, 30 to 35 miles away, where laterites occur abundantly and such rubbly beds appear to be the soil remnant of a limestone affected by the solution processes of laterite formation. Above this deposit lies the normal limestone at the top of which the vertebrate and molluscan fossils occur.

Since the limestones were formed they have been eroded by the Gregory River and other local streams reducing the once continuous exposure to a main scarp and a number of outliers, separated one from another by the old alluvial plains of these streams.

From the Cambrian limestone in the basin of the Gregory and the O'Shanassy Rivers there issue great volumes of water that David (1932, p. 118) has described as " the most powerful springs in Australia." These run the rivers as fine permanent streams. But, as related elsewhere (p. 52), these great springs are steadily declining.

Calcium carbonate, precipitated from these waters, is deposited at present in considerable amount. The sandy muds at the bottom of the pools of water in the Gregory River are somewhat calcareous. Around the surface of the streams, where drops thrown from the rapidly moving waters evaporate relatively quickly, surface tufa deposits are being formed, as shelves extending over the water of the pools, and containing within them abundant impressions of *Pandanus*, *Melaleuca*, and other plants that fringe the streams, as well as shells of the present river molluscs. The best example of this is in the gorge of Carl Creek, a distributary of the Gregory River that flows into the O'Shanassy. There a thickness of from 15 to 20 feet of these tufa deposits occurs above the present trickle of the creek and again points to much greater flow in earlier days. A certain amount of such material occurs also, apparently *in situ*, on the alluvial plains. Towards the junction of the Gregory and the O'Shanassy it is to be seen as much as 200 yards distant from the stream and perhaps 50 feet above it. It is difficult to imagine that such material would be formed there under present flood conditions when the calcareous spring water would be highly diluted by rainwater.

Many of the valleys, now dry, that issue from the Cambrian limestones immediately west of the later limestones have deposits suggesting old spring action. In the valley described above, behind the bone bed, stratified cherty rubble indicates some stream deposition. Springs lower down this valley did occur within the memory of some of the present residents.

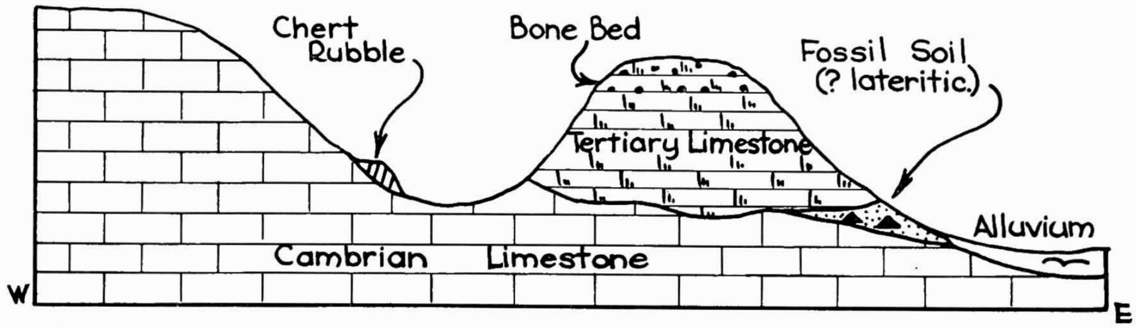

FIG. 5: W.-E. SECTION IN THE REGION OF THE BONE BED, 4 MILES N.W. OF RIVERSLEIGH.

Bearing these things in mind, it seems most reasonable to suppose that the *Helicidae* Limestone* in question was deposited in a valley eroded between the Cambrian limestones to the west and the late Pre-Cambrian quartzites lying to the east; and that the deposits were formed by precipitation from highly calcareous waters (similar to those at present) issuing from the springs along the Cambrian limestone front, springs that were greater in volume than any within the region to-day. That there could have been deposition of such a thickness of compact limestone over such a great area suggests a period of relative aridity when evaporation was high and there was little influx of surface waters to dilute the supply from the springs. Cameron (1901, p. 191), it should be noted, previously has suggested that these limestones were deposited during such a period of low rainfall.

Three different items of evidence suggest that this arid period followed upon a period of unusually high rainfall. They are:

(i.) The erosion of the Cambrian limestones to form the valley up to three miles wide in which these limestones were deposited.

(ii.) The presence of what appear to be soils of a lateritic nature below the bone bed—laterites being soils formed under conditions of high temperature and precipitation.

(iii.) The suggestion that there was at that time an output of spring water from the limestones tremendously greater than the present eflux.

* The name *Helicidae Limestone* was suggested by David (1914[1], p. 255) for these deposits. Dunstan (1916, p. 164) used the name *Barkly Series* for "The limestones (in part) of the Barkly Tableland." Since there are limestones of so many ages in this region and no one of these particularly was specified, Dunstan's name should be allowed to lapse.

The fossils give little evidence of the age of the beds, since little work has been done upon such non-marine faunas in Australia. However some estimation of the age of the beds may be made from other aspects. That the limestones are pre-Pleistocene in age may be accepted since the beds have been eroded by the rivers, and the outliers are widely separated by the old alluvia of the last great pluvial epoch.

Elsewhere (p. 17) I have pointed out that there were at least two ages of widespread laterite formation in Queensland in late Tertiary times, and I have discussed the evidence of local surface silicification in relationship to such soil processes. There is evidence here to suggest that these limestone deposits were laid down in the interval between the two periods of lateritic action. The deposit below the bone bed suggests an early lateritic remnant upon which the limestone was laid down; and the fact that in certain places the limestones subsequently have been replaced by silica and even, at one locality, by limonite, suggests that the lateritic processes supervened after the limestone was formed.

Thus it is now suggested that these deposits accumulated in a period of relative aridity, in Pliocene times, between two phases of high temperature and heavy rainfall such as were suitable for the accumulation of lateritic soils.

ROSEBERTH-CACOORY.

The road northwards from Birdsville to Boulia passes over or close to several outcrops of highly silicified limestones. There is a small patch of this material about half way between Bedourie and Marion Downs, and other small remnants occur elsewhere in this region away from the road; but the chief outcrops are in the vicinity of the deserted homesteads of Roseberth and Cacoory where they cover a considerable area.

The Cretaceous rocks that form the capping to the Great Artesian Basin are here nowhere exposed. The formations that do appear at the surface are of later age consisting of hills of sandstone (apparently a continuation of the Eyrian series of South Australia, Tertiary in age), the great plains of old alluvium of the rivers, the sandhills of the edge of the Simpson Desert, certain material of lateritic origin, and these limestone deposits.

The limestones are white and non-crystalline; and except in a few places—near the ruins of Roseberth house, for instance—where small remnants are still somewhat powdery, they are generally highly silicified. In this way they are converted sometimes into hard, flinty, calcareous-siliceous masses, and sometimes they are completely replaced by chalcedony. Irregular bands of chalcedony, an inch or two wide, interlaced between the partly silicified limestone, is a common type.

Generally these deposits are aligned in definite bars, extending in a W.S.W. direction, with alluvial deposits between. The most prominent of the bars extends westerly from the ruins of Cacoory homestead. Another bar extends westerly from Roseberth and, on the main road, is crossed in a three mile stretch from Roseberth house southwards. It would appear that these bars are the zones of greatest silicification and as such have weathered into relief, the country between being for the most part old alluvial soils. The creeks and watercourses in the region have generally a southerly course; and as they cross the bars and weather down to the material below the limestone most of them develop prominent waterholes on the southern side. Gunegoomri, Niddrawodra, Widgugomrie, Cacoory and Wandanagoolya waterholes occur in this way south of the main or Cacoory bar.

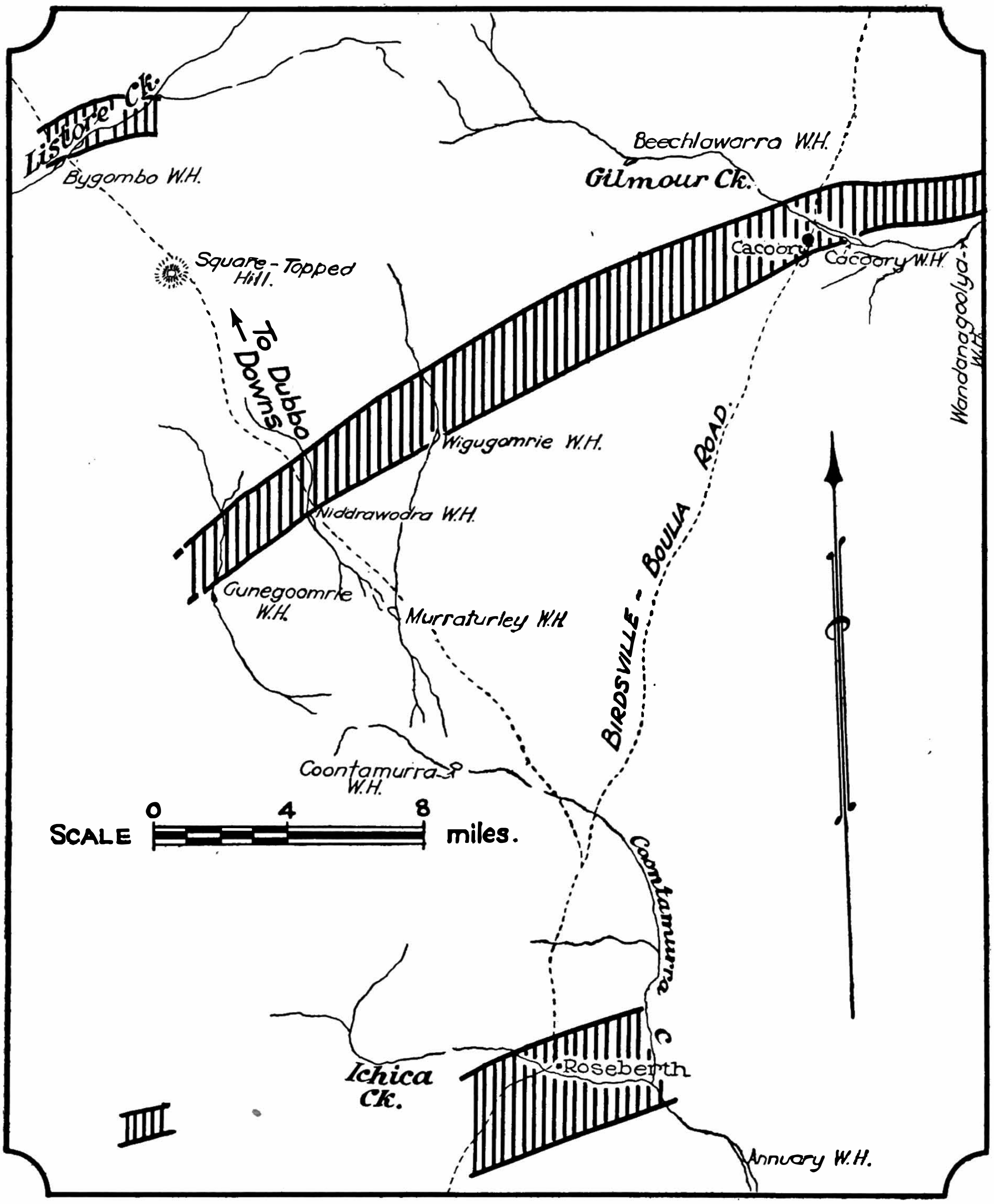

FIG. 6.- SKETCH MAP OF THE ROSEBERTH - CACOORY AREA.
SHOWING THE MAIN BARS OF TERTIARY LIMESTONE

At Roseberth house there is a well, now caved in, that, according to local information, went through 22 feet of the limestone and then finished in a compact reddish sand with a large yield of inferior and corrosive water. The most instructive section noticed was at Niddrawodra waterhole. Here a bed of horizontal limestone is to be seen, five feet in thickness. It is highly silicified, often completely replaced by chalcedony. Underlying the limestone is an old reddish soil, now very compact, with an abundance of ironshot pellets, that seems to represent the upper or ironshot zone of a red earth (or lateritic) soil. The upper portion of this soil is calcareous. A similar relationship between an earlier red soil and the silicified limestone is to be seen at Widgugomrie waterhole.

On the limestone ridge midway between Niddrawodra and Widgugomrie waterholes there is a sandhill in which fragments of the limestone occur. At its base—between it and the limestone—there is a deposit of very compacted sand that seems to represent an old alluvial deposit.

The evidence seems to be clear that these limestones are later than a lateritic soil series while, from their silicified nature, they may be earlier than yet another phase of lateritic action. No evidence could be found of any organic remains in the limestone. Similar limestones elsewhere in western Queensland (N.E. of Boulia and in the valley of Pituri Creek), although well searched, seem similarly barren. It seems most likely that these were surface soil limestones originating similarly to those of Doongmabulla (*q.v.*). Surface lime deposits are growing to-day in warm, semi-arid to arid regions; and accordingly it is suggested that these deposits accumulated in a warm, semi-arid to arid period between two periods of high rainfall when lateritic soils were formed.

It may be noted that somewhat similar limestones encrusting a reddish soil with ironshot pellets is to be seen just across the South Australian border at Miranda, some 40 miles south-west of Roseberth.

NORTH-EAST OF BOULIA

The limestones occur in this region on Warenda Station, mainly between the Hamilton and the Burke Rivers. The Cretaceous rocks capping the Great Artesian Basin occur in this region pierced by great inliers of late Cambrian (Ozarkian) limestones. These latter form the elevated masses of Black Mountain (or Unbunmaroo), Ninmaroo and Mt. Datson. Later material of lateritic origin, and possibly some Tertiary sediments, cover much of the Cretaceous shales, and there are widespread alluvial deposits.

Some of the late Tertiary limestones occur on the plains between Ninmaroo and Mt. Datson and other outcrops are to be seen north-west of this area as far as Six Mile Creek. A few more occur north-west of the region shown on the map, around Noranside. Dunstan (1920, p. 47) has noted the presence of chalcedony at this locality and has suggested that it was formed as a deposit from hot springs; but I see no evidence of this having happened.

All outcrops are of the same type as the Roseberth-Cacoory and Pituri Creek regions—that is, they are, for the most part, replaced by silica with abundant irregular deposits of white chalcedony. Near the road crossing of Six Mile Creek (six miles from Fort William) these limestones may be seen to overlie a red nodular deposit, apparently an old lateritic soil. In this way there is a particular close agreement with the Roseberth-Cacoory occurrence.

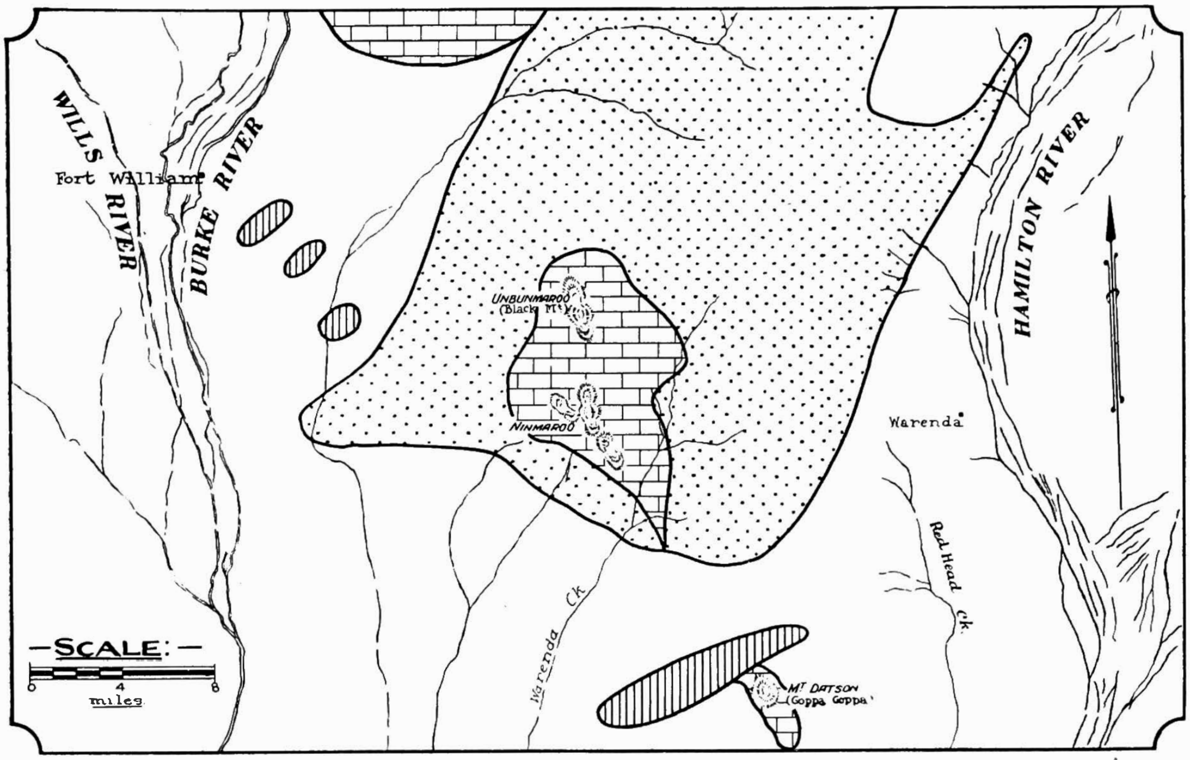

FIG. 7.— MAP OF PORTION OF WARENDA HOLDING.

