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The Phosphate-bearing Cambrian formations in the Lawn Hill and Lady Annie Districts, Northwestern Queensland

by

F. de Keyser

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SUMMARY

Since 1967, the Bureau of Mineral Resources has been engaged in the biostratigraphic investigation of the phosphate-bearing Cambrian formations in the Georgina Basin, mainly in north-western Queensland. In 1968 the studies included the Border Water Hole/Lawn Hill/Riversleigh district and the Lady Annie/Lady Jane area, both held under Authority to Prospect by Broken Hill South Limited (whose exploration is being conducted by its subsidiary company Mines Exploration Pty Ltd); a small extension of phosphatic Cambrian into the Northern Territory is held by Macmine Pty Ltd. The results of the survey are contained in this report.

The Cambrian formations unconformably overlie Proterozoic basement, and form the Barkly Tableland and the dissected low plateau remnants of Lawn Hill and the Dentalium Plateau. The Cambrian succession locally begins with the Colless Volcanics, possibly of Lower Cambrian age, but more commonly the basal Cambrian is represented by two facies types of lower Middle Cambrian age: a carbonate facies (Thorntonia Limestone) and a cherty facies (Border Water Hole Formation or, in the Lady Annie area, the Beetle Creek Formation). The two facies units interfinger and may grade into each other, and are in places underlain by a conglomeratic sandstone bed of irregular thickness.

Overlying these formations are the silt-shales of the Inca Formation, and the carbonate beds of the Currant Bush Limestone, both penecontemporaneous units of Middle Cambrian age. No Upper Cambrian formations are known from the areas mapped.

Basinwards, these formations pinch out and are replaced by the umfossiliferous "Camooweal Dolomite", which forms the major part of the Barkly Tableland and cannot be distinguished lithologically from the Thonrtonia Limestone. The "Camooweal Dolomite" (with Thorntonia Limestone included) has an age range from lower Middle Cambrian to Upper Middle Cambrian, possibly even Upper Cambrian or Ordovician in the southeastern parts of the Georgina Basin.

The phosphorites are restricted to the lower Middle Cambrian chert facies, and were deposited in a very shallow marine environment in semi-enclosed basins and estuaries. They are thought to be mainly biogenic replacement deposits, but some phosphate is of residual, secondary origin. Fine-grained silty phosphorites predominate, though pelletal phosphorite is present in the subsurface in the Lady Annie area. Some 250 million tons of phosphate rock have been indicated by drilling at the Lady Annie deposit; no figures are yet to hand for the deposits in other areas.

INTRODUCTION

The investigations in the Border Water Hole/Lawn Hill and in the Lady Annie/Lady Jane areas (see Locality map Fig.1) form part of a biostratigraphical appraisal, started in 1967, of the phosphate province of the Georgina Basin. The study has been undertaken to gain a clear insight into the circumstances under which the phosphate deposits were formed, including the factors of origin, environment, accumulation, and concentration. The survey of the Georgina Basin has been scheduled to take several years, from 1967 to 1969, and the results are to be incorporated in a B.M.R. Bulletin. At the same time, the Geological Survey of Queensland is adding to the knowledge of the phosphorite deposits by concentrating on palaeontological-palaeoecological studies of the fossil faunas.

The Border Water Hole/Lawn Hill and Lady Annie/Lady Jane areas were among the areas visited during the 1968 field season. Mapping was executed at photo-scale, the photos used being the 1:83,000 R9 Adastra Series flown in 1966. Fossils were collected where possible, and were despatched to Canberra to be identified by J. Shergold. Little work was done in the Lady Annie area as Mines Exploration Pty Ltd were already carrying out a very intensive mapping and drilling programme there, and also because the area had been included in a previous mapping programme by the B.M.R. in 1957 (de Keyser, 1958). The 1968 field party, which was based at Canooweal, included two geologists (F.de Keyser and R. Thieme, both of the B.M.R.), a Technical Assistant (K.J. Armstrong), and 4 wages hands. Total time spent in the field extended from mid-May to mid-October. R. Thieme is responsible for most of the information on the area around Highland Plains Homestead and Lawn Hill, while F. de Keyser concentrated on the strip between Musselbrook Creek and the eastern edge of the Barkly Tableland.

The Border Water Hole area can be reached from Camooweal via a 100-mile track passing through Gallipoli Homestead. A poor dirt track connects Highlands Plains Homestead with the "Babbling Brooke Hill"* on the

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* A name used by Mines Exploration Pty Ltd, but not officially recognized. Other such names used in this report are "Mount O'Connor", "Hilary Creek", "Mount Hendry Formation", "Mount Jennifer", "Phantom Hills", etc.

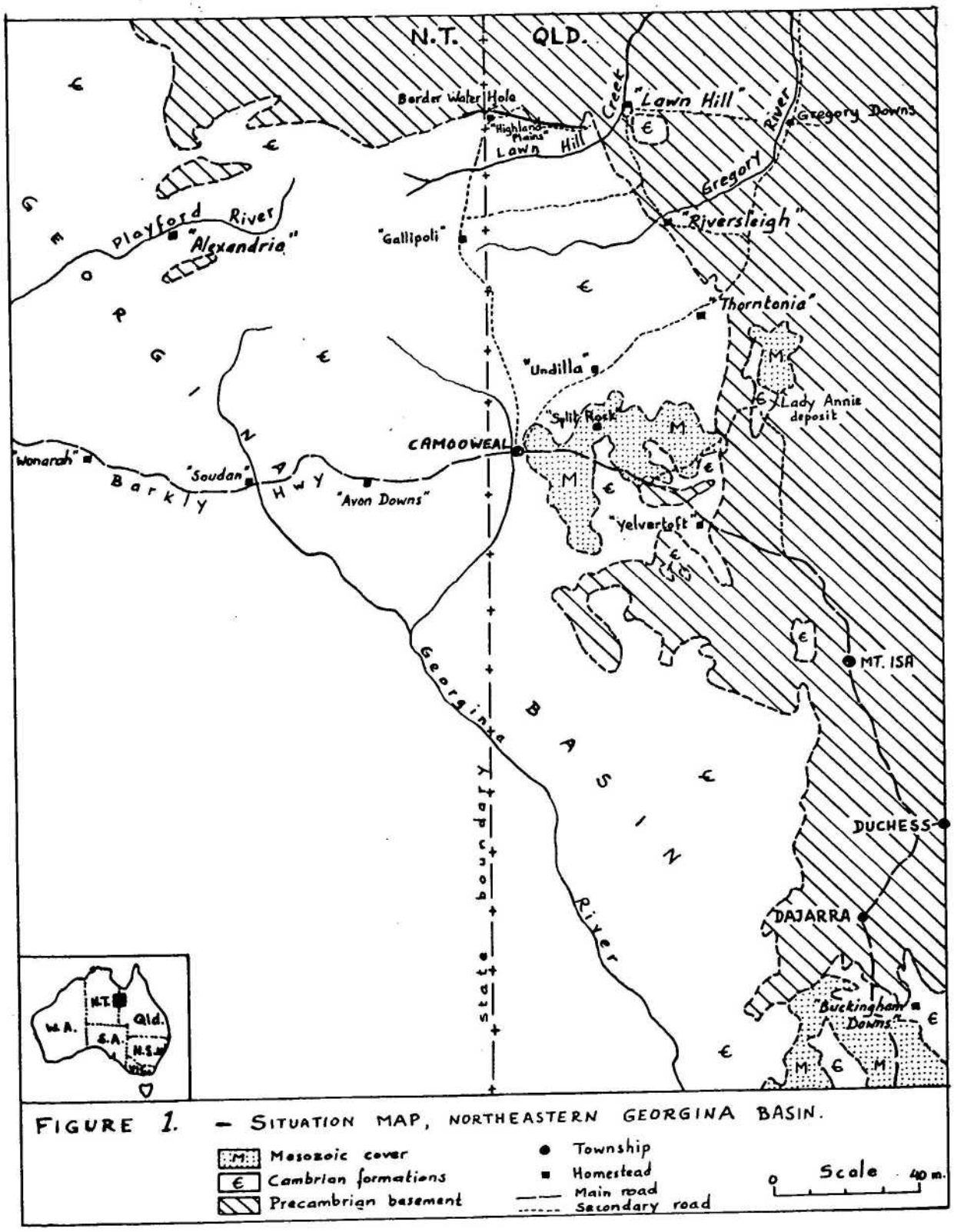


FIGURE 1. – SITUATION MAP, NORTHEASTERN GEORGINA BASIN.

eastern edge of the Barkly Tableland. Entry into the Lawn Hill region is made either via Thorntonia and Riversleigh or via Gregory Downs and Lawn Hill. Dirt tracks leading to the Lady Annie area branch off the Barkly Highway at Yelvertoft Dip ("Lady Annie road") and at a point about 38 miles from Mount Isa ("new Mount Oxide road").