CAMBRIAN LIMESTONES. TERTIARY SANDSTONES, ETC.. LATE TERTIARY LIMESTONES.

THE UNSHADED AREAS ARE COVERED BY CRETACEOUS (TAMBO SERIES) DEPOSITS AND ALLUVIUM. GEOLOGICAL BOUNDARIES APPROXIMATE ONLY.

In passing it may be noted that, according to information supplied to me, the channel in which this red nodular deposit occurs is the best channel in the creeks nearby for holding water.

THE LOWER GEORGINA BASIN.

In the lower portion of the basin of the Georgina River and its tributaries white limestones occur that are highly silicified and often completely replaced by white chalcedony. They are replicas in all aspects of the chalcedonised limestones of the Roseberth-Cacoory and the Warenda regions. In this province, however, they have their greatest distribution.

Apart from a few Pre-Cambrian inliers the oldest rocks of the region are widespread fossiliferous Cambrian limestones (the Georgina Limestones). These are succeeded in the south-west by Ordovician sandstones. In the east and the south the marine Cretaceous (Upper Albian) clays of the Tambo Series occur. Also there are scattered mesas of later sandstones and shales (? Tertiary). All these formations, from Cambrian to Tertiary, are horizontal or nearly so—except in one or two restricted areas where the older beds are faulted.

It is in the region of the Cambrian limestones that the late Tertiary limestones are most abundantly developed. They are found in scattered outcrops from the South Australian border eastwards to Herbert Downs.

But the main deposit is a long ribbon-like outcrop some five or six miles wide, through which Pituri Creek, the main western tributary of the Georgina River in this region, makes its way. These deposits are extraordinarily uniform, consisting of the highly chalcedonised types that form extremely rough plateau ridges.

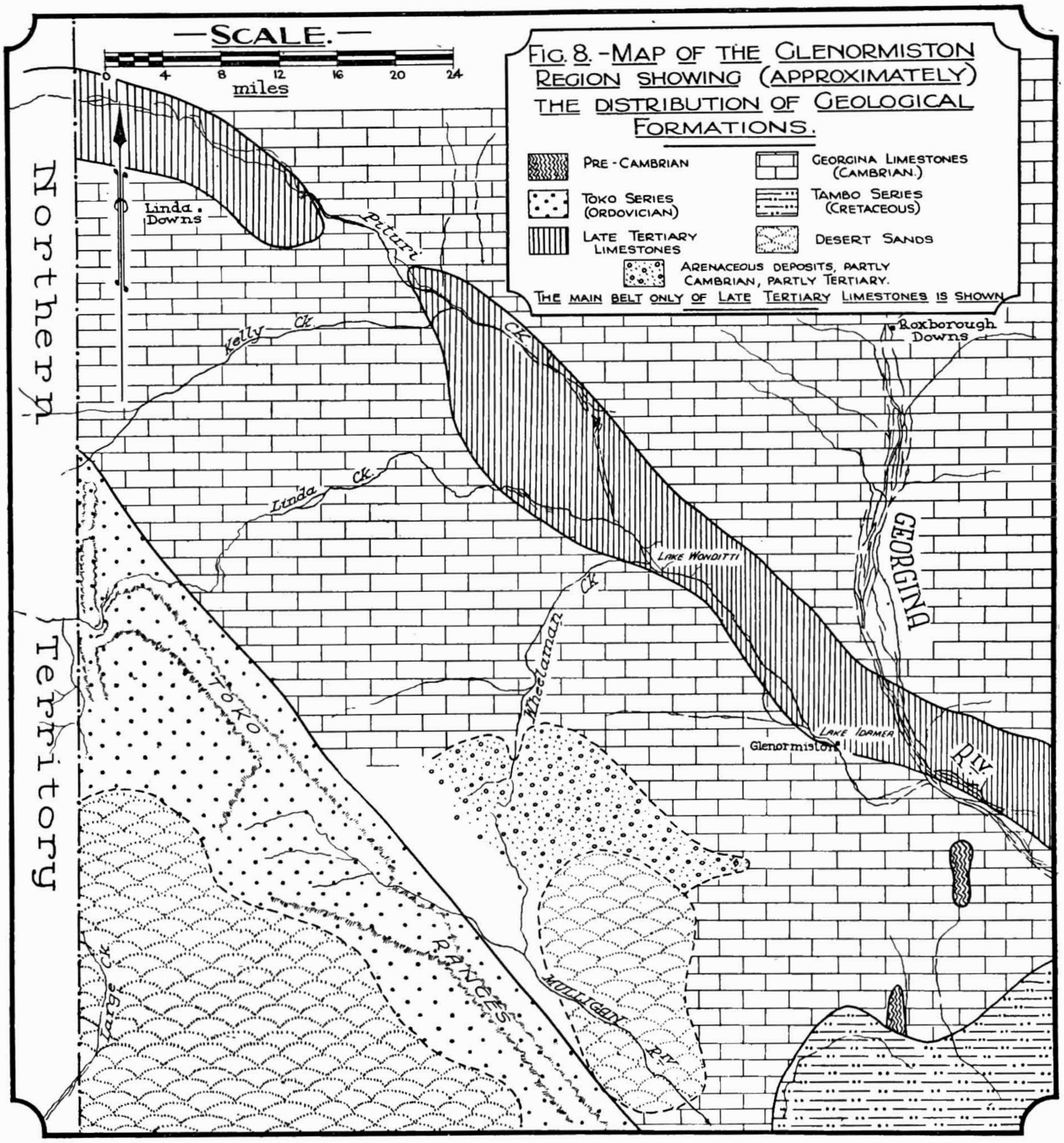

Fig. 8.-Map of the Glenormiston Region showing (approximately) the distribution of geological formations.

This was the first region in western Queensland in which I had noticed these siliceous limestones. The Cambrian limestones that are adjacent, although practically horizontal to the eye, have a general, very small dip to the S.W. The Pituri Creek deposits, aligned N.W., thus correspond to the general strike directions of the Cambrian beds and at first they were thought to be part of the earlier series. From long searching, however, no fossils were found; and when evidence was later available that such limestones elsewhere (at Cacoory and Warenda) were of late Tertiary age it seemed likely that these beds also were relatively recent.

No exposed section was known by which this could be established. However, some years ago, in one dry period, I had the opportunity of being lowered down the well at Glenormiston homestead that is sunk in these siliceous limestones. Beneath a thickness of perhaps 30 feet of the limestone is a curious deposit from which the water is obtained. This is a reddish-brown material with limonitic nodules and would appear to be an old soil comparable in a general way with the red soils below the limestone in the Cacoory and Warenda regions.

It is worthy of note that this belt of late limestones is important in water supply. The Georgina River, the channels of which lie generally in the Cambrian limestones, has, in this region, very few good waterholes. In contrast its tributary, Pituri Creek, whose course is in the late limestones, has many excellent waterholes, two of which, Lakes Wonditti and Idamea, are of considerable size. The well at the homestead to which reference has been made is one of the few sinkings (bores or wells) in the limestones on the property (3,000 square miles) that yields good and abundant water. It is the only one in the late limestones. There are many sunk in the Cambrian limestones but nearly all of these are failures. This water relationship is of interest since in both the Cacoory and Warenda regions similar relationships have been noted. The old soils below the limestone would seem generally to carry the water supplies.

Pituri Creek rises in the Northern Territory; and I have noticed that the siliceous limestone belt continues into the Northern Territory through this valley. The deposits extend much further west than the head of this creek; for I have seen similar limestones intermittently on the road west from Tobermory (at the Queensland border) as far as Alcoota, 260 miles away. In this region they have been recorded by Tindale (1931, p. 38) resting unconformably upon the Ordovician quartzites at Mt. Ultim where I have examined them. Considerably further south-west in the Northern Territory (15 miles west of Erldunda for instance) I have seen them; so that they would seem to have a very considerable distribution in the present arid and semi-arid parts of Australia.

THE BARKLY TABLELAND.

There is a variety of calcareous rocks in the region of the Barkly Tableland. Cambrian fossils have long been known from the limestones in and about the region. Daneš (1911, p. 81), referring to certain deep bores in the region entirely in limestone, suggested that from this thickness (1,700 feet in one bore on Alexandria) it is possible that they represent more than one geological period. Quite definitely a Cambrian and a late Tertiary suite of limestones are present.

The later limestones are of more than one type. Highly siliceous deposits occur, often completely replaced by chalcedony and of precisely the same type as in the three last quoted regions. I have seen such material on Yelvertoft station (in the main lateritic region) at three miles north of Headingly, and at a few other places. It is not common; a limestone in a scarp 10 to 15 feet high where the Gregory River crosses into Queensland may be of this type. It is only slightly silicified and honeycombed by weathering. There is also a series of non-silicified surface limestones. They are found so dispersed over the region that I have not found it possible to keep a list of individual localities. Most commonly they occur close to the channels of the larger streams. An abundant type is a white, non-silicified limestone with concentric layers, not unlike the surface material that is described below from Doongmabulla.

It is, however, very difficult at present satisfactorily to evaluate the evidence for late limestones. As pointed out elsewhere (p. 46)* the monotonously flat Barkly Tableland seems to consist of a very irregular buried landscape of Cambrian limestones smothered beneath a mantle of later deposits. These later deposits are partly clays and other such sediments, and partly soils of lateritic types. A surface veneer of limestone is very common in a few regions. At Headingly, for instance, I am informed that all bores on the property passed through only a thin layer of such limestones, then continued through clays for 100 feet or more and finally came to a lower limestone series below. Mr. Murray Thomas, the Manager of Headingly, even went so far as to refer to the surface limestones as " floaters." Yet they are so widespread laterally that, erroneously apparently, they give the impression of a thick series. Because they are developed so frequently about the channels of the watercourses and become infrequent away from them I have suggested (p. 49) that they are essentially lime pans in the late (? Pleistocene) deposits that have been exposed in the more corraded regions near the streams. Tentatively, therefore, much of this material may be regarded as of Pleistocene age and so beyond the scope of the present enquiry.

But some of the thicker masses may be of an earlier age. At Chester Creek a scarp of limestone perhaps ten feet high occurs beside a waterhole close to the northern edge of the main lateritic tongue in the region. This juxtaposition of thick limestone and laterite recalls the Doongmabulla occurrence and suggests that we may be dealing here with a deposit older than the pans of Headingly. Similar close groupings of limestone and laterite have been noticed further west in the Northern Territory.

The evidence is meagre; but, such as it is, it suggests the possibility of three limestone groups in the later deposits of the Tableland—the earliest group, silicified limestones, formed in an inter-lateritic phase; an intermediate group—that is, post-lateritic but older than the old alluvium; and the latest, widespread lime-pan deposits of the old silts of the Pleistocene.

THE BRISBANE VALLEY.

The most extensive limestone deposits in this region are around Ipswich. Tertiary deposits here lie in a basin eroded in the Lower Mesozoic sediments of the Ipswich coal field. Cameron (1923), who recognised a thickness of 1,200 feet of these Tertiary sediments, divided them into two series—the Redbank Plains Series below and the Silkstone Series above. It is in the latter series that the limestones occur. The two series are conformable. Hills (1934) studied the fish fauna of the Redbank Plains Series and concluded that the age of the beds was early Tertiary, most probably Oligocene. Provisionally, therefore, a Miocene age may be accepted for the overlying Silkstone Series.

Jones (1927, pp. 28-30) has well summarised our knowledge of these deposits. The Series consists of clays, fissile shales, sandstones, dolomitic limestones and basalt—that is, unlike the other limestone deposits considered in this paper, they are part of a suite of varied sediments and

* The evidence in detail for the limestone is given in another study in this series (No. 3) and consequently it is not requoted here.

basalts. A bore section at West Aberdare, Ipswich. quoted by Jones, (1926, p. 30) gave the following section:—

	Thickness in feet.	Depth of bore in feet.
Mudstones and shales	150	150
Dolomitic limestone	23	173
Vesicular basalt	44	217
Dolomitic limestone	51	268
Basalt (decomposed)	18	286
Marly clays	52	338
Basalt (vesicular in places)	481	819
Shales, mudstones, and soft sandstones	136	955

Triassic strata were then entered upon.

The only fossil known at present is an undescribed species of *Planorbis* that I found in some abundance in the silicified limestones of Limestone Hill, Ipswich, in 1922.

The limestones are sometimes chalky and unsilicified, but often are highly silicified, being completely replaced at times by chalcedony. The two adjacent and parallel ridges that form Limestone Hill at Ipswich are composed one of the unsilicified limestones and the other of silicified members.

In many parts of this region, as Jones has pointed out, the Tertiary deposits are horizontal; but in other places they have been subjected to folding to some extent as shown by the sections given by Cameron (*loc. cit.*).

The shales and sandstones of the Redbank Plains Series have been converted into red earths and laterites, as Bryan (1939, p. 27) has shown. I am not aware of any typical red earth residuals developed upon the sediments of the Silkstone Series; but the silicification of the limestones would appear to indicate some action by lateritic processes. Bryan (*loc. cit.*) has established that in south-eastern Queensland the red earths were developed on a plateau topography not since modified by folding and consequently has suggested, with every good reason, that the lateritic processes began after the folding and subsequent erosion that affected the Silkstone Series—that is, most probably in Pliocene times.

Thus of all the limestones discussed in this paper these are the only members that reasonably may be claimed as pre-lateritic. That they are fresh water sediments may be accepted from their interbedding with other sediments and their containing *Planorbis*. It may be assumed, further, that they were deposited in a time of little rainfall, when the waters of the basin could be sufficiently charged with lime to precipitate calcium carbonate. The magnesium content of the limestones is most reasonably explained by the waters draining from the basalts of the series. There is nothing remarkable in the occurrence of both silicified and unsilicified outcrops. It is what might be expected of intercalated sediments in a folded and eroded series, the surface of which at some time has been affected by siliceous solutions.

In addition to these deposits of the Silkstone Series there is at Pine Mountain, some five to six miles N.W. of Ipswich an outcrop of highly silicified (chalcedonised) white limestones. The rocks associated with them are chiefly Tertiary basalts. Rands (1895, p. 27) has noted this deposit.*

* This is the deposit referred to in the first paragraph on page 27 of Rand's report. The other limestones mentioned on the same page are Palaeozoic sediments.

It is of precisely the same type as the other highly silicified Tertiary limestones of Queensland; but whether it is pre-lateritic, like those of Ipswich, or inter-lateritic, like those of western Queensland, remains to be proved.

Dunstan (1913, p. 371) referred to deposits of dolomite in the vicinity of Flinders and Antony, some 12 miles south of Ipswich. Analyses were quoted showing low silica percentages. Dunstan concluded that these dolomite deposits " form irregular masses where basalt dykes have penetrated coal measures, appear to be of great extent, and are normal in their proportion of magnesia and lime." If this is so, these deposits appear to be sufficiently distinct from the others described in this paper to be excluded from this list.

NATAL DOWNS.

In this area a series of rocks striking east and west and dipping steeply northwards occurs near the mouth of Rocky Creek. Such rocks may be part of an early Palaeozoic or even Pre-Cambrian series with an E.-W. strike that occurs through many parts of northern Queensland.

There is also a series of sandstones and shales striking N.-S. and dipping mainly to the east at angles from 30° to 40° that appears to be part of the Drummond Series of Carboniferous age. Palaeoniscid fish scales were collected in one bed in this series (near the head of Bullock Creek).

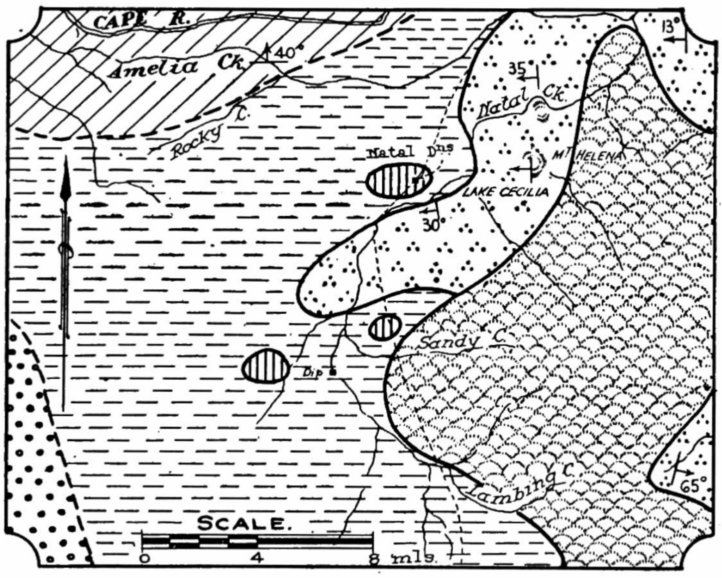

FIG. 9.— MAP OF PORTION OF NATAL DOWNS HOLDING.

PRE-CAMBRIAN (?). CARBONIFEROUS (DRUMMOND SERIES).
PERMIAN (?) TRIASSIC (DOOLOOGARAH SERIES).
LATERITIC SOILS LATE TERTIARY LIMESTONES.

GEOLOGICAL BOUNDARIES APPROXIMATE.

On the eroded surface of the Drummond Series and generally west of the outcrops of it, are extensive plains—open downs and gidgea scrub —with black soil in which no outcrops have been found. However, from the logs of bores on the property and from the relationship of these regions to the areas of early Mesozoic beds further west, it is believed that they are formed from horizontal or low dipping Permian deposits such as give rise to similar pedocalcic soil plains with little outcrop elsewhere—Mantuan Downs for instance.

The great lateritic plateau of the Prairie-Pentland-Jericho-Barcaldine region extends into this area and soils of lateritic origin occur overlying the older series.

It is in the black soil region that the limestone deposits occur. They are most abundant around the homestead, but there is a smaller deposit some four to five miles further south and another about three miles west of the Natal Downs cattle dip.

No information is available about the thickness of these limestone deposits and little about their relationship to the rocks on which they lie. Sometimes they are uncemented, chalky deposits such as commonly are excavated around the homestead, and which contain a species of land gastropod (*Helix*—sensu lato). Sometimes they are highly silicified into white, flinty masses and sometimes they are completely replaced by chalcedony. Around the homestead all three types are abundant. I have not seen any specimens of the gastropod in the silicified material.

Whether they were formed as surface limestones (similar in some general way to those of Doongmabulla) or whether they were deposited in lagoons it is difficult to determine. Probably from the type of gastropod that is found with them they are land deposits. I have not seen them immediately adjacent to the laterites, so to determine their relationships; but at one locality, ten and a-half miles N.E. of the homestead, large lumps of clear white chalcedony were found on the lateritic plateau associated with the "billy" deposits that are silicified lateritic material. Apart from this deposit I have not seen, anywhere in western Queensland, clear white chalcedony except in limestone areas. It is possible therefore that this represents a denuded silicified limestone remnant on top of these laterites.

The extreme silicification of much of the material suggests that these deposits may best be correlated with the Birdsville-Boulia-Pituri Creek types.

BULLIWALLAH.

In the neighbourhood of Bulliwallah the same rock formations occur as are found at Natal Downs, with the exception of the old rocks striking east and west. The Drummond Series occurs in the north-eastern part of the property and the deposits of the black soil plains are found seven miles south of the homestead from where they may be traced to the great black soil country of Moray Downs further south. Lateritic deposits are widespread and the later alluvium of Bully Creek is extensively developed.

At the homestead of Bulliwallah silicified limestones of precisely the same types as those of Natal Downs occur. Unfortunately, owing to the alluvial deposits of the region, their relationship to the other series could not be ascertained.

DOONGMABULLA.

Doongmabulla homestead is 36 miles S.S.W of Bulliwallah and lies nearer the centre of the great lateritic plateau that here, as elsewhere, is considerably dissected by the watercourses. Relationships are perhaps best understood by considering a section generally from east to west, from Moray Downs homestead, on the Belyando River, to Doongmabulla house, beside Dooyne Creek, a tributary of the Carmichael River.

The Belyando and its tributaries have cut down through the lateritic soils to the Permian series that here are represented by the black soil country of the downs. Such country, with occasional deposits of sandy lateritic detritus, occurs for 20 miles west of Moray Downs, after which there is a steady rise for two miles to the red soil plateau. This plateau region is unbroken for five miles after which the surface slopes gradually downwards, in a distance of three miles, to the alluvial plain of Dooyne Creek. On this slope sandstones of the Dooloogarah Series (late Permian or early Triassic) outcrop through the lateritic cover.

The limestone deposits occur in the front of this " scarp " of the lateritic soils abutting on Dooyne Creek. They form a step-like zone, rather more than a quarter of a mile wide and about 30 feet above the level of the creek. Doongmabulla homestead is built on the western edge of the limestone step overlooking the creek which here flows from a great spring nearby. The eastern portion of the limestone is covered by red sandy detritus from the scarp.

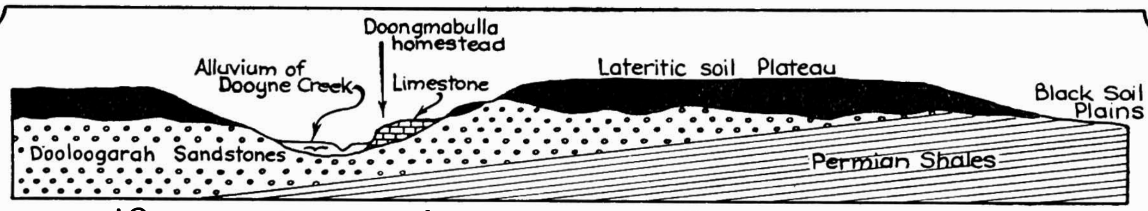

FIG. 10: W-E SECTION (NOT TO SCALE) TO ILLUSTRATE THE OCCURRENCE OF THE LIMESTONE AT DOONGMABULLA.

The limestones are concretionary, and perhaps the height of 30 feet of the step represents approximately their full thickness. The lower members consist of soft, white, somewhat chalky deposits with nodular nuclei assembled into blocks, from one to three feet in diameter, that are crusted to a depth of about half an inch with a hard, concentric lime deposit that also is often nodular. Upper layers are sometimes more solidly cemented by lime and may be coloured pink. At the surface the individual nodules, from an eighth of an inch to two inches in diameter, occur loosely in a soft, loose, red soil. No organic remains were found in these limestones and no evidence of any silicification was seen.

The deposits are of the same type as much of that now crusting the Nullarbor Plains in the arid region at the head of the Great Australian Bight and which may be still in process of formation. They appear to be materials formed on the surface of the ground as a progressively increasing superficial lime pan in an arid region.

From the topographic data there can be little doubt that these deposits are later than the red earths of the lateritic plateau and earlier than the alluvium of Dooyne Creek. From the complete absence of silicification it may be taken that they are later than the deposits of Natal Downs and Bulliwallah nearby.

CORINDA.

Corinda woolshed lies 52 miles due west of Doongmabulla and on the eastern fringe of the same great lateritic plateau. In type and in occurrence the limestones here are closely to be compared with those of Doongmabulla.

The lateritic plateau, which extends unbrokenly eastwards for 30 miles, nearly to Annievale, descends westerly in a gradual scarp over a distance of two to three miles towards the alluvial area of Thunderbolt Creek and the marine Cretaceous rocks exposed in its valley. Fronting the scarp there is a step some two miles wide and (in a N.-S. direction) some six or seven miles long, on which great blows of limestone occur through the soft, red, surface soil. The deposits are of the same nodular types as occur at Doongmabulla and no evidence of any silicification was noticed. The arguments used to determine the age and origin of the Doongmabulla deposits apply equally to those of Corinda.

THE ROCKHAMPTON DISTRICT.

Both to the north-west and to the south of Rockhampton there are enormous deposits of Devonian limestones well exposed in such places as Mt. Etna, Olsen's Caves, Bajool, Marmor, and Raglan. In 1925, when mapping such older beds, I noticed that frequently in the neighbourhood there were small basins of white, powdery limestone. Some of these deposits are quarried and used locally for agricultural purposes. In no exposure did I see any evidence of subsequent cementation.

The largest exposure examined was at Bajool on the southern side of the Gladstone road about two miles from Bajool railway station. Here the deposit has been systematically quarried for some years. It is composed of a soft, white chalk, indistinguishable in appearance from the softer types of the English chalk. No fossils are known from the deposit. In 1926 when this region was tested by the company that works the material, the limestone was found to extend over an area of some 13 acres and to vary from 18 to 20 feet in depth. There was about a foot of black soil overburden. The quarried material, on analysis, showed 87 per cent. $CaCo_3$.

The fineness of the sediment suggests that it was a chemical precipitate; and the nearness of a bluff of Devonian limestone prompts the suggestion that calcareous waters coming from such a source and discharging into a lake-like depression have precipitated the lime in such an evironment when there was little rainfall to impoverish the solution. The complete absence of traces of cementation in any of these deposits may indicate a very late age; although it must be borne in mind that a survey of lateritic processes has not yet been made in this part of Queensland.

THE REID GAP.

The deposits in this region are of the same type as those around Rockhampton. That is to say they consist of soft, white, chalky deposits developed in little basins in a region of abundant Devonian limestones. Several very small outcrops of this type were noticed around Calcium (where Devonian limestones are quarried); but the largest seen was a few miles south of Kopi railway siding where a deposit similar to that of Bajool is being worked not far from some bluffs of black Devonian limestones.

GENERAL CONCLUSIONS.

It is abundantly clear that limestones were developed in many areas in Queensland in late Tertiary times. Some of them, like those of Corinda and Dongmabulla, were land surface deposits such as accumulate to-day in arid and semi-arid regions. Others, like those of the Gregory valley and at Ipswich, were fresh water sediments. These too may be claimed as deposits of a relatively arid climate when rainfall was not sufficient to dilute the waters and so prevent the precipitation of the carbonates. Many, but not all, of these late limestones are developed in regions where there are earlier calcareous rocks—limestones, calcareous shales and sandstones, or basalt. This is probably an important relationship for the late limestones that were deposited as lacustrine sediments, in that an immediate source of carbonate-rich waters is available.

Some of the deposits, like those of Ipswich, seem earlier than the known lateritic processes. Others, the Corinda and Doongmabulla types particularly, were formed apparently after the lateritic processes ceased. If it be conceded, as is maintained elsewhere in these studies (p. 13), that the silicification so common at present on the surface in Queensland is a feature of laterite formation, then some of the limestones, such as the Georgina, Cacoory and Warenda groups, must be accepted as having been formed in an inter-lateritic age.

Certain lime pans have been developed in Queensland soils since the last pluvial epoch (of the Pleistocene), and these are discussed elsewhere (p. 66). But the deposits discussed in this study are those that, from their relationships to old alluvium, may reasonably be claimed as earlier than that last pluvial phase.

Accepting Bryan's reading of the age of the first laterites (see above p. 17) the late Tertiary limestones of Queensland may be grouped spatially as follows:

Last pluvial phase (older alluvium)	Pleistocene
Third period of limestone formation (non-siliceous)—e.g. of Corinda and Doongmabulla; and probably Rockhampton, Reid Gap and the Barkly Tableland	Later Pliocene
Second pluvial phase (last laterites)	
Second period of limestone formation (siliceous)—e.g. of the Gregory, Georgina, Cacoory and Warenda; and probably Natal Downs, Bulliwallah and the Barkly Tableland	Earlier Pliocene
First pluvial phase (first laterites)	
First period of limestone formation—e.g. the Silkstone Series	Miocene

3. THE EVOLUTION OF THE BARKLY TABLELAND.

Summary: The Barkly Tableland is a savannah region in which an irregular surface of Cambrian limestones, modified by lateritic processes, is buried beneath late sediments. In late Tertiary times it extended considerably further to the north and east. Pleistocene erosion has reduced it to a plateau nucleus fringed with a zone of dissected limestones (to some extent a rediscovered topography), beyond which there are limestone outliers. This erosion was accelerated by the action of powerful springs of water that have decreased since the Pleistocene. The watercourses in the eroded marginal zone retain the characteristics impressed upon them when the Tableland was more extensive. A long series of geological events has been evaluated and summarised on p. 55.

The name Barkly Tableland was given by William Landsborough (1862, p. 31) to a great area of open, tropical grasslands, partly in Queensland and partly in the Northern Territory of Australia. The Queensland section lies between the latitudes of 19° and 22° S. The extract from Landsborough's dairy for 6th December, 1861, reads:—" A plain with tableland of the richest soil, and with grasses of the most fattening nature, but which at this time are old and dry. This tableland I have named Barkly Plains, after His Excellency Sir Henry Barkly." Although thus he called the region " Barkly Plains," he referred to it more frequently in his diary as the " Barkly Tableland " and that term has survived . It is unfortunate that the name Barkly Plains was not continued, for the region is not very high. Also the term " tableland " suggests something with a noticeable edge, but it is a most unsatisfactory procedure to attempt to define the southern limits of this " tableland," at least in Queensland. In the basin of the Georgina River the region slopes imperceptibly southwards and no suitable line topographically marks its limits. To the north and the east in Queensland it is relatively easy to define a margin. Daneš (1916), Dunstan (1920) and others have included all the limestone region in the Barkly Tableland. If the name is to be used it were better to restrict it, as Landsborough suggested and as the residents still do, to the Mitchell grass plains.

In this study I shall be concerned only with that portion of the Barkly Tableland and its environs that extends into Queensland. Northern Territory evidence is quoted only in so far as it bears upon the Queensland problem.

SURFACE FEATURES.

The Tableland proper is a very flat region of greyish-brown, pedocalcic soils that grows rich Mitchell grass but very few trees. Camooweal, the only township upon it, is at a height of 788 feet above sea-level. The rocks that do outcrop (and exposures are not common) are for the most part limestones. To the north and the north-east these plains are bordered by a region of well-exposed, dissected limestones that, except in certain small areas, are of Cambrian age. Similar limestones, though not dissected to nearly such a degree, nor so well exposed, fringe the region to the south. The two belts of dissected limestones are separated by a great tongue of lateritic soils that, extending westwards from the region of Yelvertoft, reaches to within two miles of Camooweal. Eastwards of all these divisions lies the rugged country of Pre-Cambrian rocks that form N.-S. ridges in the mineral belt of Cloncurry, Mt. Isa and Lawn Hill. On it, towards its western margin, scattered outliers are found of the sediments that occur in and about the Tableland. The largest of these is the limestone plateau on which the homestead of Lawn Hill is built.

The Tableland proper and the lateritic tongue are drained by the Georgina River and its tributaries, flowing to the south through the more dissected limestones in that region. Westwards of the Georgina watershed, in the Northern Territory, an area comprising perhaps two thirds of the Tableland has no streams draining from it. The only watercourse in that region is the normally dry Playford River that ends in a depression of the Tableland itself. The north-eastern region of dissected limestones is drained by streams that flow to the Gulf of Carpentaria.

In addition to the laterites in the main tongue remnants of such soils are common. In the north-easterly region of dissected limestones they frequently occur on the divides between streams. Relics also are scattered over the Mitchell grass plains of the Tableland as small plateau masses and a great quantity of "billy," the weathered, silicified material of lateritic origin.

GEOLOGICAL DETAILS.

1. THE OLDEST ROCKS:

The Pre-Cambrian rocks in the areas nearest to the Tableland are, for the most part, quartzites, belonging presumably to the Mt. Isa Series.* They strike N.-S. and form a series of meridional ridges such as the Constance Range, the Waggaboonyah Range, and so on. These old quartzites commonly have ripple marks, sun cracks and rain spots, indicating their shallow water origin. They are folded and dip usually at not very steep angles—10° to 30° is a common value. They are, from all evidence, of late Pre-Cambrian age. Further east a complex of earlier and more varied rocks occurs. Pre-Cambrian rocks follow round the northern end of the province, through the valley of the Nicholson River into the Northern Territory, where they occur as the Oggajumna and other ranges that bound the Cambrian basin to the north.

Unconformably upon such rocks rest the Cambrian limestones, still virtually horizontal. Measurements taken over a long distance east of the O'Shanassy River indicate a dip to the west of the order of 50 feet per mile. Occasionally small, gentle folds of no great distribution disturb the otherwise monotonously even grade of the beds. The Cambrian sequence begins with limestones that stratigraphically are approximately at the junction of the Lower and Middle Cambrian. Then follows an unbroken series of Middle Cambrian limestones, with some beds of contemporaneous or penecontemporaneous cherts and shales. These beds are amazingly rich in well-preserved fossils—trilobites, brachiopods, mollusca and echinoderms being the chief—such fossiliferous sediments bringing the sequence to the top of the Middle Cambrian. Conformably succeeding these are unfossiliferous, brown or cream-coloured, crystalline limestones, sometimes pure, sometimes sandy, apparently of Upper Cambrian age.

Such is the order seen in a westward traverse from the Thornton River towards the O'Shanassy River, beyond which the flat plains of the Tableland begin. Further west in the Northern Territory, on Alroy Downs and Alexandria, the earlier beds of the fossiliferous Middle Cambrian outcrop. It would seem, accordingly, that the Tableland is developed on a broad syncline of Cambrian limestones.

* As defined recently by the Aerial Geological and Geophysical Survey of Northern Australia. See their Annual Report for 1936.