The climate is tropical continental ("steppe climate") and is semi-arid, with rain mainly from December to April, usually in heavy downpours. The annual rainfall is 20-25 inches in the Lawn Hill/Border Water Hole area, 15-20 inches in the Lady Annie area, of which no more than a fraction falls during the dry season. The average daily maximum temperature is probably 95° or more in the Lawn Hill area, and over 85° in the Lady Annie district during the summer; the average daily minimum temperature for the same period in both areas is about 80°. During the winter season, the maximum daily averages are about 80° and 55° in both areas.

PHYSIOGRAPHY

The Lawn Hill/Border Water Hole district can be subdivided into a number of physiographic units (see Carter & Öpik, 1961):

1. the Precambrian Constance Range block ("northern upland" in Carter & Opik, 1961);
2. the narrow, depressed lower Middle Cambrian zone along the Little Range Fault;
3. the deeply dissected northeastern part of the Barkly Tableland composed of Middle Cambrian dolomites;
4. the Cambrian outliers of Lawn Hill and the Dentalium Plateau, forming low, dissected mesas or small plateaux;
5. parts of the Carpentaria (coastal) Plain and the Isa Highlands in the east;
6. the valley between the Barkly Tableland and the Isa Highlands in the Riversleigh area.

These units are the combined result of a number of factors: - lithological differences, structure, geomorphological history - and have been described in Carter & Opik (1961).

The Cambrian zone along the Little Range Fault forms a shallow broad valley with low-relief floor (Fig.14), bounded against the Constance Range block in the north generally by a scarp up to 200 feet high, against the dolomitic plateau of the Barkly Tableland in the south by a much lower scarp or slope several tens of feet above the valley floor. This topographical difference between the cherty facies (valley) and the dolomitic facies (tableland) is the result mainly of their different reactions to erosion, the cherts being amenable to mechanical denudation, the dolomites more susceptible to dissolution and the formation of underground channels, so that their main mass stands up reasonably well against denudation notwithstanding the removal of much material from internal caves and underground water courses.

The Dentalium Plateau and Lawn Hill dolomite areas are low dissected mesas, remnants of a once coherent carbonate blanket interconnected with the Barkly Tableland dolomites via channels through the Proterozoic quartzite ridge barrier which now forms the eastern margin of the Tableland. In the area mapped, the Tableland at present shows a rough dolomite landscape characterized by karren topography (Figs. 3,4), deep canyons, and numerous springs at river level. The discharge of underground water from the springs is sufficient to turn the rivers that originate from the Barkly Tableland into permanent water courses with clear running water throughout the year.

Farther south, in the Riversleigh area, the quartzite barrier has disappeared, and the margin of the Barkly Tableland is no longer as straight as farther north. It can be seen, here and at the Dentalium Plateau, that the floor of the valley between the Tableland and the Isa Highlands almost coincides with an exhumed pre-Middle Cambrian surface of erosion, and that soil and alluvium form but a thin veneer over the Proterozoic. This shows that the valley floor, from Lawn Hill south to Riversleigh and beyond, is essentially a very old feature already in existence before the deposition of the Cambrian sediments. A similar situation exists in the "Babbling Brook Hill" area (Fig.13). There are therefore at least two recognizable pre-Middle Cambrian surfaces of erosion:

(a) one which is now represented by the plateau remnants and the summit levels in the Proterozoic blocks and highlands;

(b) a later surface cut into the former, and which served as the floor of the succeeding Middle Cambrian seas.

The effect of the faulting and warping on the present-day topography becomes clear when it is realized that towards the north the Constance Range block rises higher and higher above the level of the Carpentaria Plain, whereas the Proterozoic block forming the base of the Carpentaria Plain (and initially with the same morphological development age as the Constance Range block) sinks progressively deeper below the alluvial cover of the plain.

In the Lady Annia area, the Cambrian forms thin outliers unconformably overlying folded Precambrian strata in the low hilly country between Paradise Creek in the east and the faulted basement in the west. Towards the north this Cambrian disappears underneath a cover of Mesozoic sandstone and associated sand flats, and the contained phosphorites form the "Lady Jane" deposit of Broken Hill South Limited.

PREVIOUS INVESTIGATIONS

A. Border Water Hole - Lawn Hill district.

Estimates of the age of the Cambrian sediments in this area ranging from Lower Cambrian to post-Tertiary have been put forward. The deposits were usually referred to as "limestones", although most of them are dolomites.

Daintree (1872), followed by Jack (1892), postulated an Upper Cretaceous and Lower Cretaceous age respectively for the "limestones" of the Barkly Tableland because of a find of Tellina, a fossil not older than Cretaceous.

Cameron (1901) believed that he could see a difference between the carbonate rocks at Lawn Hill and the Dentalium Plateau on the one hand, and those capping the southern extension of the Constance Range and continuing onto the Barkly Tableland, on the other hand. The outcrops at Lawn Hill and the Dentalium Plateau were provisionally mapped as Devonian, while those of the Constance Range and adjoining tableland were considered to be (post-) Tertiary on the ground that limestone outcrops around Ribersleigh Homestead contained marsupial and reptilian fossil remains. Cameron was confusing the Cainozoic Carl Creek Limestone with the Thorntonia Limestone, but his error is understandable as both rocks seem very similar in some outcrops and are closely associated. Consequently, by extrapolating his deductions over the whole of that part of the Barkly Tableland which is occupied by the "Camooweal Dolomite" and Thorntonia Limestone, he visualized this area as "..the site of a great inland sea into which carbonate of lime was brought by the streams draining into it".

Ten years later, Ball (1911) rightly included the carbonate rocks at Lawn Hill and the Dentalium Plateau with the main dolomite sequence on the Tableland. However, like Cameron, he failed to note the difference between the Carl Creek Limestone and the Cambrian dolomites, and even thought to have additional evidence for a Tertiary age in the occurrence of "Dentalium" (actually a mistaken identification of Biconulites or Hyolithes).

In 1920, Dunstan, on very meagre and too widely extrapolated evidence, attributed a Jurassic age to the sequence on the Barkly Tableland (as well as in the Burke River outlier and elsewhere), although it had already become apparent that the deposits on the Barkly Tableland in the adjoining Northern Territory were of Middle Cambrian age (Jensen, 1914).

Shephard (in Ball, 1931) was the first to recognize the Middle Cambrian age of the strata, and this was confirmed by Jensen (1941) when the true identity of the "Dentalium" was revealed. Jensen referred to the Cambrian deposits in the general area as the "Constance Range Series", a term not to be confused with the Upper Proterozoic Constance Sandstone of modern usage.

Noakes and Traves (1954), participants in a C.S.I.R.O. survey of the Barkly Tableland from 1947 to 1948, used the term (now abandoned) of "Barkly Group" to include all the Cambrian Formations on the Tableland. Subsequent work mainly by Öpik (1956a, b) established the modern subdivision of the Cambrian in northwest Queensland. Öpik's work remains essentially valid, with the notable exception of his "Camooweal Dolomite", which he considered as the base of the succession and of Lower to early Middle Cambrian age; regional mapping by Smith and Roberts (1963), Randal and Brown (1962), and Mulder (1961) indicated that the unit is the dolomitic lateral equivalent of several Middle Cambrian formations, and this has been further confirmed by our present fieldwork.

B. Lady Annie - Lady Jane district, Paradise Creek region.

In the Paradise Creek area, the presence of Cambrian outliers was discovered as late as 1957 by a combined field party of the Bureau of Mineral Resources and the Geological Survey of Queensland (de Keyser, 1958, unpubl.), who collected Xystridura, Redlichia, Lingulella, Hyolithes, Biconulites, and Aluta specimens identified by Öpik (pers. comm.) De Keyser described the deposits as consisting of a polymictic poorly sorted basal breccia with calcareous sandy matrix, overlain by fine sandstone, sandy dolomite, limestone and dolomitic limestone, soft weathered white "kaolinic" beds (now recognized as phosphorite and phosphatic siltstone), chert beds, chert breccia, and siliceous shale. The rapid lateral facies changes were also noted.

No subsequent work was done until Broken Hill South Limited discovered phosphorite on their A. to P. over the area in 1967. By the end of that year sufficient phosphorite had been found to justify a full-scale mapping and drilling programme.

STRATIGRAPHY

A. Border Water Hole - Lawn Hill district.

Figure 2 diagrammatically presents the succession and interrelations of the Cambrian units in the area, as found during the 1968 field season. They unconformably overlie Lower and Upper Proterozoic strata and are in places overlain by remnants of Mesozoic sandstone.

Precambrian Basement.

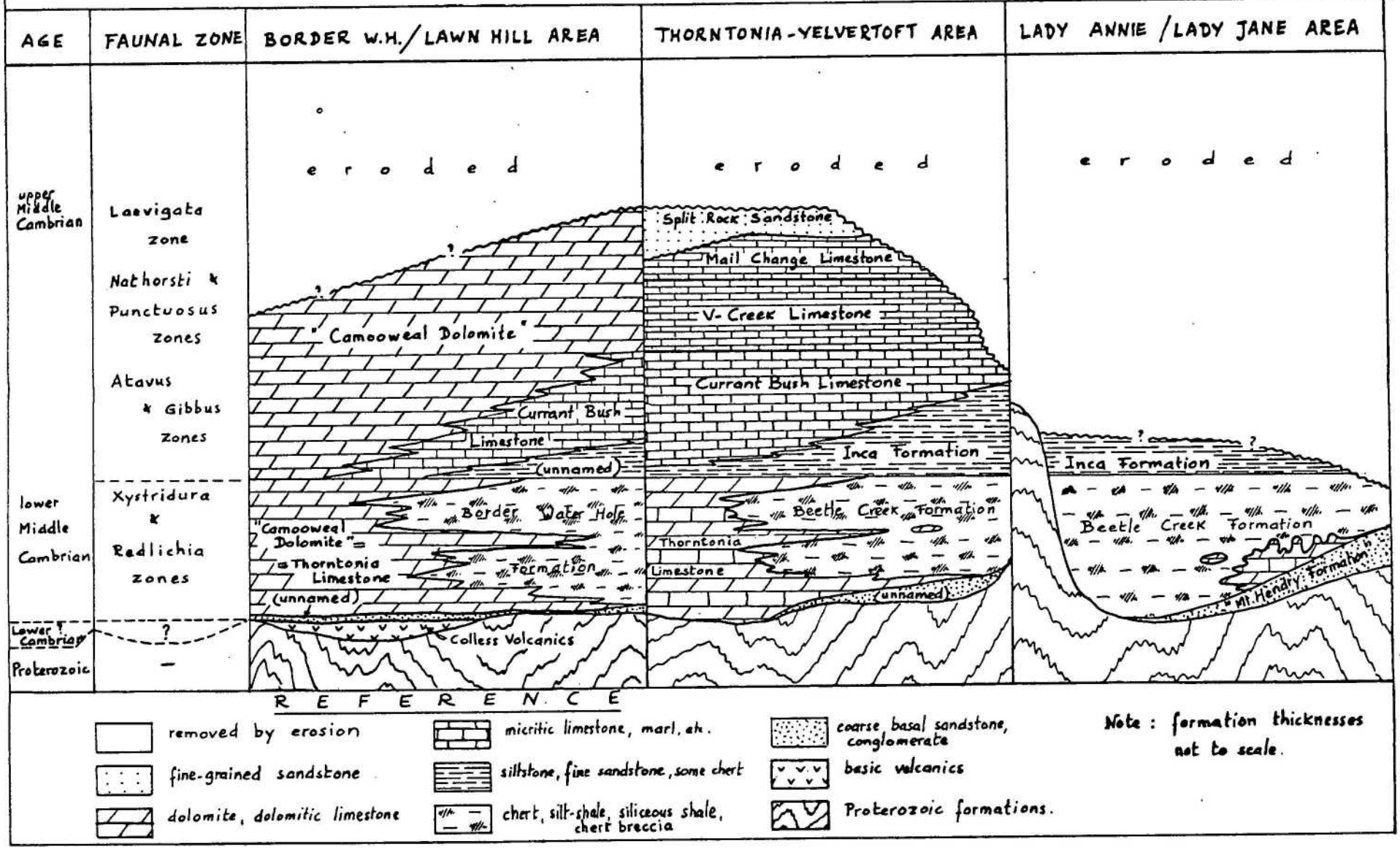
The formation underlying the Cambrian succession include the Lower Proterozoic Bluff Range Beds (in the west) and Lawn Hill Formation (in the east), and the Upper Proterozoic Constance Sandstone and Mullera Formations in the north and east. The rock types comprising these units include sandstone, siltstone, shale, and, in the west, some limestone and dolomite. They are described by Carter (in Carter and Öpik, 1961) and by Smith and Roberts (1963).

Colless Volcanics.

Where present, the Colless Volcanics form the base of the Cambrian succession, and unconformably overly the Upper Proterozoic strata. Their main outcrop areas are the eroded centre of the Precambrian syncline east of the Ridgepole copper prospect, and a similar syncline about 12 miles west-so8thwest of Lawn Hills Homestead. Very small, isolated outcrops are known from the Border Water Hole area and near Lawn Hill, the latter occurrence at "Mount Jennifer" having been found by Mines Exploration Pty Limited. The maximum thickness of the formation was estimated to be about 200 feet by Carter and Öpik (1961).

The Colless Volcanics comprise basic and some intermediate volcanics, generally weathered rusty red-brown or pale dusty grey-brown. Near the top of the section they are usually strongly vesicular or amygdaloidal, and commonly contain tongues of a brown-red silicified sandstone. In places the amygdules are filled with chlorite, and in one of the eastern outcrops with quartz. In the latter area the volcanics also contain layers of agate-banded chalcedony and coarse quartz with thin plate-shaped or wedge-like solution cavities possibly representing leached-out hematite or baryte. Commonly the vesicles are superficially stained green by an unknown mineral.

FIGURE 2 - SUMMARY OF STRATIGRAPHIC RELATIONSHIPS, NORTHEAST GEORGINA BASIN



Petrographically the basic Colless Volcanics appear to be basalts or dolerites with (sub)ophitic texture. A thin section made of one of the rare samples of fresh rock shows a composition of about 55 percent plagioclase, (laboradoritic in the core), 40 percent monoclinic pyroxene, and 5 percent magnetite and hematite. The plagioclase is clear, lath-shaped, albite-twinned, and up to 0.8 mm long. There are some large feldspar phenocrysts(?) up to 1.5 mm across, generally with opaque inclusions and also corroded remnants of pyroxene. All feldspars show continuous zonation. The monoclinic pyroxene is very pale green, uralitized in part, and occurs in irregular grains up to 0.8 mm long, or in clusters up to 1.5 mm across. A few small rare interstitial grains of quartz are also present. Intermediate volcanics, which are much rarer, seem to be concentrated in the upper, vesicular section, and to be composed mainly of sanidine with little else, as suggested by inclusions in the tuffaceous dolomite overlying the volcanics, and by an X-ray diffractogram.

In the easternmost outcrop in the "Babbling Brooke Hill" area, the Colless Volcanics appear to be overlain by a medium-to fine-grained yellow sandstone several feet thick, with laminae of coarse quartz grains and some conglomeratic layers. The quartz is rounded to well-rounded and has a somewhat frosted appearance. The pebbles in the conglomerate layers are subangular to rounded, and consist of Precambrian quartzite and micaceous siltstone. Some coarse cross-bedding in the sandstone indicates a derivation from the north-east.

In thin section, the sandstone appears to be bi-modal, with larger, extremely well-rounded grains of quartz (0.4 - 0.6 mm range) in a matrix of smaller (0.07 - 0.25 mm range) grains mainly of quartz and minor amounts of feldspar (including microcline), chert, and Precambrian rock types such as quartzite, siltstone, granophyre, etc. Authigenetic secondary quartz growths between the quartz grains have transformed this sample into a quartzite. In places there is much microcrystalline secondary apatite in the interstices between the quartz grains, evidently re-precipitated after having been leached out of the overlying phosphatic sediments.

Thorntonia Limestone.

The Thorntonia Limestone and the Border Water Hole Formation are interfingering formations of equivalent age, as shown in Fig.2, the former being developed as a carbonate facies, the latter as a chert facies.