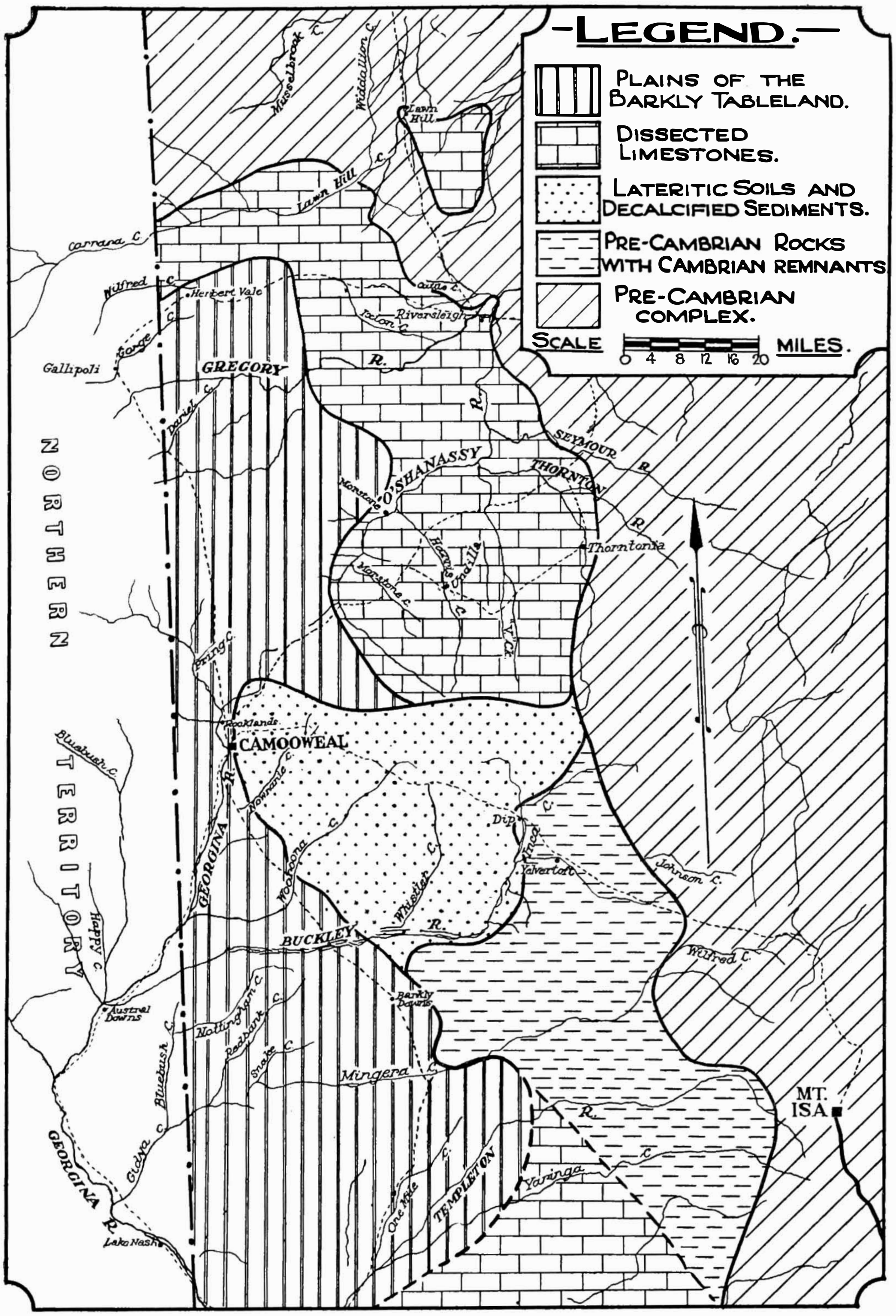

FIG. 11 - THE NATURAL REGIONS OF THE QUEENSLAND PORTION OF THE BARKLY TABLELAND AND ADJACENT AREAS.

The Middle Cambrian limestones (and associated sediments) are of the order of 800 feet in thickness. Because of later occluding deposits the thickness of the Upper Cambrian members is not known. I have measured 200 feet of them in the cleft that forms the Nowranie Caves, south of Camooweal, but this is only portion of the series. Danes (1911, p. 81) refers to a thickness of 1,700 feet of limestone in a bore on Alexandria that finished in limestone; but much of this would be pre-Upper Cambrian.

Detailed work—measurements and collecting—has been done on the fossiliferous Middle Cambrian sequence. From Thorntonia to Undilla and then towards Morstone a sequence has been measured that is shown in text-figure 12. The range of some of the more significant trilobite genera is indicated alongside, for some of these details are important in interpreting the surface features in other portions of the area. The full palaeontological succession has not yet been published. Beside this sequence is placed the driller's log of a Government bore recently sunk unsuccessfully for water at Bull Creek on Morstone, with a suggested correlation of the two sections.

The section as shown in text-figure 12 is not to be regarded as the ever-present succession of Middle Cambrian beds in the region. Slightly further north, along the old Burketown road, where fossils are just as abundant, the sedimentary succession differs. There the early part of the sequence (where also, for some distance, dips are higher than elsewhere in the region) consists largely of massive, echinodermal limestones, while the later siliceous limestones descend to considerably lower horizons than they do in the more southerly section. There is, accordingly, a considerable lateral variation to be recognised in the series.

Lower down the Georgina the Cambrian sequence varies again. There, in great contrast to this northerly area, the Upper Cambrian beds are richly fossiliferous.

No later beds of Palaeozoic or Mesozoic age are known in this region. However, a few years ago, a block of quartzite was found four miles north of Camooweal in which there is the impression of a hemicycad, possibly *Otozamites* or *Ptilophyllum*. I have noticed that, in a few, isolated regions in Western Queensland and the Northern Territory, there are small areas of apparently Jurassic sediments but never any great extent of them. I hope to describe these occurrences on some other occasion. This quartzite remnant may represent one such Jurassic lacustrine basin.

Over the flat lands of the Barkly Tableland proper, recognisable outcrops of Cambrian limestones are known in only a few localities. At the Nowranie Caves, mentioned above, the brown, crystalline limestones remain constant in character for 200 feet, down to groundwater level. There can be little doubt that they are Upper Cambrian, corresponding to the brown, crystalline limestones that succeed the fossiliferous Middle Cambrian beds in the neighbourhood of Morstone. Other thick limestones in cave sections, *e.g.* those two miles east of Camooweal, are to be correlated with these. So also would be an outcrop of somewhat sandy limestones, containing a small lode of galena, that I have seen on Little Tott's Creek, about three miles downstream from B Bore on Morstone. A fossiliferous Cambrian outcrop is to be seen on Mingera Creek beside the No. 6 bore on Barkly Downs. On these plains further west in the Northern Territory a few outcrops with fossils are to be found near the No. 1 bore on Alroy Downs,

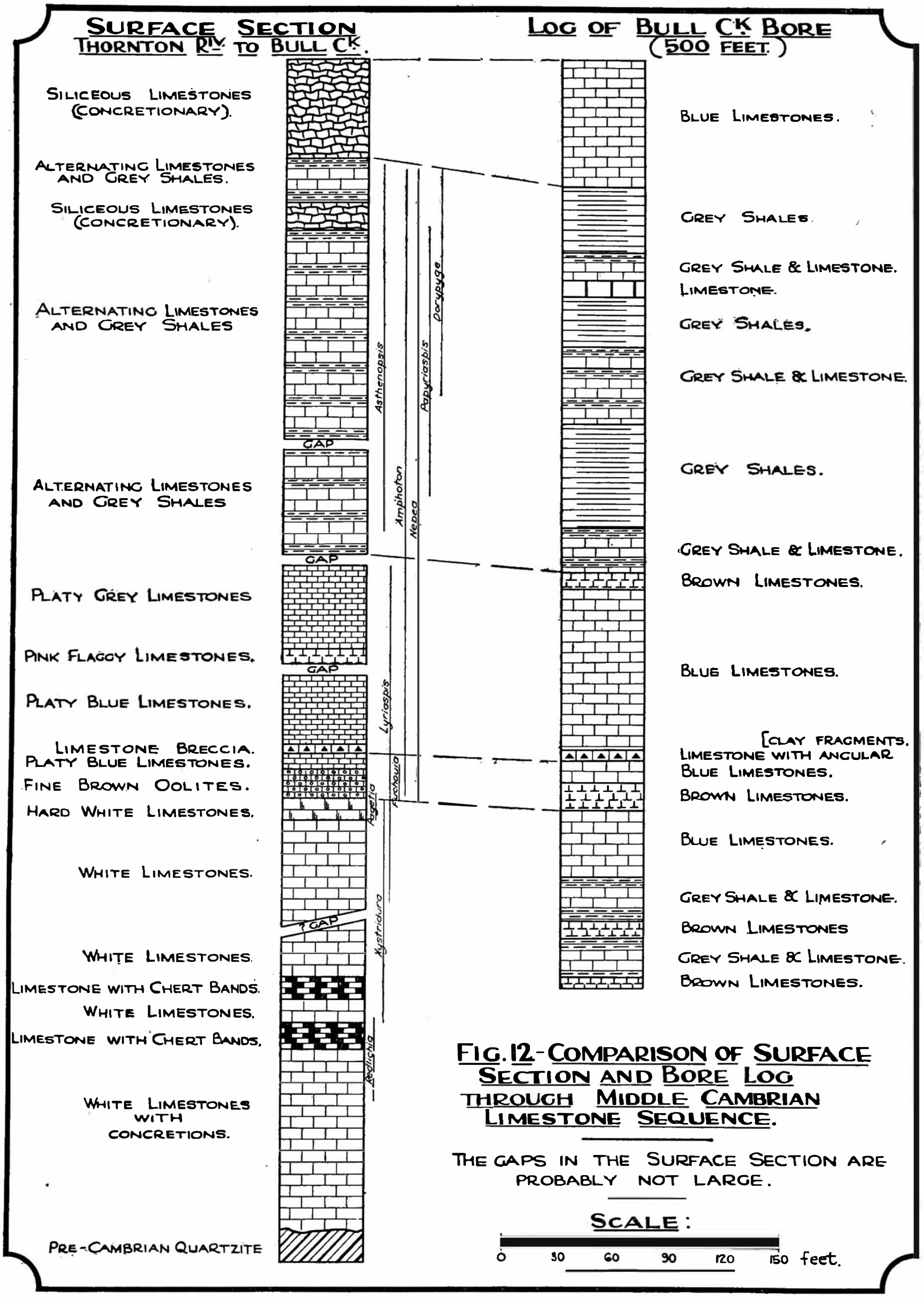

FIG. 12—COMPARISON OF SURFACE SECTION AND BORE LOG THROUGH MIDDLE CAMBRIAN LIMESTONE SEQUENCE.

THE GAPS IN THE SURFACE SECTION ARE PROBABLY NOT LARGE.

and at other localities on Lake Nash and Alexandria. But much of the compact limestone that occurs sporadically upon the surface of the Tableland is a panel of late Tertiary age (see p. 33); and since both Cambrian and Tertiary beds are horizontal, or virtually so, it is often most difficult, sometimes impossible, to discriminate at present between the two in small surface outcrops. At Headingly (see p. 34) the Tertiary limestones form a surface skin upon clays that are pierced bv bores for some distance before they reach a lower, and presumably, Cambrian limestone. On Alroy Downs, in the Northern Territory region of the Barkly Tableland, so Mr. J. Crouch the Manager informs me, no solid rock is met with in most of the bore holes for 100 to 200 feet, after which the bores enter " red rock." At No. 4 well however, fossiliferous, blue Cambrian limestones were struck at 80 feet, after passing through a continuous section of " soil," while at No. 1 bore Cambrian beds form surface outcrops.

These things suggest that over the Barkly Tableland proper the Cambrian limestones form a dissected surface, probably an old landscape, now buried by later deposits; and that only occasionally the higher parts of this landscape are found as inliers on the present surface. The age of the later deposits is discussed below.

2. THE LATERITIC SOILS:

In late Tertiary times a lateritic mantle seems to have clothed much of the region; and remnants of it are to be found in the eastern area of dissected limestones as well as in small plateau areas on the surface of the Tableland itself. In the area of dissected limestones these remnants occur on the divides between the creeks. Around V Creek and that watercourse that locally is called the Harris but which, on the maps, appears as Magenta Creek,* the base of these remnants was found, by levelling, to be at a fairly constant height—about 120 feet above the main road crossing of the bed of the Magenta. This suggests that when the laterites were formed in Pliocene times (see Study No. 1) the region, in this section at least, was a plainland.

The weathering of limestones in warm, humid regions results in their decalcification to produce a reddish soil that is, in essentials, the oxidised and insoluble residue of the eroded mass. The familiar " terra rossa " are soils of such type in less moist conditions. In this region where the limestones are commonly impure—calcareous shales and calcareous sandstones are both abundant—typical lateritic soils, complete with silicified sandy layers (" billy ") were produced. In the Magenta Creek region particularly, where argillaceous limestones are most common, such soils occur upon the divides.

Further east, near the Thornton River, another type occurs. In this area the limestones themselves are relatively pure but they contain, on many horizons, zones of intercalated, platy cherts. These often contain fossils and were deposited probably as contemporaneous masses of colloidal silica, rather than as subsequent replacements of the limestone. Commonly

* There is some confusion in the naming of some of the watercourses in this region. The Creek marked as Harris Creek on the State maps is locally known as Douglas Creek; while Magenta Creek of the maps is called Harris Creek locally. The names Harris and Douglas were given by Landsborough in 1861. Mr. E. T. Holdaway and Mr. R. H. Stevens of the Queensland Lands Department have kindly plotted Landsborough's journey for me, from the notes in his diary; from which it appears that the Harris Creek of the maps is the Douglas of Landsborough; but the Harris in Landsborough's naming is that creek that locally and on the maps is known as Opal Creek.

they have concentric, liesegang-like structures (see Whitehouse, 1936, p. 67). They are so sharply differentiated from the intervening layers of the limestone that subsequent replacement seems unlikely. Upon the divides in this area the reddish soil remnants consist of masses of cellular, limonitic and slightly siliceous material in which angular fragments of cherts (insoluble) are abundant. These fragments are packed closer than they occur in the limestones and for the most part are still horizontal. It is immediately suggested that the soil-forming process that produced them was not disturbed by erosional effects; but that, as the limestone was dissolved and only the siliceous and ferruginous material remained as the insoluble residue, the plates of chert subsided slowly in the soil and retained their horizontal posture.

The remnants of laterites that occur upon the Tableland are more noticeable in the Northern Territory (where they rise above the general level) than they are in Queensland where usually they are flush with the surface of the "black" soil plain.

In 1936 I divided the Cambrian limestones of the region into two series—the Templeton Series below and the Georgina Limestones above. The name Templeton Series was proposed for certain non-calcareous beds with trilobites, that occurred in an eastern salient of the region between Mt. Isa and Camooweal. I noted at the time (1936, p. 66, footnote) that not always were the basal Cambrian beds of the area non-calcareous, and suggested that possibly such beds of the Templeton area might be, after all, a local, limeless variant in a succession that essentially was a limestone sequence. At the time this suggestion was not favoured; but later detailed field work has established this in a most curious and unexpected manner.

The tongue of lateritic soils shown on the present map (fig. 11) is succeeded eastwards by a region in which remnants of non-calcareous sediments—cherts for the main part—are to be found, in small and scattered regions on a surface that otherwise is composed of Pre-Cambrian quartzites. The evidence is now clear that both of these areas were once covered by Cambrian limestones; but that in the period of lateritic soil formation the limestones were decalcified. In the more westerly of the two regions the laterites remain as typical soils; but in the eastern region the softer fractions have been removed gradually, so that generally only the angular chert and silicified shale fragments remain, forming remnants upon the Pre-Cambrian rocks. In support of these statements are following evidence is offered:—

1. No Cambrian limestones are known in this region except near the margin of the red soil tongue, where the soils may be transported locally by stream action for a short distance over the adjacent limestones. There are a few, very small patches of silicified limestone that seem to belong to the late Tertiary group. Such few outcrops of the older series that are known in the red soil region are non-calcareous. The best known exposure is at "Split Rock," a waterhole at the Yelvertoft-Camooweal road crossing of Wooroona Creek. Here there is a platy sandstone, containing trilobites and brachiopods, which is so friable and porous that it has quite the appearance of some of the soft Tertiary sandstones of south-eastern Queensland. Daneš (1911, p. 2) published a photograph of this exposure and, evidently by mistake, labelled the rock an impure limestone; but it has virtually no calcareous cement in its present condition. Calcareous sandstones that, if decalcified, would give such a rock are known in the unaffected region, a very typical exposure being in a creek section five miles west of Morstone.

2. The red soils are very typical of the upper, ironshot zone of a red earth or lateritic soil, and contain limonitic nodules and nodular pans.

3. In the more easterly region where fossiliferous chert fragments or shales form a mantle on Pre-Cambrian rocks it is noticeable that in none of the fossiliferous localities are fossils from different horizons mixed. At Yelvertoft homestead only the *Redlichia* suite of fossils occur (as abundant chert chips strewn over a surface of Pre-Cambrian quartzites). At Beetle Creek and other localities nearer Mt. Isa only *Xystridura* and its usual associates are found. At Beetle Creek there are definite beds of these shales overlying Pre-Cambrian quartzites; in a number of other regions in the neighbourhood fossiliferous shale fragments litter the surface of the older rocks (quartzites and sometimes granites).

A very informative occurrence is at a locality 16 miles north of Yelvertoft Dip. Here there is a landscape of hills and valleys of typical Pre-Cambrian quartzites The surface is littered with fragments of cherts and chertified shales. Two faunas were collected. The chips in a valley contined *Redlichia* only. Others from the top of a hill perhaps 30 feet higher had *Xystridura* and its common associate, *Pagetia*. This fauna in the unaffected series further north immediately succeeds that with *Redlichia*. A third and slightly later fauna with agnostids has been collected on a hilltop somewhere in this region by Mr. Dalling, Manager of Yelvertoft, but I could not find this. The occurrence of loose cherts still in their correct vertical order recalls the lateritic action upon cherty limestones slightly further north at Thorntonia (mentioned above) where the chert chips, still with a limonitic soil cement, retain their correct relative placing, and thus suggests a gradual and complete decalcification of the parent limestone over an irregular Pre-Cambrian floor.

The form of this tongue-shaped area of lateritic soils and decalcified limestones calls for some comment. I have not a series of figures for the relative heights of the different portions of the region. But several of the major tributaries of the Georgina River rise in this tongue, so that, compared with other sectors, it is not a low-lying region to-day. Since therefore the Pre-Cambrian rocks have been exposed extensively within its limits it is possible that, when the Cambrian sedimentation was in progress, there was a buried ridge of the old Pre-Cambrian surface in the region. Furthermore, it is important to stress two features—first, that the tongue forms an abrupt partition between two areas with fossiliferous Cambrian limestones and itself has altered remnants of such rocks; and second, that to the north, in the region of V Creek, as already has been shown, the laterites were formed on a level surface some 120 feet higher than the present creek beds. Since this tongue narrows to the N.W. while to the S.E. the denudation of the limestones and soils has been the more effective, an early drainage system to the S.E is indicated, producing a broad, shallow valley roughly coincident with the present limits of the tongue. The most likely explanation seems to be that the valley existed within the limestone plain before the laterites were formed; and that the laterites, developing over the whole region, retained the form of the older surface and its original drainage.

3. THE LATEST DEPOSITS:

One other aspect of sedimentary deposition remains to be considered —the age of the sediments that cover the denuded surface of the Cambrian limestones on the Tableland proper. It is suggested here that, for the most part, these are Pleistocene deposits. The reasons for this, briefly, are as follows:—

Over the plainlands of the Tableland outcrops of limestone are really rare, particularly in the Northern Territory, away from the margin and the streams. The soils are of the greyish-brown pedocalcic type that, except in river silts now forming, occur in western Queensland under only two conditions—either as sedentary soils formed directly from a calcareous series (such as the Cretaceous sediments), or as the transported soils of the old alluvium, particularly the later phases of it. Since in this region bores often pierce 100 to 200 feet of loose material before reaching the limestone, the soils, in all probability, are not to be regarded as sedentary types but secondary, and, from occurrences elsewhere in western Queensland, an old alluvium is the most likely filling. Furthermore the experience on Alroy Downs already has been quoted, where, after traversing such a thickness of soft material, the bores enter " red rock." I know of no surface material in the region to correspond with this other than the lateritic soils; and I have noticed that occasionally the spoil heaps from shafts sunk on the Tableland for sundry purposes do yield a mottled sandy clay that suggests some lateritic or podzolic influence—either an original soil or a redistributed laterite. One such occurrence, for instance, is the excavation beside the house of Alroy Downs.

If that buried " red rock " is a lateritic soil (and I know of nothing else locally with which to group it) then either it is a valley laterite distinct from the high level types in the same region, or else it represents a redistributed material. Elsewhere (p. 17) I have shown that both plateau and valley laterites occur adjacently in Queensland. But the difference in height between the surface and the buried red deposits is here much more marked than in any known area of plateau and valley laterites, so that I would prefer to regard the lower deposit as redistributed material.

The evidence is not conclusive; but such as it is would favour a late (Pleistocene) filling of the limestone valleys to form the flat lands of the region to-day. Accepting this as the most reasonable interpretation, then it follows that much of the late limestone that forms a veneer upon the surface, as at Headingly, is also of Pleistocene age. Probably it is somewhat later than the alluvium and so corresponds to the lime pans in the old red silts of south-western Queensland. It is very noticeable that such limestone deposits are most abundant close to the watercourses. This is strikingly illustrated all along the Georgina, on the Tableland proper, where the limestones form a zone adjacent only to the river. Apparently the stream has cut down to and exposed the prominent soil pan in its valley. Such lime deposits accordingly would be of later age and different origin from the Tertiary limestones of the Riversleigh region in this province (see p. 24).

The high sulphate content of the ground waters (see p. 51) accords well with this thick soil layer in which arid or semi-arid pans (lime definitely and possibly gypsum) occur.

THE SURFACE WATERS.

The contrast between the watercourses on the plains and those in the dissected limestone country immediately to the north-east is most striking. The Georgina flows only in the rainy seasons. For the most part of the year its bed is dry, except for the widely separated waterholes that have the usual, turbid, milky-brown water typical of the western rivers. The grade of its bed is very slight as it extends through the plains.

The Gregory, flowing to the N.E. through the rocky region of the Cambrian limestones, is the reverse in all these things. Here, except in the upper portions of its course, it flows as a continual stream of limpidly clear, sparkling, blue water, foaming over the rapids and small waterfalls in its more steeply graded bed. Close to the flowing waters grows a matted mass of varied vegetation—pandanus, cabbage-tree palms, paper-bark tea trees, white cedars, the stately Leichhardt tree, native figs, native plums, a host of fruiting vines and tall rank grasses. It is a most beautiful setting for the loveliness of the stream. And yet, only a few yards away the country is dreary, spinifex-covered ridges of limestone. The vegetation again contrasts most strikingly with the Georgina territory. There a line of river gums and coolibahs along the channels is all that, for the most part, varies the grassy vegetation of this savannah region.

The lime-rich waters of the Gregory and other similar streams in the dissected limestone belt flow perennially because of great springs in their beds. Tributaries that have no springs are dry except in the rainy months. The source of this water will be discussed below.

In spite of these great contrasts there is one remarkable agreement between the rivers. Both have braided streams, though braided a little differently.* It may be mentioned, in passing, that the many channels of the Georgina inter-twine, and that in the lower reaches of the river one such channel, or a braid of channels, may leave the main swarm, deploy for a great distance from it, and then either return to it or join some other river system. The Gregory River, when at last it descends to the great alluvial plains towards the Gulf of Carpentaria, does the same. Beames Brook, for instance, leaves the Gregory and joins the Albert. But curiously enough, in this highly dissected region of limstones and, lower down, in the Pre-Cambrian quartzite ranges, the streams have many of the same peculiarities. Carl Creek, for instance, is a distributary of the Gregory joining the O'Shanassy just before that stream comes into the Gregory, cutting a deep channel through the limestones. The curious maze of watercourses in the region of Lawn Hill and Widdallion Creeks is even more striking (see fig. 4).

Lawn Hill Creek (a tributary of the Nicholson River), flowing strongly from spring waters, leaves the limestone mass and comes on to the Pre-Cambrian quartzites at the southern end of the Constance Range. In a great gorge of these old rocks it splits into two branches,† Lawn Hill Creek and Widdallion Creek, each of which has a great flow. Each of these streams in turn subdivides in the quartzite country lower in its valley and a network of watercourses is produced. Where the valleys are flat and filled with alluvium, as in the Danes Valley, it may be, as Ball (1911, p. 13) has suggested, that there has been some Recent or sub-Recent stream capture. But in the rugged country of the Pre-Cambrian quartzites this is not likely to have happened so effusively as the tangle of braids would require. Rather the features suggest that the present stream system, as an entity, has been impressed upon this topography. That is to say, it is the characteristic system of a very flat surface; and it is suggested accordingly that it developed on a plain, and that by gradual denudation the same system has been superimposed upon the harder rocks below. In effect they may be regarded as "Incised Braids."

* The intersepts are far greater than in what usually are called "braided streams." An account of this peculiar braiding will be published in Vol. LIII. of Proc. R. Soc. Q'land.

† The creek forms a large crescentric waterhole around the end of a low quartzite ridge; and from the opposite horns of the crescent the two branches arise.

The flow from these limestone rivers is rapidly declining; but since this is a feature of spring action it is discussed in the chapter that follows.

THE UNDERGROUND WATERS.

The outstanding asset of the Barkly Tableland as a pastoral region, apart from its excellent grasses, is that, in spite of the lack of surface streams, underground waters of good stock quality and abundant are everywhere available. Very few bores on this part of the region have failed. The supply is obtained from depths that vary from about 150 to 350 feet. These waters, although well " mineralised," are often not so highly charged with carbonates as the calcareous deposits in the region might lead one to expect. They are, however, often rich in sulphates. Supply seems just as reliable when the bores pierce the Cambrian limestone as when they traverse the later deposits and bottom only on the limestones.

The region lies between the 10 and 20 inch isohyets; and the absence of any surface run-off by streams over two-thirds of the Tableland is in accord with a good underground supply. A goodly proportion of the waters that fall upon the surface must percolate below. Also in agreement is the cavernous condition of much of the Cambrian limestone when it outcrops within this zone. In the Nowranie Caves, for instance, it is possible to descend by ropes to the water level 200 feet below the surface.

It would be reasonable to believe that the subsurface waters, in the region of the thick alluvial cover, are restricted downwards by the buried surface of the limestones, producing either a natural or a perched water-table; and also that the higher portions of the buried limestone have been so affected, by solution possibly, that they too carry water.

But the region of exposed Cambrian limestones both to the north-east and to the south are very differently equipped with contained waters. Where, some distance to the south, the limestones are clearly of Cambrian age, as over much of the country of Walgra and Glenormiston, very few bores have yielded an adequate supply. Such too, is the general experience in the dissected region of the north-east, for instance in the basins of the Gregory and the O'Shanassy Rivers. Yet in this latter region springs issue abundantly from the limestones and flow the watercourses as the turbulent streams that have been described. The springs commonly issue from the soil of the banks or, more usually, are to be seen bubbling up under the waters of the stream; so that rarely is it possible to estimate individual yields. But the flow is colossal. It is sufficient, for example, to flow the Gregory abundantly, over a variety of country, all the way to the coast, a distance of over 100 miles from the last limestone outcrop.*

That such supplies, issuing from the limestones, are in great quantity yet bores in the region generally are failures, is at present hard to understand. For the time being I do not propose to suggest any explanation. But one observation that calls for comment is the declining flow from these springs.

* Measured flows are quoted elsewhere (p. 52).

Evidence of such a decline is to be obtained both at the heads and in the lower courses of the streams. The local species of *Pandanus* and *Melaleuca* (the paper-bark tea tree that here grows to magnificent size) will live only in regions of abundant fresh water, with their roots either in the permanent waters or in the soil nearby that adequately is water-charged. Some of the creeks that flow abundantly from the springs—such as Lawn Hill and Widdallion Creeks—do not carry on to the main rivers or to the sea. In such regions the lower portion of the stream courses, below the limits of flow, are crowded with dead *Pandanus* and *Melaleuca*, still in their position of growth. The residents have known much of these courses when the water flowed in them and the trees were alive.

So also at the head of the streams. To-day the O'Shanassy is a stream of permanent water only immediately below its junction with the Thornton River. Twenty years ago, so I am told, it was permanent from Morstone homestead, some 16 miles further upstream. In this now dry upper course there are masses of dead *Pandanus* and *Melaleuca*, although in the region of the larger waterholes they still flourish.

Neither the Thornton nor the Seymour flow to-day although, when the country was first settled, they had flowing water. The abandoned homestead of Mt. Margaret on the Thornton was beside a group of good springs that since have failed completely. Harris Creek, Magenta Creek, V Creek and many others have a similar recent history. There are small springs still to be found in these regions, for example about three miles upstream from the old road crossing of the Harris, but they are small trickles that are sufficient to fill adjacent waterholes but not to flow the creek.

The earliest available record of conditions in the region is Landsborough's diary (1862). Where is now the dry bed of the O'Shanassy, in the region above the Thornton junction, he speaks of deep waters where in places he had to swim across. Such waters occurred in the bed, at his furthest crossing, 12 miles above Morstone, probably maintaining a series of long and almost continuous waterholes; but the river was not, even then, flowing continuously. There were certain dry crossings that Landsborough mentions between the present Morstone and the junction of the Thornton. Another interesting record is that of Jack (1885, p. 9) who is 1881 described Carl Creek, the distributary of the Gregory that has been referred to, as "a fine rushing stream." To-day it has only a trickle.

Incidentally very definite evidence of the decline of the springs from a period far ante-dating white settlement is given by the tufa deposits of Carl Creek. But these are described elsewhere in this series (p. 26).

All of this is useful but qualitative information. There is, however, material for quantitative estimation. In 1919 and 1931 the flow of the Gregory was measured at two places—at Riversleigh, on the edge of the limestone area, and at Gregory Downs, some 46 miles further downstream. Mr. Adam Conroy of the Government Stream Gauging Department kindly has supplied me with these figures as follows:

RIVERSLEIGH	GREGORY DOWNS
8th June, 1919: 155 cusecs	7th May, 1919: 184 cusecs
25th June, 1931: 113.5 cusecs	27th June, 1931: 75 cusecs

These are winter figures, and the winter is the dry season. The meteorological records show that, in each year for the three months preceding, little rain fell in this region, so that virtually this is an estimate of spring flow. As such the rapid decline is very striking.

At first sight these enormous springs would seem to have some intimate connection with the great storage of ground water beneath the neighbouring Tableland, particularly since the markedly graded streams in the dissected limestones must, in this region, have cut down to somewhere about the level of that watertable. Indeed they may have, and the gradual slow recession of the watertable that must have taken place since the last great pluvial period of the Pleistocene may be reflected in the tardy abatement of the springs.

But there need not be such a direct connection. The water of the springs may be a local storage in the limestone, dating from that same last period of abundant rainfall, and such local supplies, not being adequately replenished, are declining. Such a possibility is strongly enforced by the features of other local springs. Although most of the spring water comes from the limestones there are good springs issuing hereabouts from the faces of Pre-Cambrian quartzites. Many of these are shown in position on the map that is fig. 4, and include the Lilydale Spring and the long line of springs in the front of the Constance Range. Actually, Lilydale is perhaps best regarded as on a continuation of that range, where it is breaking into smaller hills. Many of these sources gave copious issues even, according to all reports, in quite recent years. Gorge Spring still runs a good stream of water but that, they say, has lessened. Shadforth Spring, one of the best in recent years, may be taken as typical. This issues from a cave at the intersection of joints in a quartzite cliff about 30 to 40 feet above its base. The water falls into a great circular pool at the base, from which very recently a creek flowed. Along its dry bed at present, for about half a mile, there is a fringe of living *Pandanus*, *Melaleuca* and palms.

Such generous but declining springs in the quartzite cannot be regarded as coming from the groundwaters of the Tableland; so that there is no obligation to regard the more copious springs of the limestones as having such an origin—particularly since the limestone spring water is ordinary carbonate water, while the groundwaters of the Tableland are so largely sulphate-rich. In either case, whether the waters come from the supplies of the Tableland or whether they are more locally impounded, the uncertainty of bores in the region is not easy to understand. As noted below, they have increased and declined in earlier ages, before there was a "Barkly Tableland" as a potential reservoir. There is a local belief that the decline of the springs is due to a relatively recent decrease in rainfall. But from Landsborough's experience, and from the geological history, it is more likely to antedate any such minor change and to be, possibly, a general decline in the less rainy period since the close of the Pleistocene.

THE SEQUENCE OF THE LATER CHANGES.

The more pertinent details have now been presented from which an idea of late Tertiary and Recent changes can be gathered. The earliest time-datum practicable for this purpose is the onset of laterite-soil processes early in the Pliocene. It has been established that at the time of the formation of these soils much of the region was a plain or plateau, but that there was at least one wide shallow valley draining to the south-east. The changes that followed the warm, humid conditions that produced these laterites are most readily assessed in the Gregory Valley where (pp. 24 to 28) the study of late Tertiary limestones around the junction of the Gregory and O'Shanassy Rivers allowed the following conclusions to be drawn:—

(i.) Subsequent to the plateau-forming period of the first lateritic soils a large valley was carved in the old limestones towards their eastern limits.

(ii.) In this valley some material of lateritic type was deposited, possibly a redistribution of the plateau soils.