The Thorntonia Limestone in the area contains little limestone, but comprises mainly dolomite and dolomitic limestone with varying amounts of chert nodules and stringers. They range from thin-bedded to massive, and the colour of the fresh rock is white, pink, fawn or yellow. The weathered rocks are generally grey, occasionally ochre-brown, but the basal 3 or 4 feet are commonly yellow to pink. The grain size of the dolomites varies from micro-crystalline to fairly coarsely crystalline.

The base of the formation is usually a sandy dolomite, in places grading into a conglomeratic dolomitic sandstone. A thin section of a sample from the "Babbling Brooke Hill" area shows well-rounded quartz grains (0.1 - 0.6mm) that may make up to 40 percent of the rock, grains of micrite, a few chert grains, detrital carbonate lumps, and rare quartzite and feldspar. Where the dolomite overlies the Colless Volcanics, irregular volcanic fragments (sanidinite?) may be included as well as tuff laminae. Sandy dolomites are also occasionally found higher in the section.

White "quartzite" layers are in places found at or near the bottom of the section. They strongly resemble the "quartzite" described from the Duchess area, and are silicified carbonate beds (de Keyser, 1968, unpubl.).

Some dolomite beds contain an abundance of chert nodules (Fig. 5) and, where outcrop is poor, leaching of the carbonate leaves a thick layer of residual chert rubble on the surface (Fig. 6) so that such beds have the appearance of being original chert beds. Their true nature is evident in the well-exposed sequence in the Lawn Hill - Border Water Hole area, but similar chert rubble "outcrops" in poorly exposed

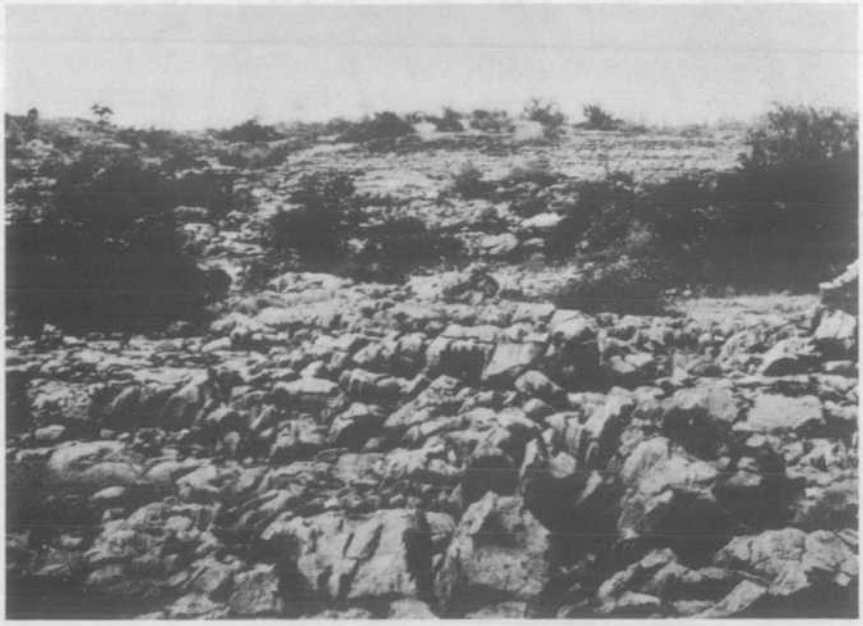


Fig. 3

Karren surface on "Camooweal Dolomite", Colless Creek area, northeastern part of Barkly Tableland. Neg No. 1802

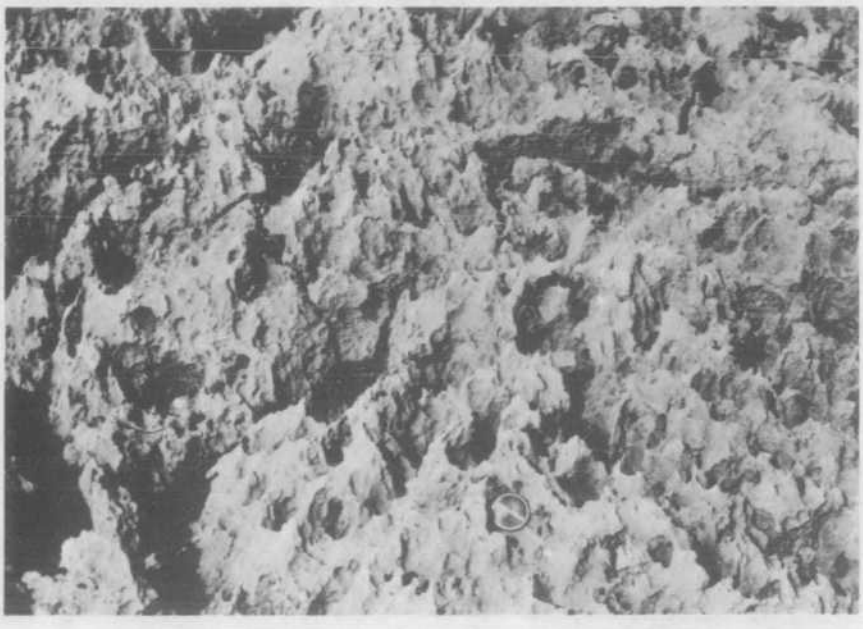


Fig. 4

Detail of Karren surface. Neg No. 1804

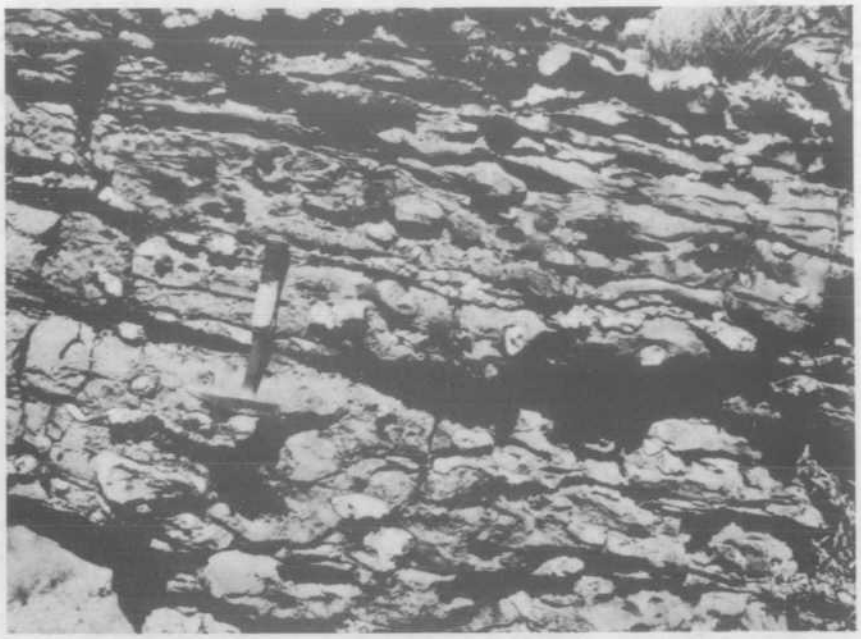


Fig. 5

Dolomite with chert nodules. "Camooweal Dolomite" = Thorntonia Limestone, Colless Creek area. Neg No. 1810

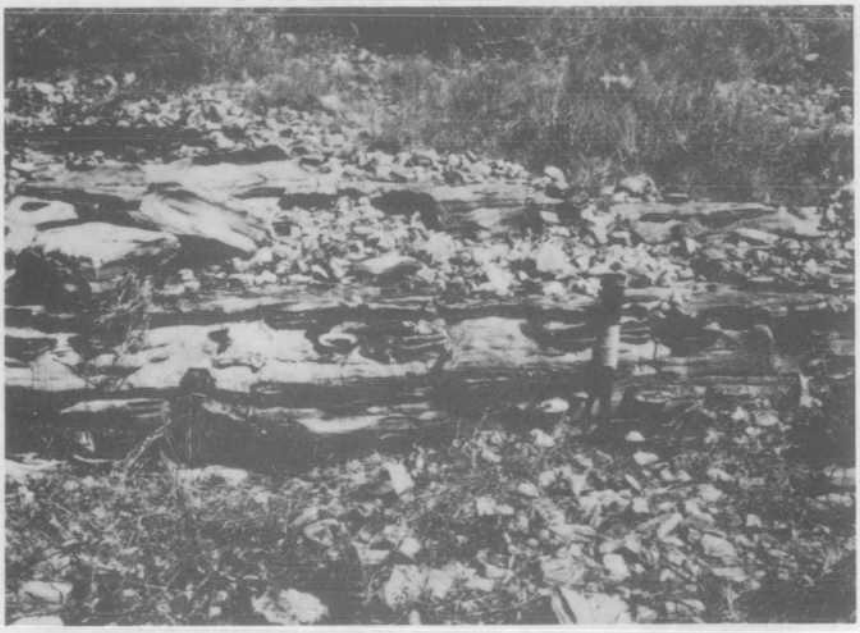


Fig. 6

Dolomitic limestone with layers and nodules of chert. Weathering and leaching of the limestone produces residual mantle of chert rubble at the surface. Colless Creek area. Neg No. 1808

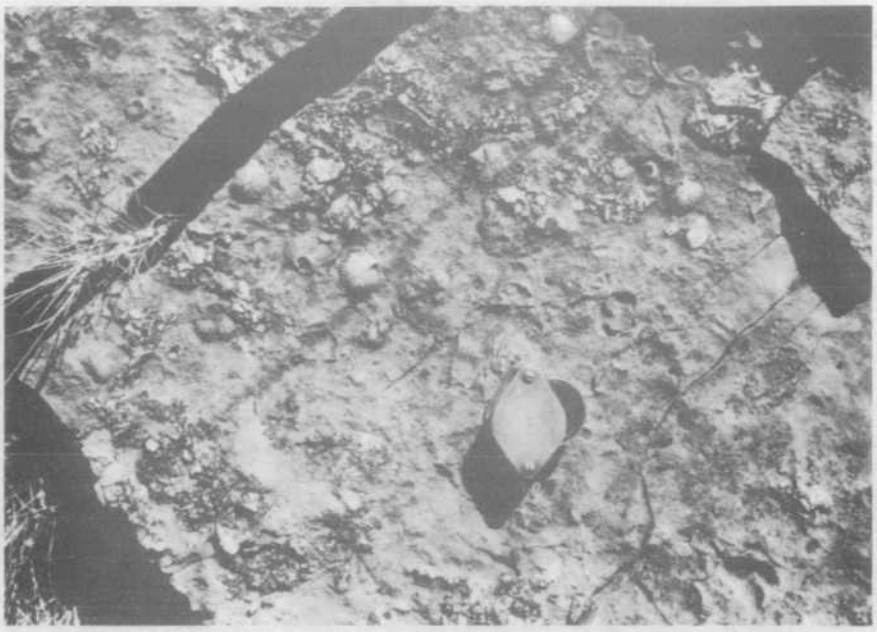


Fig. 7

Bedding-plane view of fossiliferous layer in Thorntonia Limestone. (Locality 161). Neg No. 1816

Fig. 8

As above. Fossil fragments include Xystridura and Nisusia sp. Neg No. 1812

areas elsewhere are easily mistaken for genuine chert beds. There is a tendency for these thin-bedded, chert-rich carbonate beds to be less dolomitic than the massive dolomites poor in chert.

Not all of the chert rubble found at the surface has this origin - disintegration of the chert breccias and chert conglomerates, of course, leads to similar rubble deposits.

The Thorntonia Limestone interfingers with the Border Water Hole Formation, but no attempt has been made to show those tongues on the geological map. A study of the airphotos combined with field observations also shows that the chert tongues of the Border Water Hole Formation laterally grade into the chert-rich dolomites of the Thorntonia Limestone.

As a result of the interfingering, the basement rocks and the Colless Volcanics are overlain in some places by dolomite, elsewhere by chert, and this may have given the impression of an unconformable relationship between the volcanics and the overlying Cambrian sequence (cf. Carter and Öpik, 1961).

The thickness of the Thorntonia Limestone shows a considerable range, from zero to more than 500 feet measured (Plate 3 Section GP. 162) owing to the lateral facies changes. Figure 13 gives an example of the differing conditions observed in different outcrops spaced within a short distance of each other. In the westernmost outcrop known of Thorntonia Limestone, some 4 miles southeast of the old BHP camp, the formation occurs as a lens 250 to 300 feet thick, but owing to structural complications due to the Little Range Fault this may be an exaggerated or reduced thickness.

Fossils (See Appendix and Figures 7 - 9). Fossils are scarce in the actual carbonate beds, where they are represented only by algal balls (Girvanella) and echinoderm ossicles, which are fairly common in places. Normally, however, all fossils are restricted to the silicified layers in the dolomite. They include Biconulites, Hyolithes, Xystridura, Pagetia, and Redlichia species and Nisusia sp. In places, veritable coquinites are formed especially of Biconulites or echinoderm ossicles. The "monofaunal" character of many of the coquinites may be due in part to the sorting effects of wave action and water currents.

Distribution: As a result of the 1968 field work, the distribution of the Thorntonia Limestone has been expanded considerably beyond the boundaries shown on the published Lawn Hill 1:250,000 Geological Sheet, and at the cost of the "Camooweal Dolomite". Also, Thorntonia Limestone does occur locally in the zone along the Little Range Fault structure, contrary to the statement (in Carter & Öpik, 1961) that the formation was never deposited there.

Border Water Hole Formation

The Border Water Hole Formation consists mainly of irregularly bedded or nodular chert (with small limestone lenses) (Fig. 15) and silicified micro-coquinites, chert breccia and chert conglomerate, and minor siltstone and siliceous shale. In the area just east of Highland Plains Homestead, these sediments towards the top grade into, or interfinger with, a fine-grained, thin-to-medium bedded, fawn to mid-gray, usually fetid limestone containing up to 50 percent of highly irregular schlieren, lenses, and nodules of chert.

The chert beds of the formation grade into, and interfinger with, the dolomites of the Thorntonia Limestone, as is quite evident in the north-eastern part of the Tableland, and the limestone east of Highland Plains Homestead (described above) is an example of a similar transition in the west.

The chert breccia is in places more a chert conglomerate. Figure 10 shows the two variants together: a lower chert conglomerate, apparently an original bedded deposit (probably accumulated as a result of the removal of a limestone matrix) is erosionally abutted by a chert breccia in which the fragments are more angular than in the conglomerate, and which could represent an ancient scree or slope breccia or perhaps a reworked breccia, derived from the conglomerate. Elsewhere, west of "Mount O'Connor" for example, the breccia or conglomerate may contain rare, rounded pebbles of Precambrian quartzite and some thin grit interbeds. This shows that the chert conglomerate, although of residual origin, may have been somewhat reworked and perhaps transported over short distances during their formation, possibly in a littoral environment.

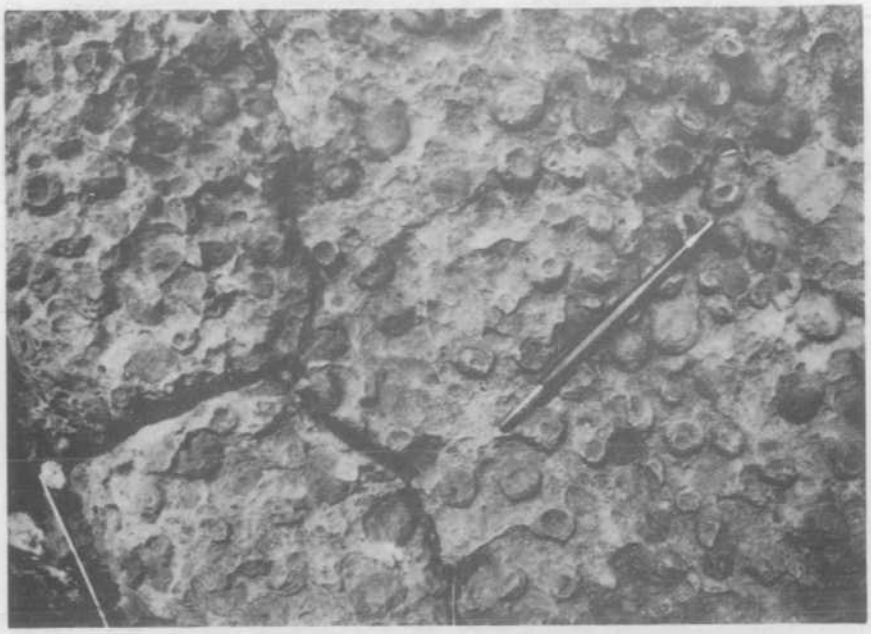


Fig. 9

Spherical algae ("Girvanella pudding") in Thorntonia Limestone. Locality 162. (See section, Plate 3). Neg No. 1818