(iii.) An arid period succeeded the erosion interval, during which the escape of spring waters from the limestones was far greater than at present, being possibly the maximum output of which we have record. The limestones of Verdon Creek were formed at this time.

(iv.) Lateritic conditions returned, the newly formed limestones being affected to some degree by siliceous and ferruginous solutions.

(v.) Subsequently the newer limestones have been eroded into wide valleys, such as the Danes Valley, that have been floored with old alluvium. The once continuous later limestones have been dissected and large outliers (mesas) produced.

(vi.) There has been a later reduction in the output of the spring waters.

This sequence of events may serve as a measure of, and a check upon, evidence elsewhere. It has been noted that on the Tableland the sequence of events seems to have been—

(i.) The dissection of the laterite-capped limestone plateau to form an irregular landscape.

(ii.) The deposition of laterites in the lower regions—to some extent, at least, by the redistribution of the original cap.

(iii.) The deposition of limestones.

(iv.) The silicification of the earlier limestone presumably by lateritic action.

(v.) Possibly a further period of limestone formation.

(vi.) The complete covering of the old landscape by deposits, apparently of Pleistocene age.

(vii.) The development of extensive lime pans in the soil.

(viii.) The initiation of the Georgina River system in the old alluvium and across the old S.E. valley, with the consequent exposure of the lime pans in the corraded region of the channels.

A marked agreement will be noticed between the two regions in the first four events that can be determined—an agreement that should allow a general statement to be made to cover the whole province. Subsequent to these happenings the histories of the two areas are not in perfect accord, since evidence for changes in the one region has not always been noticed in the other. To this extent the records may be regarded as complementary.

With these things in mind it is advisable to look again at the evidence of the incised braids of the Lawn Hill and Widdallion Creek systems. Here the direction of the major courses corresponds generally with the N.-S. "grain" of the Pre-Cambrian quartzites over which they flow. Consequently it seems unlikely that the braids date from the time of the lateritic plateaux when the only directional influence would be the general slope of the country; for it would be a mere coincidence if such a slope corresponded with the grain of the Pre-Cambrian beds, which, at that time, were deeply buried beneath the Cambrian limestones. However, there is evidence that, later than all lateritic processes, the plateau was worn into valleys that, over the Tableland at least, were deeply filled with silt in early Pleistocene times. If, as is quite likely, hills of the old Pre-Cambrian ridges of the Constance Range were not completely submerged in the silt, both a braided beginning and a directional course could be produced. Accordingly it is suggested that both the Georgina and the Gregory River systems date, as entities, from the Pleistocene period. The Gregory and its Gulf associates have eroded the region more markedly than the Georgina because of the steeper grade from the Tableland to the Gulf than to Lake Eyre, whither the Georgina flows.

CONCLUSIONS.

Considering the facts that have been presented in this and in the previous study, together with the comments that have been made relevant to them, the following order of events seems most adequately to summarise the historical sequence.

1. In Cambrian times a series of marine limestones was deposited over the whole of the region now occupied by the Barkly Tableland, extending further north and east to the limits of the region of known Cambrian remnants. The deposition, which occupied the whole of the Middle, and part of the Upper Cambrian, began over an irregular floor of Pre-Cambrian rocks, one ridge of which extended S.E. from the site of present Camooweal.

2. The region sagged very slightly, possibly during the time of Cambrian deposition, to form a wide but very gentle syncline, with its axis somewhere west of Camooweal. Little lateral movement has affected it since.

3. There is no trace of any marine influx since the Cambrian. The region has been a land area ever since, occasionally with lacustrine or marshy depressions. One or more small lagoons seem to have existed, for example, in Jurassic times; but generally, owing to later planation, little is known of the history of the region between the Cambrian and the Pliocene.

4. At the beginning of the Pliocene the region was a limestone plain or plateau with at least one very broad shallow valley—draining S.E. in the direction of the buried Pre-Cambrian ridge.

5. In the first warm, pluvial period of the Pliocene a thick capping of lateritic soil developed over the whole region, covering plain and broad valley alike, but, to some extent, retaining the line of the old south-eastern drainage. A great store of underground water accumulated in the limestones at this time.

6. In the closing phase of this first pluvial period there was considerable erosion of the limestones over the site of the present Tableland and in the region of the Gregory watershed. A new drainage system seems to have been initiated. Much of the lateritic soil was washed from the hilltops into these newly formed valleys. That the pluvial period had two phases—one quiet, producing a thick, undisturbed mantle of lateritic soils, and the next turbulent, resulting in its destruction and in the erosion of the rocks below—seems to suggest a change from uniform steady rains to marked seasonal fluctuations.

7. A period of relative aridity followed in which the lime-rich waters, stored underground in the previous rainy era, poured out as springs into the depressions on the eastern portion of the area and precipitated the lime to form a thick series of limestones. A rich reptilian, mammalian, fish and molluscan fauna existed in and around these waters. Surface limestones were formed at the same time on the land surfaces further west in the region of the lateritic remnants.

8. There came a second pluvial period (late Pliocene) in which some of the newly formed rocks were affected by silica and limonite replacements due to excessive soil leaching.

9. Some of the unsilicified limestones in the regions of the laterites may indicate a second arid period.

10. There seems to be evidence of two pluvial phases in the Pleistocene. In the first of these the valleys now existing in the region were filled with alluvium. This was markedly so in the neighbourhood of the present Tableland where the old land surface virtually was entirely smothered under this alluvial cover. In the north-east it is likely that the burial was not so complete, the tops of N.-S. ridges, such as those of the present Constance Range, standing out.

11. An arid period followed in which extensive lime pans and some gypsum developed in the old alluvial soils.

12. In the final pluvial phase of the Pleistocene the present drainage system, both of the Georgina and the Gulf waters, was firmly established. The rivers, on the old alluvial plains, developed a braided character. The gradient from Camooweal to Lake Eyre is considerably less than that to the Gulf of Carpentaria, correlated with which is the greater erosion of the Gulf waters but more noticeable corrasion of the Georgina channels. Most of the old alluvium thus has been removed from the Gregory basin but it remains still as a great sheet in the Georgina basin. The final stage in the dissection of the limestones, Cambrian and Pliocene, took place during this phase.

13. The sheet erosion of the old alluvium was a very gradual process, so gradual that, as the old limestones and quartzites became exposed in the Gregory basin, the braids of the previous sluggish streams became incised in the older rocks. At this time, as shown by the great tufa deposits in the gorges cut in the Pliocene limestones, there were great volumes of spring water issuing from the limestones, having been stored there, no doubt, in the previous pluvial phase. It is suggested that this constant supply was the only considerable source of stream water at the time. Were there marked floodings, due to seasonal rainfalls, it is doubtful whether the incision of the braids could have been accomplished in this critical stage of the uncovering of the older rocks.

14. There has been a later improvement in rainfall conditions, in that seasonal floodings now occur. But the improvement has not been sufficient to build up the supplies of underground waters so to restore the volume of the springs. The springs on the contrary are declining, a decrease that, no doubt, with some fluctuations, must go back to the last pluvial period of the Pleistocene.

AN ADDITIONAL NOTE.

In the section that follows (on "Changes in the Valley of the Flinders River") an arenaceous series is described that, for convenience, may be called the *Glendower Series;* and information is offered that such sediments may have been widespread in Pliocene times. Since this paper has been set in type additional evidence on this matter has been obtained.

In several places in the region north of Amby, Roma and Yuleba an arenaceous, conglomeratic series has been found resting upon the eroded surface of the Blythesdale Series (late Jurassic or early Cretaceous). Pebbles in it include material from local Mesozoic formations (sandstones and fossil wood) and rocks foreign to the district (acid volcanic rocks and granite). There are also, in it, dimpled boulders of billy. Coarse sandstones sometimes are found as well as the conglomerates. The evidence has been seen most clearly on the northerly road from Yuleba to Clifford, on a minor divide ten miles north of the Great Divide. Only a portion of the series (sandstones and conglomerates both) remain intact in this exposure, the remainder being reduced to an aggregate of loose boulders and sand. It would appear that some (though maybe not all) of the boulder mounds mentioned by Jensen (Geol. Surv. Q'land., Pub. 277, 1926, p. 42) are of this type.

Jensen (*loc. cit.*) mentions that they are pre-basaltic. Such evidence was seen on a hilltop about five miles north of Waroonga where a remnant of such a conglomeratic series containing billy boulders underlies the basalt, being between it and the sandstones of the Blythesdale Series. It would seem therefore that the basalts in this southerly region, like those of the Flinders basin described below, are of late Pliocene age.

4. CHANGES IN THE VALLEY OF THE FLINDERS RIVER.

Summary: There are inter-lateritic, clastic sediments in the Flinders Valley; the great basaltic sheets of the region are later than the laterites and probably late Pliocene in age; the Flinders River, in its upper courses, dates only from the Pleistocene; and from late Pleistocene times there has been a marked decline in the river flow.

The Flinders is the largest and most important of the rivers that flow to the Gulf of Carpentaria. The main channel and the upper tributaries take their rise on a basaltic tableland that is the second largest area of basalts in Queensland.* Such courses are carved in narrow gorges that pierce the basalt and continue into the clastic sediments of the Dooloogarah Series below. The scenery in the Galah Gorge—the gorge at the head of Galah or Porcupine Creek—is magnificent, the stream being hemmed in narrowly by towering sandstone cliffs topped by basalt; and I am given to understand that in the gorge of the main stream itself, which I have not seen, the effects are more arresting still.

The great plateau of lateritic soils that extends continuously in the region of the Great Divide from latitude 24° S. to latitude 20° 30′ S., enters the basin of the Flinders River. In this basin there are both lateritic soils *in situ* and transported soils, outwashed from the main plateau.

The relationship between laterites, basalts and several sedimentary series is well seen in places along the left bank of the river, nowhere more conveniently than on the road from Prairie to Glendower, one mile from Glendower homestead. In this region the river flows in a south-westerly direction near the southern limits of the great basaltic field. Here, near Glendower, there is a scarp where the Flinders has cut through the basaltic plateau; and along it the sequence of rock types is most clearly to be seen.

Towards the base of the scarp the olive-coloured shales and calcareous sandstones of the marine Cretaceous beds are exposed, a thickness of at least 40 feet of such shales being visible. To the eye these beds are horizontal. Upon them rests a most curious sedimentary series, arenaceous and non-calcareous in type, consisting mainly of sandstones and conglomerates, but with some white shales as well. The series was noted long ago by Daintree (1872, p. 275), possibly here or at a locality a little further upstream and is the type area for his "Desert Sandstone." Near where the road descends the scarp, a thickness of about 20 to 30 feet of such unaltered sediments is exposed. At the top these sediments grade into the mottled zone material of a lateritic soil which retains traces of its arenaceous origin in the sandy nature of the substance and the presence of many pebbles of quartz. At the same place, near the road crossing, there is about 30 feet of these lateritic soils capping the unaltered sediments. On the surface of the lateritic member rests the basalt. There is only a thin capping of the basalt near the road crossing; but at no great distance along the scarp the basalt is 50 feet or more in thickness with the other members of the sequence below it.

The arenaceous sediments vary rapidly. The conglomerates are thick, with crowded pebbles of white quartz, quartzites and metamorphic rocks, but they are discontinuous—lenticular—in lateral distribution. A

* This basalt region is exceeded in area by the flows of the Carnarvon-Peak Downs' region to the south.

section through the sequence at one place may be made largely of the conglomerates, while only 40 feet away the section may be dominantly of sandstones with relatively few conglomerates. Such things indicate deposition under torrential conditions.

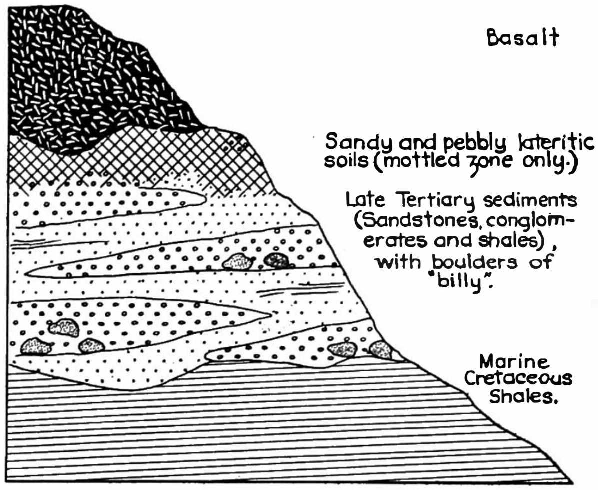

FIG. 13.—DIAGRAMMATIC SECTION THROUGH THE SCARP ON THE SOUTH SIDE OF THE FLINDERS RIVER AT GLENDOWER.

With one exception the pebbles in the conglomerates do not exceed six inches in diameter. But here and there there are "nests" of large boulders of "billy," the typical quartzite formed at the base of the laterites in western Queensland. These boulders are up to three feet in diameter and appear not to have been transported far. They have the smooth, polished and dimpled surfaces so characteristic of the material in places where it has weathered out *in situ*. It is quite clear, however, that they have not been developed within the sediments that house them at present; for, although occurring within the heavy conglomerates, they are usually silicified sandstones and not silicified conglomerates. In passing it may be noted that, apart from the boulders of "billy," this sedimentary series bears an extraordinarily close resemblance to the Dooloogarah Series in the Galah Gorge, some 20 miles to the N.W., and elsewhere. Such beds, which contain *Glossopteris* (recorded by Marks, 1911) and *Taeniopteris* and underlie the marine Cretaceous sediments, likewise consist of sandstones, conglomerates and white shales. Maitland recognised these as two very similar series as long ago as 1898. The similarity is no doubt due to a similar origin of the two deposits.

The lateritic capping of the arenaceous series is, in most places, normal mottled zone material. It is sandy and contains frequent quartz pebbles, as might be expected from the beds seen beneath it Near where the road crosses the scarp some of this material has been converted into the white, bleached and leached type, with some silica impregnation, weathering into columns, such as were noted elsewhere in lateritic regions (p. 10).

The base of the basalt is most irregular. In the section now given the basalt rests upon the mottled zone of the laterite. Sometimes prebasaltic erosion has gone further and the basalt rests upon the unaltered arenaceous sediments. Elsewhere even these are eroded away and the basalt sits directly upon the marine Cretaceous shales. All such junction types may be seen within 100 yards of the road crossing of the scarp. One valley in the face of the scarp shows, on the western side, the basalt descending down to the Cretaceous shales but, on the eastern side, an abutment of the basalt against a sub-vertical face of the arenaceous sediments with a capping of basalt upon them—indicating a buried, highly dissected landscape over which the basalt flowed. I have not seen a section in which the upper, ironshot deposits of the laterites are preserved below the basalt.

From the boulders of " billy " that occur within the arenaceous beds it may be conceded that such beds are later than a lateritic process that has affected the region. But since the surface of the sediments themselves has been converted into lateritic soils, with the mottled zone in places still unremoved, the deposition of the series must have taken place in an interval between the acmes of two periods of lateritic soil formation. Elsewhere (p. 17) it has been shown that there were two periods of the lateritic processes in Queensland, between which relatively arid conditions occurred. On the Barkly Tableland (p. 56) a phase of highly seasonal rainfall seems to have followed immediately the formation of the first lateritic cap. For the present, therefore, it is best to correlate the evidence in these two separated regions and to regard this Glendower conglomeratic series, deposited under torrential conditions, as having formed in the declining phase of the first Pliocene rainfalls rather than in the onset of the second humid phase.

Subsequently the region suffered erosion. The ironshot zone seems to have been stripped completely and it is only in places that the mottled zone material remains. The erosion sometimes has removed the arenaceous beds as a whole. On this eroded surface the basalt has outpoured.

Bryan (see above, p. 28) has established that the lateritic processes in Queensland began in Pliocene times. Since therefore these basalts are post-lateritic and have been themselves deeply eroded by the river and its tributaries in the last pluvial epoch, a late Pliocene age is suggested for the basaltic flows.

The Flinders and its tributaries have cut great, cleft-like gorges 300 feet deep and more through the basalt capping and the Mesozoic sediments below. The flow in these streams to-day is very meagre. At the best it is for most of the year a mere trickle. Sometimes the bed is dry for many months. The only extensive flow is in the short period during and immediately after the rainy season. The gorges must have been carved at a time of greater rainfall; and some direct evidence of this is to be seen within them. In Galah Gorge, for example, about five miles above the Bottletree waterhole, the valley has practically vertical sides down to the basal bed which is a uniform, thick bed of sandstone. On this there is a platform in the centre of which is a very much narrower cleft some 10 to 20 feet wide and 10 to 20 feet deep, at the bottom of which the water flows. The sandstone of this bed seems no more resistant, only more uniform than the sediments above it; and the suggestion almost inevitably arises that this narrow cleft has been carved after the run of the river has considerably and possibly rapidly declined.

From such premises the following suggestions are made. Since the basaltic plateau in which these watercourses lie was formed in late Pliocene times, the streams themselves began not earlier than the beginning of the Pleistocene. The great gorges and valleys at the head of the Flinders and its upper tributaries were formed in the Pleistocene period, late in which, or afterwards, the volume of water declined and the abrading action nowadays is relatively slight.

There is an application in certain of these matters elsewhere in Queensland. In 1872 Daintree coined the term " Desert Sandstone " as a stratigraphical name. Clearly from the manner in which he discussed the " Desert Sandstone " Daintree intended the term to apply to the lateritic residuals over the State which, in western Queensland, usually are referred to popularly as " desert." The term has been extended by geologists to arenaceous deposits of so many ages and origins that nowadays it has fallen largely into disuse. However, even in its original usage it covered formations of many kinds. If the term is to survive then, by strict definition, it should be restricted to the Pliocene arenaceous deposits described above; for Daintree's original observation (1872, p. 275) was: " On the eastern branches of the Upper Flinders River and elsewhere fine sections are exposed of lava resting on horizontal beds of coarse grit and conglomerate, which lie in turn unconformably on olive-coloured and grey shales with interstratified bands and nodules containing fossils of Cretaceous affinities. I have called this upper conglomerate series ' Desert Sandstone ' from the barren character of its disintegrated soil, which makes the term particularly applicable." Since, in his application of the term, Daintree was more concerned with the lateritic residuals, it would be mere pedantry to urge that the term be applied according to the type definition. It were better, as virtually has been done, to abandon the use of it.

I have called attention to the great, superficial similarity of this Pliocene deposit to the arenaceous series nearby (the Dooloogarah Series) of late Permian or early Triassic age. Daintree (p. 277) included in his Desert Sandstone representatives the beds of Betts Creek in the Upper Flinders which, containing *Glossopteris*, are now known to be part of the earlier series.*

Frequently I have noticed that the marine Cretaceous beds of the Great Artesian Basin are, near their margin, often strewn with pebbles of quartz. It is possible that deposits analogous to those now described might once have been widespread and have been removed in the pluvial periods that followed, in which case those of the Flinders River have been preserved by the accident of a basaltic overflow. Some light on this matter is given by evidence as far remote as the Brisbane district. Near the mouth of Oxley Creek there is a curious conglomerate in which the pebbles are all of moderate size except for some colossal boulders of " billy," one of them being 15 feet across. These deposits were first recorded by Skertchly (1908, pp. 30, 31) and have been described and figured more recently by Jones (1927, p. 26). Skertchly was inclined to postulate a glacial origin for the deposit. Jones placed them as part of the Redbank Plains Series (? Oligocene). They are so different from the sediments of the Redbank Plains Series in any of its fossiliferous localities that they are more likely to be a later deposit and conceivably may be contemporaneous with those far-distant beds in the valley of the Flinders.

* The discovery of *Glossopteris* by Rands in 1891 in the Betts Creek beds resulted in the range of the genus, in local and some other records, being extended to the Cretaceous. Reid (1916) showed that the Betts Creek beds underlie the Cretaceous sediments of the region, confirming Maitland's mapping of 1898 in which a great range of these earlier beds were placed as pre-Cretaceous.

5. THE CLIMATES OF QUEENSLAND SINCE MIOCENE TIMES.

Summary: Since early Miocene times pluvial and arid or semi-arid periods have alternated in Queensland. Temperatures generally were higher in the Pliocene and lower in the Pleistocene than at present. The changes are indicated graphically on text figure 14.

Virtually the previous studies in this series have been a prelude to this—an evaluation of the climatic evidence in Queensland in the immediate geological past. No systematic attempt hitherto has been made to investigate these changes; and the conclusions to which these pursuits have led are stated in a general way to be, at this early stage, a stimulus to the collection of further data and for the more systematic review of such factors that here have been assessed.

Climatic evidence of the type required may be gained from three separate sources—geological, topographical and pedological. Since it can be established that there have been alternations of extreme climatic types at this time it follows that the evidence will be fragmentary and sometimes inconclusive. The great erosive and depositive powers of water in a very rainy epoch will act to remove or conceal many of the traces of less humid climates that preceded. The deposits and soils of the earlier type may be removed or covered, and the physiographical changes of that time modified beyond recognition. For instance, the great gorges of many of the coastal rivers are clearly too large to have been carved by rivers with their present flow. They are the legacies of previous pluvial ages. But since there was more than one such period of great rainfall the present topography is, in most cases, the resultant of all of these; and the topographic details of the individual rainy periods and the more delicate evidence of the inter-pluvial phases may not now be traceable. Sometimes such residual effects may be seen; and if a river, such as the Upper Flinders, can be determined as having originated later than most, there may be more opportune conditions for gathering the evidence that is needed.

A soil formed under one condition may, if it survive into a period of very different climate, be profoundly modified; and one of the interesting features of such a search has been the evaluation of such compound soils. Lime, among other things, is removed from a soil by the process of lateritisation. A lateritic soil containing pans of lime therefore gives evidence of some changed condition—from rainy to less rainy conditions. Similarly, but in a reversed manner, a dense black chernozemic soil with few lime pellets may testify also to a subsequent change.

It follows, almost inevitably, that the traces of earlier climates that are required will be found more readily in the interior parts of the country where the high rainfalls of the coastal area to-day are not operative to conceal the effects even further.

For an appraisal such as is now attempted two stratigraphical datums are of particular importance—the lateritic plateaux and the older alluvia. Each of these is the result of pluvial environment and each appears to be a double, if not a multiple, index. Woolnough (1927, p. 40) and more recently Bryan (1939, p. 27) have suggested that the lateritic remnants have such unity that they may be regarded as a definite stratigraphical datum for fixing relatively the ages of events that preceded and followed those soil-forming lateritic processes that Bryan, from his review, placed in Pliocene times. My own investigations have concurred in this, with the proviso that there is evidence that there were at least two phases of lateritic soil processes in the Pliocene; so that not only is there facility for placing pre- and post-lateritic events as Bryan claimed, but also for assessing some inter-lateritic changes.

In western Queensland particularly it is most noticeable that old alluvial deposts extend into regions remote from those reached by any major flood of modern times and so indicate a not very distant period of greater stream action. There is even a suggestion in certain of the evidence that, as with the lateritic phase, this pluvial epoch may have had more than one maximum. Such old alluvial deposits are the later stages of reference for these purposes.

The lateritic soils of western Queensland have already been treated in some detail (Study No. 1) and it has been shown that the conditions of high temperature and high rainfall suitable for the production of laterites occurred at least twice during the Pliocene period, and that there were, on those occasions, variations from uniform to seasonal rainy conditions. There is no need to repeat that evidence here; but the climatic conditions under which the old alluvia were formed need to be reviewed.

On the Darling Downs and elsewhere in eastern Queensland there are great areas of black soils that were not formed *in situ* from the underlying rocks but are transported soils. The most definite evidence for this is the presence in these soils of a varied and abundant vertebrate fauna of extinct giant marsupials, reptiles and birds. Usually the fossils are found as fragments and separate bones, not as complete or moderately complete skeletons that might be expected in a sedentary soil. They occur both near the surface in black soil and buried at considerable depth; but sometimes they occur in silts of other characters. For instance, the cranium of the extraordinary marsupial *Euryzygoma dunense* described by Longman (1921) was found in sandy soil at a depth of 70 feet in a well at Brigalow where the surface is a black soil plain. Clarke (1869, p. 383) recorded *Dinornis* at a depth of 150 feet in a well on the Peak Downs in central Queensland in sandy and gravelly soil below a black soil cover, 30 feet in thickness. Owen and, in recent years, Longman and de Vis have recorded a great many genera and species of this earlier fauna. The summary by Jack (1892, pp. 604-609) is still the best general account of the old alluvia in eastern Queensland. How extremely abundant are the fossils in these silts can best be learned from a paper written long ago by Bennett (1876).

Alluvial deposits with such fossils are widespread throughout the State of Queensland and indeed in the other States of the Commonwealth. The relationship of the fossils to the existing fauna, and the nature of the alluvial deposits themselves, suggests inevitably a Pleistocene age for such series. Often silts, fossiliferous or otherwise, are remote from the present flood plains of the streams, and have soil characters different from those of the alluvium that is being deposited to-day. This latter feature is not so noticeable on the Darling Downs where the present alluvium is still a black soil—due either to a continuation of chernozemic conditions (the most likely reason) or to a redistribution, in part at least, of the old chernozems in a period of reduced rainfall. But in the far south-west of the State it is very evident. West of a line from Eulo to Boulia the old red silts discussed above (p. 16) occur. These cover amazingly large areas often far removed from the present watercourses and in appearance are quite unlike the olive or buff coloured silts that form there to-day. They are sometimes very sandy and, as already mentioned, seem to represent a time of rapid denudation of the lateritic plateaux under heavy, seasonal rainfall conditions. No fossils are known from such red silts in Queensland; but from apparently the same formation in New South Wales David (1914[2], p. 608f) records undescribed mammalian bones.

It is evident, however, that the old alluvia represent more than one phase of high rainfall. Later than the old red silts of the far south-west of Queensland there are olive-coloured alluvial deposits, of the same colour and texture as the silts now forming, but often more cemented by lime, and containing the bones of extinct giant marsupials. The Diamantina River, towards Birdsville for example, has a very wide flood plain—some 30 miles wide in the Durrie-Betoota region—wherein the old red silts either have been removed by erosion or are covered by the later deposits. But at the river crossing at the township the more cemented olive silts in the bed of the stream have abundant bones of *Diprotodon*.

On the Darling Downs and the Peak Downs the sandy silts already mentioned, that contain *Dinornis*, *Euryzygoma*, etc. and lie beneath other chernozemic silts, may also indicate two periods of previous great alluvial activity. But some caution is needed in interpreting this evidence; for the chernozemic properties are most probably a later development (they are hardly consistent with high rainfalls), and may be a surface soil condition subsequently imposed upon a uniform series of silts. Clarke (*loc. cit.*) suggested that the upper 30 feet of black soils that covered the fossiliferous sandy silts in his section represented a basaltic soil distinct from that below. Were that so there might be good evidence for two distinct phases of deposition. But black soils are by no means necessarily of basaltic origin. On the Darling Downs some of the fossiliferous chernozems are found so far from basalts and from the present streams that they might be regarded as alluvial deposits formed in a rainy period that thereby would be unsuitable for the production of chernozemic characters; and apparently such properties were acquired after deposition in a time of greater desiccation. What probably is significant is the change in texture (from sandy to clayey) between the lower light coloured sediments and the black capping.

Thus the evidence is not so clear nearer the coast as it is in the far south-west, that there were two phases of pluvial activity in the Pleistocene. But there are significant sections that, if studied carefully, must be of very great value in determining the climatic sequence.

Helpful information on this matter should be gained also by a re-examination of the fossil evidence. So far the vertebrate fossils in such late deposits have been treated as a single, stratigraphical assemblage, yet some members of the group must go back beyond the Pleistocene.* A review of all available evidence of mutual associations, matrices, localities, depths and so on for all records might even now be fruitful in attempting to find whether more than one horizon can be recognised in these deposits from purely the palaeontological evidence.

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* For instance de Vis (in Cameron, 1901, p. 190) has noted that mammalian bones in the Pliocene bone bed at Riversleigh, described above, belong to Nototheriidae.

There is some evidence on the Barkly Tableland (see above, p. 56) for two phases of pluvial activity in the Pleistocene; but once again the evidence is not so striking as in the far south-west of the State.

In passing, it is well to recall the opinion expressed long ago by A. C. Gregory (1879, p. 607) that the giant marsupials, reptiles and birds of these widespread Pleistocene deposits must have existed under conditions of good water and herbage, probably at a time of great swamps; and that they may have become extinct in a period of desiccation that has changed those swampy regions to the sparsely watered grasslands of to-day.

We may postulate therefore that in Pliocene times there were two periods (at least) of heavy rainfall when laterites were formed; and that subsequently, in the Pleistocene, heavy rainfall conditions recurred, probably in more than one phase, when the older alluvia accumulated. With this as a basis for correlation we may consider the other sediments that occur with these deposits and their climatic significance.

In the second study of this series it has been shown that non-marine limestones are recurrent features in the late Tertiary sequence in Queensland, and it has been pointed out that, from their nature, they indicate depositions in times of sparse rainfall. The earliest of these limestones are earlier than the laterites and tentatively are regarded as of Miocene age. Others, very widely spread in Queensland, were deposited between two periods of laterite formation. A third group is later than the laterites. It remains to be seen how much later was this third period of relative aridity.

The physiographic evidence at Doongmabulla (p. 37) shows clearly that this limestone is later than the local laterite, that it is later than some period of erosion that carved a great valley in the laterites, but that it is earlier than the alluvium that at present fills the valley; for the limestone forms a step within the valley with its surface some 30 feet above the alluvial floor.

Three possible considerations of the age of the limestone obtrude themselves as follows:

(i.) The laterites of the plateau may belong to the first group. If so the valley may have been carved during the pluvial epoch of the second lateritic period, the limestones formed subsequently, and eroded to a scarp in the pluvial periods of the Pleistocene. Or

(ii.) The laterites of the plateau may belong to the last lateritic phase. If so the valley may have been carved during the first pluvial period of the Pleistocene, the limestones developed subsequently and eroded during a second Pleistocene phase of great rainfall. Or

(iii.) There may have been pluvial periods, inter- and post-lateritic, other than those that have been established, during which the erosion of the valley and the limestone took place.

The third suggestion must be dimissed for want of evidence. Of the two remaining suggestions, the first seems the more likely. The two greatest rivers that erode this vast lateritic plateau are the Alice and the Carmichael. There is evidence (p. 17 above) that the carving of the valley of the Alice was begun during the second period of laterite formation, for there are valley laterites (mottled zone) in its bed. The same may be true for the Carmichael, of which Dooyne Creek at Doongmabulla is a tributary; for I have seen mottled zone material elsewhere in the bed of the Carmichael though I was not able to demonstrate definitely that it was *in situ*.

Assuming then that the first suggestion is correct, the Doongmabulla limestones would be placed as later than both lateritic periods but earlier than the formation of the old alluvium. Much the same arguments would apply to the limestone at Corinda, where conditions are so very similar to those at Doongmabulla.

Since the old alluvia were formed in western Queensland three things affected them that are significant in evaluating climates—the formation of the river terraces, the production of lime and gypsum pans in the old alluvia, and the development of the sandhills of the Simpson Desert upon them.

Terraces in the valleys of the larger watercourses are common throughout Queensland, usually three terraces being developed. The lowest terrace is occupied by the waters in ordinary flooding; the middle terrace may be covered in major floods; but rarely, if ever, do flood waters reach the level of the upper terrace. Terraced banks are usually explained by changes in the level of the mouth of the stream resulting in the rejuvenation of the whole course. Such an explanation is obviously inadmissible for the western rivers. Terraces are well developed near the heads of the Warrego and the Maranoa, for instance, at a distance of some 900 to 1,000 miles in a straight line from where the Murray, into which they flow, enters the sea. Commonly they are as prominent in that region, and of comparable relative height, as in the coastal streams. Eustatic changes at the river mouth capable of forming such terraces in a coastal region must be imperceptible in their effects 1,000 miles or so from the coast. Some other explanation is necessary; and the one that seems most probable is that, following upon the last pluvial period, when flooding and the accumulation of silts was widespread, the flow of the streams declined to their present volume, not gradually but in perhaps two stages, allowing time at each stage for such corrasion in the old silts that would incise a terrace. The platform in Galah Gorge referred to previously (p. 60) is perhaps another result of the last pause in the decline of the flow of the rivers.

The characters of the soils in the old alluvia give evidence of major changes since they were deposited. Originating, as we have seen, in times of great rainfall they would not, as they developed, have pronounced pedocalcic properties even if formed in a region of lime-rich rocks such as the Tertiary basalts or the Cretaceous shales. Yet in western Queensland such soils do have those features. In the Darling Downs and the Peak Downs districts the *Diprotodon* alluvium is usually a chernozemic soil. The extensive red silts west of the Eulo-Boulia line which, as already demonstrated, are there the older of the two alluvial groups, have almost invariably great lime pans within them. An earth tank sunk on Boorara, in the Hungerford district, for instance, passed through a solid and virtually continuous lime pan some nine or ten feet thick. Sometimes by erosion thin layers of lime pan material show at the surface of these silts as in the Caiwarro-Currawinya region. It may be noted also that water from wells and bores sunk in such soils is invariably " hard " and lime-charged. Some of the lime pans that are developed with the laterites, *e.g.* those at Back Creek on the Jericho-Barcaldine road, also may date from this time.