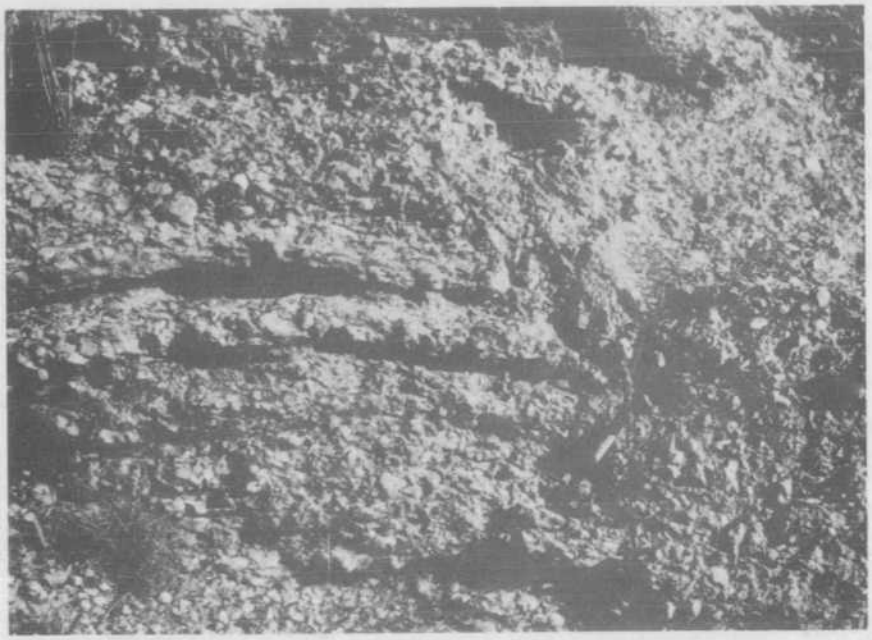


Fig. 10

Chert conglomerate (left) and chert breccia (right) in Border Water Hole Formation. "Mount O'Connor". Neg No. 1815

The conglomerate itself in places appears to grade again into the chert and siltstone sequences with undulating or almost nodular bedding plane surfaces characteristic of much of the Border Water Hole Formation, Beetle Creek Formation, and Burton Beds elsewhere in the Georgina Basin.

A type of chert rather characteristic of the Border Water Hole Formation and its equivalents is a lumpy, rounded variety very commonly representing a silicified micro-coquinite. This proves that at least some of the chert in the Border Water Hole Formation is silicified limestone, and it is possible that almost all of the cherts in the area were derived by replacement of carbonates.

In general, the siltstones and cherts of the formation can be distinguished from those of the Inca Formation by their lesser regularity and their shape. Any chert in the Inca Formation, for example, is almost always thin and platy, and micro-coquinites are very rare.

The thickness of the Border Water Hole Formation varies very much, as can be expected in view of the lateral facies changes. A maximum measured thickness of some 400 to 500 feet may be present in the steeply dipping strata about 3 miles west of the Ridgepole copper prospect, but it is possible that the thickness here may have been structurally increased as a result of movements along the Littles Range Fault. Farther west the thickness appears to be of the order of 200 feet.

The distribution of the formation was fairly accurately mapped by Öpik, Casey, and Randal, as shown in an unpublished B.M.R. map compiled in 1955. However, the Lawn Hill 1:250,000 Geological Sheet, published in 1960, misrepresents the true situation here probably owing to over-simplification .

The Border Water Hole Formation is economically interesting because it - and its equivalents elsewhere - contains the phosphate deposits of the Georgina Basin.

Fossils (Appendix). Fossils collected from the formation include species of Xystridura, Redlichia, undetermined ptychoparioid trilobites, Pagetia, and Biconulites. Remarkably poor in fossils seems to be the northeastern-most chert area south of "Babbling Brook Hill".

Inca Formation(?).

Between the cherty Border Water Hole Formation and the limestones of the Currant Bush Limestone in the 11-mile stretch of Cambrian sediments west of "Mount O'Connor", there usually is a zone of thin-bedded, platy or flaggy red silt-shale and very fine sandstone with occasional thin chert laminae. These sediments strongly resemble those of the Inca Formation found elsewhere, and carry fossils of equivalent age (Appendix). The zone is therefore indicated on the map (Plate 1) as Inca Formation, although the explanatory notes (Carter & Öpik, 1961) make no mention of its occurrence here. Its thickness has not been measured because of the lack of good outcrops, but may reach a total of the order of 100 to 200 feet.

Currant Bush Limestone.

The Currant Bush Limestone comprises yellowish to dark grey, fetid, marly and silty or sandy limestone, grey or yellow dolomitic limestone, and soft marls. The limestones are thin to medium-bedded and flaggy, locally occur as large ellipsoids in a marly matrix, and contain some thicker interbeds of dolomite and dolomitic limestone (Fig. 16). Chert bands and layers, and irregular silicified patches, are common in places. Internal lamination is common, and there is some faint cross-bedding.

The upper boundary of the formation in the area mapped has been a matter of dispute since Öpik's original statement that this was a faulted boundary separating the younger Currant Bush Limestone from the older "Camooweal Dolomite". It is now certain, however, that on the contrary, the formation is conformably overlain by the "Camooweal Dolomite", which therefore must be younger. The upper section of the Currant Bush Limestone, below the "Camooweal Dolomite", is characterised in the west by the diagrammatic section shown in Figure 11, in which no thicknesses are given because they vary from place to place.

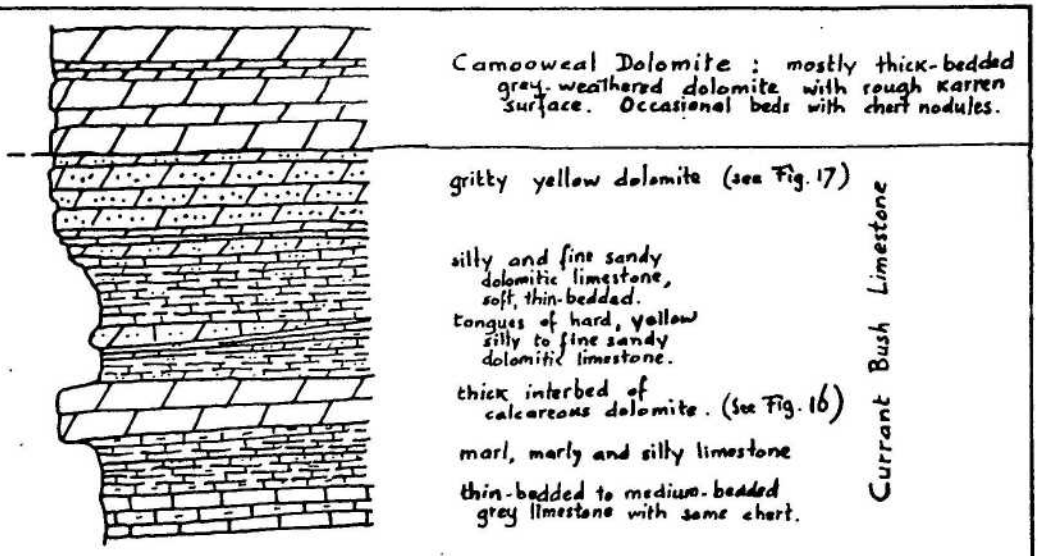


FIGURE 11 – Diagrammatic presentation of top part of Currant Bush Limestone. Thickness not to scale.

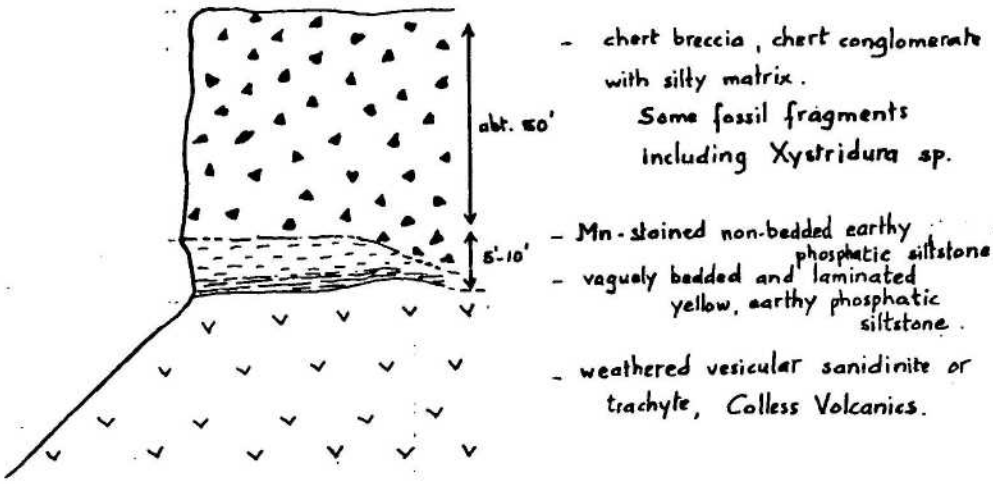


FIGURE 12 – "Mount O'Connor" section.

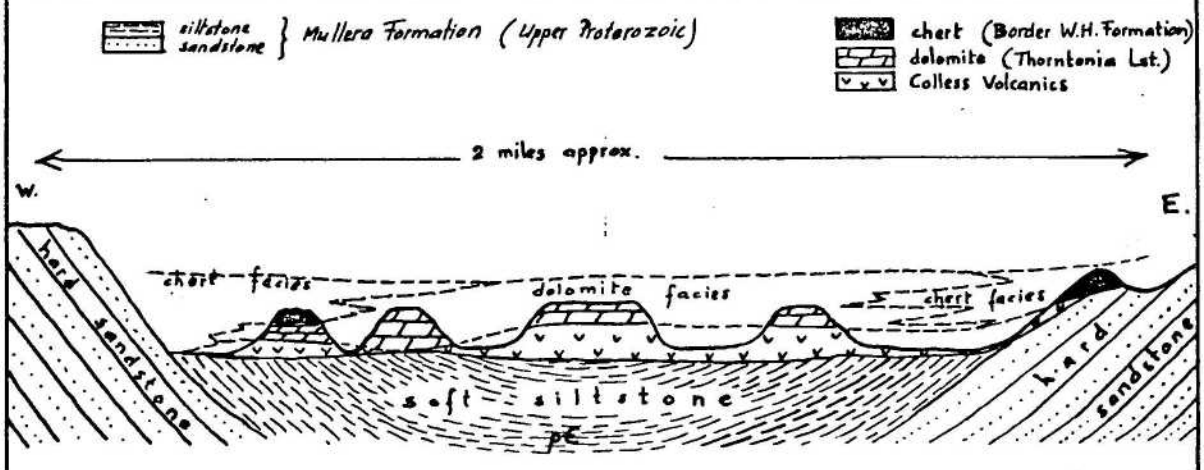


FIGURE 13 – Diagram showing facies distribution in "Babbling Brooke Hill" area, 12 miles west-southwest of Lawn Hill HS.

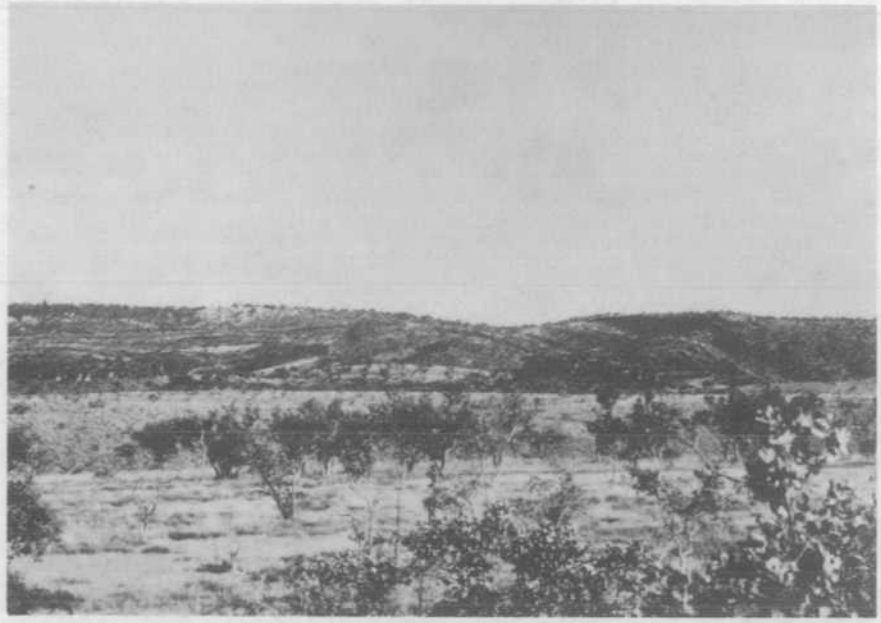


Fig. 14

Cambrian valley, with Proterozoic upland in the back ground. Low dark cliffs in the valley are residuals of Thorntonia Limestone. (cf. Fig. 13). "Babbling Brooke Hill" area. Neg No. 1801

Fig. 15

Uneven, almost nodular, bedding plane typical of chert sequence of Border Water Hole Formation. Neg No. 1785

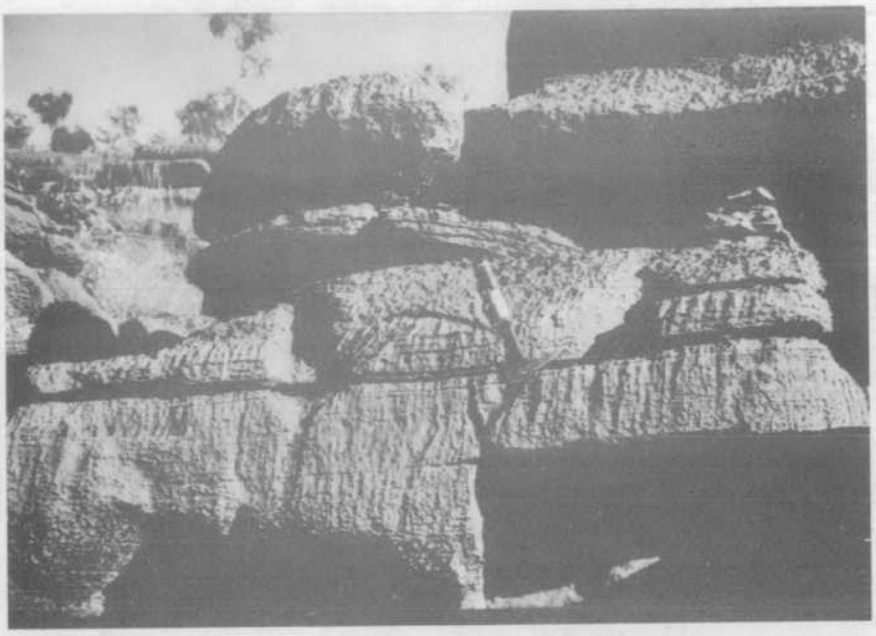


Fig. 16

Thick darkgrey dolomite bed intercalated in upper section of Currant Bush Limestone, east of Highland Plains Homestead. cf. Fig. 11. Neg No. 1809

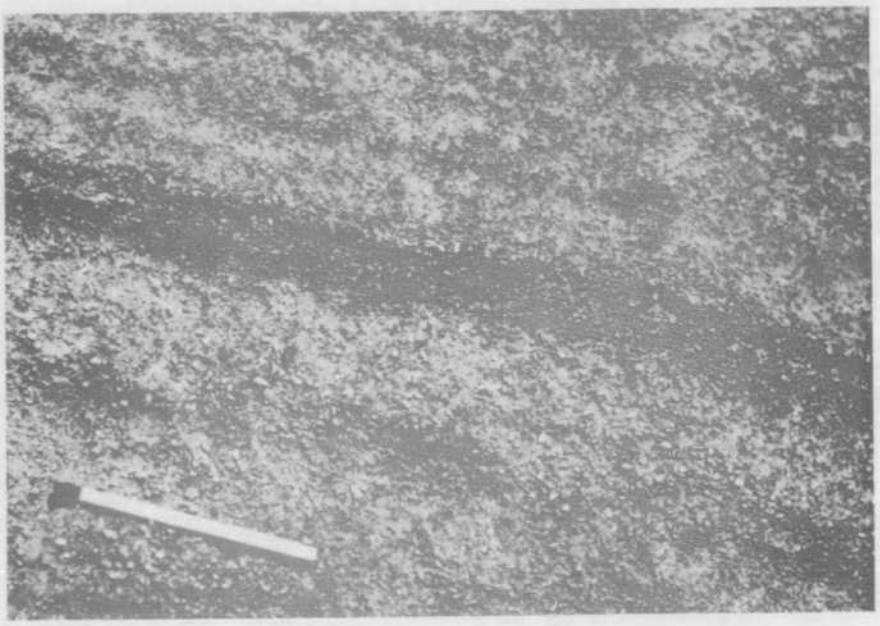


Fig. 17

Gritty dolomite typical of uppermost section of Currant Bush Limestone east of Highland Plains Homestead. cf. Fig. 11. Neg No. 1787

In thin section, the gritty dolomite (Fig.17) contains angular fragments of chert and rounded carbonate pellets (up to 0.5mm across) in a fine-grained dolomitic matrix. In the yellow sandy zone, the weathered rock has a characteristically sandy touch, and this feature fairly persistently presents itself in most places along the inferred boundary between Currant Bush Limestone and "Camooweal Dolomite", and helps to identify it, even in the far east and south-east where the Currant Bush Limestone facies has cut out completely and all rocks are dolomite.