It has been well established by pedologists that lime pans in the soil develop in times of low rainfall. With decreasing rainfall gypsum pans occur, while in the most arid regions salt remains in the soil. Evidence for this is abundantly to be seen in the arid parts of Queensland. For example, in the very far west, on the fringe of the Simpson Desert, the present sand drifts of the Mulligan River contain both rosettes of gypsum and crystals of salt. But all three types occur in western Queensland in areas remote from this present arid region and in soils that could not have contained them originally. Gypsum, locally called " kopi," occurs in great sheets in places within the soils of the Downs and the flooded country. Commonly it occurs within the calcareous shales of the marine Cretaceous beds as sheets and replacing the calcite of fossils. It is sometimes hazardous to claim this as a Pleistocene change, for at first sight it might appear that it could have accumulated in any of the previous arid periods. But often, as in the Upper Flinders valley and around Winton and Warenda, it is found in such Cretaceous beds in areas which, having lateritic residuals, must have been capped by the thick lateritic cover until relatively recently. Such pans suggest a post-lateritic change. And when, as is quite commonly found in the pastoral lands of western Queensland, gypsum pans occur in the old river silts themselves the evidence of a late Pleistocene change to more arid climates is most definite.

Jackson (1902, pp. 16, 28, 30, etc.) has recorded gypsum and magnesia in the lateritic remnants of a number of the opal fields. On the eastern side of Lake Buchanan in the near west of Queensland, laterite soils eroded to the mottled zone, actually contain salt. Daneš (1910 p. 95), who in those years did not recognise the deposits as a lateritic soil, was so impressed by this occurrence that he proposed the name " Salt Mountain " for these hills.

Thus there is sufficient evidence in the soils of western Queensland to establish that more arid conditions supervened after the pluvial phase of the old alluvia. But the evidence goes even further and suggests that, subsequent to that more arid period, slightly greater rainfalls returned. The dense, black soils of the Darling Downs have their lime pellets. Nevertheless some years ago, so Dr. W. H. Bryan informs me, Sir John Russell when visiting the area gave it as his opinion that these chernozemic soils were not quite typical but showed signs of degradation due to later and moister conditions.

The sandhills at and about the present margin of the Simpson Desert give evidence confirmatory to and quite as definite as that of the soils. Two types of sandhills may be recognised which, for general descriptive purpose, one might refer to as the " live " and the " dead." The " live " sandhills occur west of Cooper's Creek and it should be noted that all sandhills in that region are of this type. They are steep, they have sharp crests, the slope is different on each side, they are unvegetated except for a little spinifex and a few shrubs, while their tops change with every breeze as the sand is blown about them. The " dead " sandhills occur to the east of the Cooper and are to be found intermittently as much as 120 miles east of the furthest " live " sandhill. Although composd of red sand similar to that of the " live " hills, the " dead " dunes are low and vegetated. Their slopes are uniform and there is no movement by the ordinary winds. Clearly they are sandhills that once were " live " but nowadays, in this higher rainfall area to the east, they have sufficent water to bind the sand and they are being destroyed slowly by weathering processes.

Both " live " and " dead " hills commonly are found established on the old alluvia and indicate that, since the alluvium was deposited, arid conditions have developed to such a degree that desert sandhills could be formed.

The zone of " dead " sandhills indicates that arid conditions were once so far advanced that they grew on their present sites as " live " hills; but conditions have so far improved that the region will no longer support them as active structures. That is to say, since the acme of aridity when sandhills were formed there has been an increase in moisture conditions sufficent to reduce the effective area of the active types.

Some confirmation of this is to be found within the area of the " live " dunes. Madigan (1936, p. 208) has shown that the alignment of the sandhills in the Australian desert is in the direction of the prevailing winds. I have noticed that, after a long dry season when the binding properties of the little water that is within the dunes is consequently lowered, any extension of the sandhills is not laterally but in the direction of their maximum length. But there is little, if any, general movement. This is based upon my own intermittent examination of some of these " live " dunes during the past nine years, and on the experience (related to me) of the residents of that district who have lived there for thirty years or more. Ratcliffe (1937, p. 6) has come to the same conclusion. Yet there must have been active movement of the sandhills in the not distant past comparable to sand movements that go on to-day still further west in the more arid parts of South Australia and the Northern Territory. The great rivers of this region have a series of lakes associated with them, forming large and very shallow basins in the old alluvium—Lake Yamma Yamma with the Cooper, Lake Machattie with the Georgina, Lake Wickamunna (or Phillipi) and Lakes Muncooney and Silesia with the Mulligan. Each such lake is lateral to the river and is connected to it by one or more channels, but with no other entrance or exit for the waters. The lakes of the Cooper and the Georgina are filled to-day through these conduits in the ordinary times of flooding; but the lakes of the Mulligan further west, within the zone of the Simpson Desert proper, have been modified. A sandhill has grown across the channels of Lake Wickamunna so that it never is filled from the river nowadays. The other lake has been divided into two by a long sandhill and only the portion nearest the river (Lake Muncooney) receives flood waters; the other (Lake Silesia) remains dry. That is, although there seems to be no effective movement of these sandhills in Queensland to-day they must have grown and extended since the lakes were developed on the alluvial plains.

Both soils and sandhills in western Queensland therefore give evidence of two changes since the development of the old alluvium—first a more arid period and then a return to moister conditions. Neither change, probably, would be of the same magnitude as the other climatic variations that have been evaluated above.

Some correlation is possible with coastal evidence. Along the eastern seaboard of Queensland, in the region of marshy, coastal flats, white sandhills are growing to-day. As the coast is recessed by sea action (and a relative rapid recession is noticeable in some regions, such as Southport) the sandhills seem to move a little inland, for they are found enveloping the trunks of living trees. But they form only a marginal zone a few yards wide and never extend far into the coastal plains. The sand is moved along the crests by the ordinary off-shore winds. In addition to these " live " dunes there is a remarkable series of " dead " sandhills between the latitudes of 25° S. and 28° S. They form a limited zone, but a very wide one, and constitute Stradbroke, Moreton, Bribie and Fraser Islands and, in addition, the great sandhills of the Teewah beach north of Noosa. Behind the Teewah beach the region is still a coastal plain though with great lagoons. Behind the other great sandhills the region is flooded by the sea to form the very shallow basins of Moreton Bay and Hervey Bay. These sandhills are heavily vegetated with, among other things, very large trees. On Fraser Island there is even a rain-forest or jungle growth. Many of the dunes rise to great heights. Mount Tempest on Moreton Island is 920 feet high and may be the highest sand dune in the world. In spite of the deep valleys beside these high dunes, no rocks are known in their locality except close to sea level, and these are in but a few places. Their great height, as compared with the small present-forming dunes, is in accord with the corresponding greater width of the belt that they form along the coast.

They are clearly " fossil dunes." Not only are they heavily vegetated and so prevented from moving, but individual dunes are steeply truncated by the present coastlines both to the east and the west. On Stradbroke and Moreton Islands there is a coastal plain or coastal swamp developed on the eastern or oceanic side of these truncated dunes, on the outer or seaward edge of which the present, small, active dunes are growing.

The dunes are aligned in a N.W.-S.E. direction. This is clearly shown on the Redcliffe sheet of the Commonwealth military contour maps (sheet 6, 56, V.I. north). The present prevailing winds in the region are the north easters and the south easters, the south easterlies forming the dominant gales. Maybe by an interaction of these two wind systems these quite abnormally high sandhills were formed. Two suggestions occur as possible explanations of why they grew to mammoth size only in the past. Either the winds were stronger in force and so had greater accumulating power, or else conditions were drier, with reduced binding power in the sands, and allowed the ordinary strong coastal winds to pile higher structures. Whichever is the right explanation—possibly there was a combination of the two effects—the process reached a climax in the not distant past and has since declined.

There is a general impression among the pastoralists of Queensland that, in eastern Australia, rainfall conditions are declining. These things are difficult to establish. The changes since Miocene times have been interpreted in this paper as a sequence of variations from arid to humid conditions. But just as there are major waves in the climatic curve, so also there will be superimposed minor ripples; and the personal experience of a lifetime in western Queensland indicating a decline in rainfall conditions might be evidence, not of a major change but one of the minor fluctuations in the climatic curve. Nevertheless there is a variety of evidence that does suggest some general decline. The following selected examples are often quoted by residents:

(i.) The depletion of trees from areas that were wooded when first settled.

(ii.) Water holes once permanent are now everywhere being silted instead of scoured, even in regions that have never been stocked with sheep or cattle and where, consequently, there has been no accelerated man-made soil erosion.

(iii.) Dry rivers in the far west and further away still in the Northern Territory are fringed with great river gums (eucalypts) that it is difficult to imagine could gain a footing at the present day.

(iv.) The springs of water in Queensland are everywhere declining, many of them having ceased to flow.

For myself, I have been impressed by the abundance of aboriginal artifacts in the far west of Queensland in many regions where now there is no permanent water but which, so it would appear, were once favoured camping places.

However the evidence is most difficult properly to assess, and I do not feel convinced that a very definite pronouncement can yet be made upon the general climatic trend at present. It is, for example, difficult to separate evidence of recent changes from those immediately previous, as is shown, for example, in the declining springs on the edge of the Barkly Tableland. On the chart that I have given (fig. 11) a decline in humidity is shown at the end of the curve. But this is yet not really established. It is merely the most likely of the alternatives.

So far the evidence that has been considered is that which bears upon humidity and precipitation. There is also the question of temperatures. Here it is more difficult to generalise, for only a few conclusions can be drawn, and these really from regions away from Queensland. The temperatures in western Queensland to-day might possibly be sufficient under conditions of much increased rainfall, to cause laterites to form. But the fossil red earths extend as far south as Tasmania, where I have seen residuals of them in various parts of the island. It cannot reasonably be postulated that such soils could form in Tasmania to-day; for although parts of the west coast have great rainfall sufficent for the purpose, they do not form now, except as basaltic red loams (Prescott, 1931, p. 69) in the most humid regions, patently because of the lower temperatures in those latitudes. Assuming for the present that the lateritic and red earth residuals of Australia form a definite stratigraphical unit, this would suggest that the temperatures of those times (Pliocene) were higher than at present.

Similarly it is necessary to turn southwards for an explanation of the temperature conditions of the post-lateritic developments. It is inconceivable that the alluvial deposits of the Pleistocene were formed in Queensland under temperatures comparable to those during the pluvial phases of the Pliocene; for although the rainfall was abundant these soils were not converted into red earths or laterites. Long ago Wilkinson (1888, p. 33) pointed out that in New South Wales there was a correlation to be made between the glacial epoch of the Pleistocene when Mt. Kosciusko (and, of course, the plateau of Tasmania) were ice-covered, and the extention of the older alluvia. This has since been generally accepted by Australian geologists. We may legitimately apply this reading to Queensland and infer that there were, at those times in this State, colder periods than at present.

More than that it is not possible to state at present. No doubt the temperature curve from Miocene times must have had many maxima and minima. All that can reasonably be inferred is that generally the Pliocene climates were warmer than at present and the Pleistocene climates were colder than now.

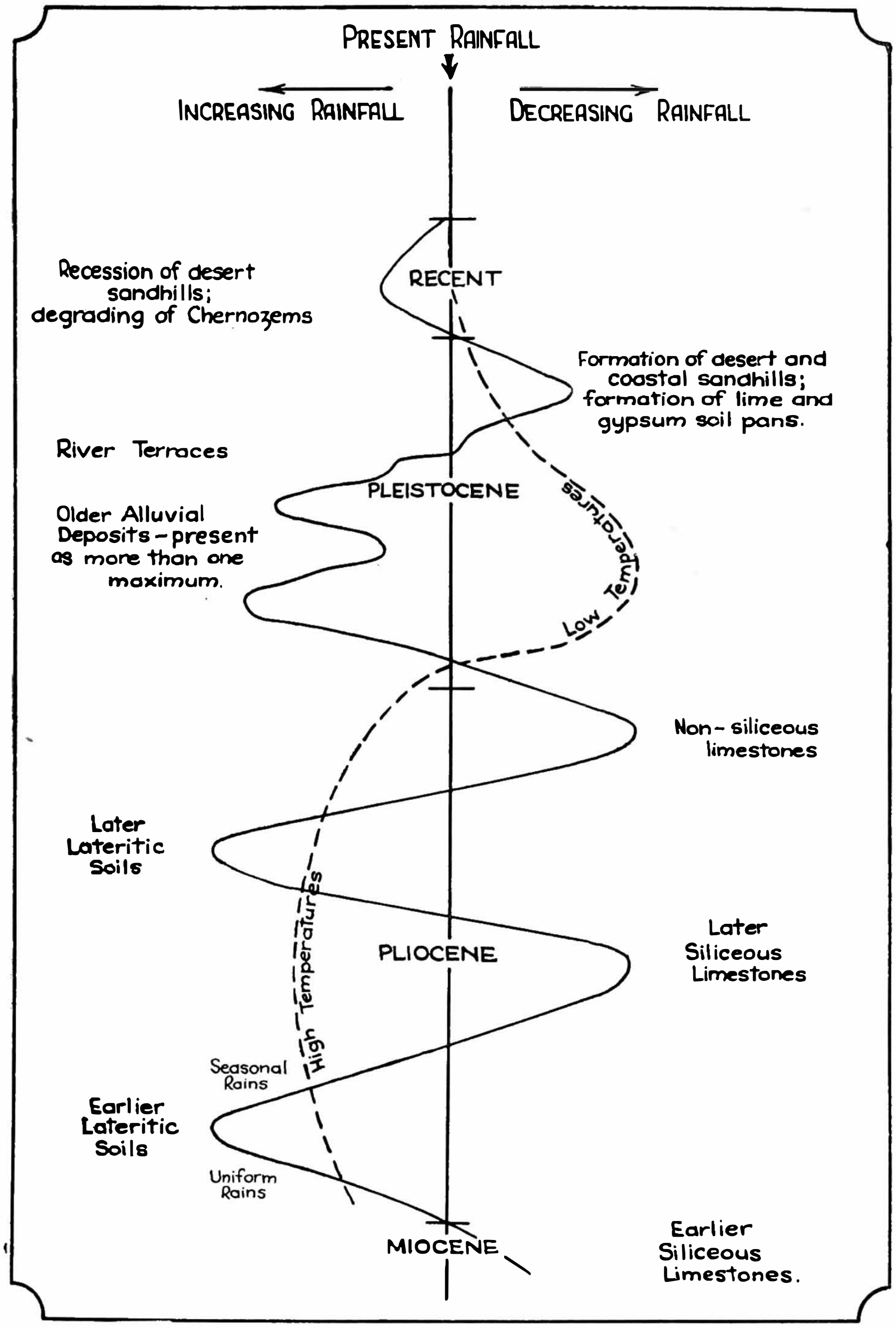

FIG. 14—GENERALISED CURVES TO INTERPRET THE MORE IMPORTANT CLIMATIC CHANGES IN QUEENSLAND SINCE MIOCENE TIMES.

THE CENTRE-LINE REPRESENTS PRESENT-DAY CONDITIONS. THE CONTINUOUS CURVE ASSESSES RAINFALL VALUES. THE BROKEN LINE IS A GENERAL TEMPERATURE CURVE. IN BOTH CURVES THE CUSPS TO THE LEFT REPRESENT VALUES HIGHER THAN AT PRESENT ; CUSPS TO THE RIGHT ARE LOWER VALUES .

CONCLUSIONS.

It is the thesis of this paper that since early Miocene times the climatic curve for Queensland, independent of minor changes, has had a number of maxima and minima corresponding to relatively humid and arid periods and to high and low temperatures.

The evidence of relative aridity, particularly for the earlier phases, has been based mainly on the deposition of limestones as fresh water sediments, as surface accumulations and as pans developed subsequently in the soil. Such evidence, it should be stressed, will give only approximate values. In the most arid climates salt and gypsum will develop in the soil. If, as happened in Queensland, an arid period is succeeded by one or more of considerable rainfall, all the salt and some of the gypsum may be removed so that evidence of extreme aridity will be hard to assess. It is only in the last arid phase that such true readings may sometimes be possible. Therefore in the curve that has been drawn to interpret these conclusions (fig. 11) the degree of departure of the cusps in the direction of aridity must be regarded as in no wise a reflection of absolute values.

Similarly the cusps in the direction of humidity are, in general, to be interpreted as giving only relative values; for it is not possible to assess the comparative amounts of rainfall that produced lateritic soils under warm conditions (in the Pliocene) and the old non-lateritic alluvia in cold climates (during the Pleistocene).

What can be stated with rather more assurance is that the earlier of the pluvial phases, when the old alluvia formed, was probably the more effective of the two Pleistocene maxima; and the last departure to more humid conditions, in post-Pleistocene times, was the least pronounced of those that have been plotted.

It is possible, indeed very likely, that when more evidence is available, there may be more maxima and minima than yet can be postulated.

The lines of division between Miocene, Pliocene, Pleistocene and Recent on the curve are to be regarded as approximate readings. Fossil evidence for the definite placements of such boundaries is not available.

The curve, as drawn, shows an almost regular rhythm. No stress is to be placed on this for it is a generalised expression. There is no means available of assesssing the relative intervals between the several maxima and minima.

Finally, the temperature curve is a most generalised feature designed only to express a preponderance of high temperatures in the Pliocene and low temperatures in the Pleistocene.

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