The thickness of the Currant Bush Limestone is about 300 feet in the 11-mile stretch of Cambrian deposits west of "Mount O'Connor", and Öpik (in Carter & Öpik, 1961) has estimated a thickness of 60 to 100 feet in the Highland Plains area. The formation pinches out completely in the headwater region of Colless Creek and is no longer recognizable farther east or south.

Fossils (Appendix) - Fossils include agnostids, nepeids, dolichometopids, phosphatic brachiopods, sponge spicules, etc. Some of the forms are new geni. The age of the unit ranges from the atavus zone to the pre-punctuosus zone.

Lancewood Shale

Outcrops of massive siltstone and thin-bedded silicified silt-shale (Fig. 20) along Lancewood Creek, southwest of Highland Plains Homestead, were given the name of Lancewood Shale by Öpik (1960), who describes them as deeply lateritized, indistinctly laminated sandy shale and siltstone beds resting conformably on Currant Bush Limestone, and containing undeterminable agnostids and dolichometopid trilobites. In 1961, Öpik (in Carter & Öpik) saw the unit as the probable equivalent of an undefined upper part of the Currant Bush Limestone. Fossils listed include Fuchouia, Peronopsis, Ptychagnostus, and cystids, and the preserved thickness was given as 70 feet seen.

The formation occurs in erosional residuals only, and does not occur elsewhere. It forms the greater part of the mesas south of Lancewood Creek, the tops of which have been mapped as Cretaceous.

The Lancewood Shale amd the upper part of the Currant Bush Limestone appear to grade into each other, as the latter is still present in three large lenses(?) in the shale, and the Currant Bush Limestone in the fault zone south of Highland Plains Homestead contains lenses of calcareous siltstone and some shale.

"Camooweal Dolomite"

The term "Camooweal Dolomite" was given by Öpik (1954 unpubl., 1956a) to the large expanse of dolomites on the Barkly Tableland and typically developed in the Georgina River/Camooweal area.

In the Border Water Hole/Riversleigh area, the dolomites are buff, light brown, ochre yellow, cream, white, and mottled in colour when fresh, but the exposed surface is usually tarnished grey to dark grey. There are intercalations of sandy dolomite, fragmented dolomite, micrite-pellet dolomite, oolitic dolomite, and dolarenite. The strata are generally thick-bedded and massive, but alternate with thin-bedded intervals. Internal laminations and banding are common, as are stylolites and, in places, cross-bedding structures.

The age and stratigraphical position of the "Camooweal Dolomite" have been a matter of dispute since Öpik created the unit, and a synopsis of its history is given in Smith (1967, unpubl.). Fossils being absent, Opik originally suggested on circumstantial evidence that the unit forms the base of the Cambrian sedimentary sequence, from which it might be separated by an erosional break, and that it could be of Lower Cambrian or late Precambrian age (Öpik, 1956a). This point of view was later disputed, on various grounds, by Mulder (1962, unpubl.), Randal and Brown (1962, unpubl.), and Smith and Roberts (1963). During the present field survey, lower Middle Cambrian fossils were collected from a number of localities in areas previously considered to be "Camooweal Dolomite", indicating that the basal dolomites overlying the Precambrian belong to the Thorntonia Limestone. It has also been confirmed that the Currant Bush Limestone in the headwater region of Colless Creek is overlain by the "Camooweal Dolomite". This is an indisputable fact, not subject to any other interpretation such as faulting.

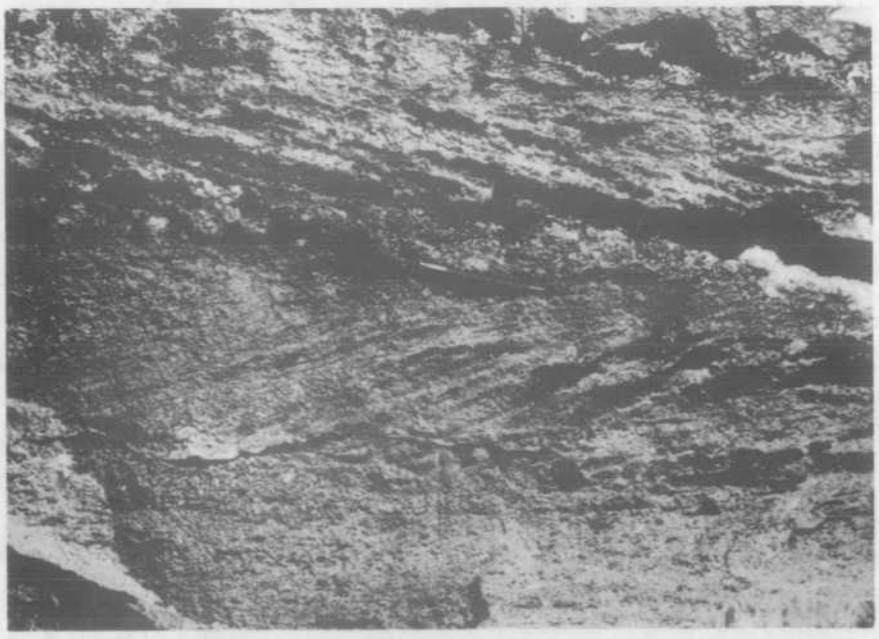


Fig. 18

Cross-bedding in "Camooweal Dolomite" (= Thorntonia Limestone), Colless Creek area. Neg No. 1793

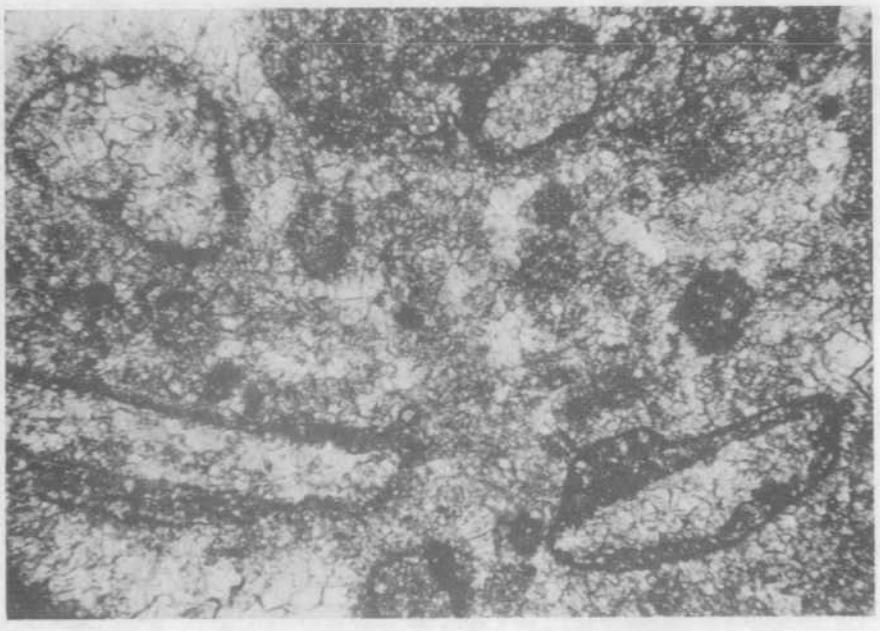


Fig. 19

Photomicrograph of "Camooweal Dolomite" showing ghost remnants of fossil fragments replaced by dolomite. Camooweal area. Neg No. M/853-17

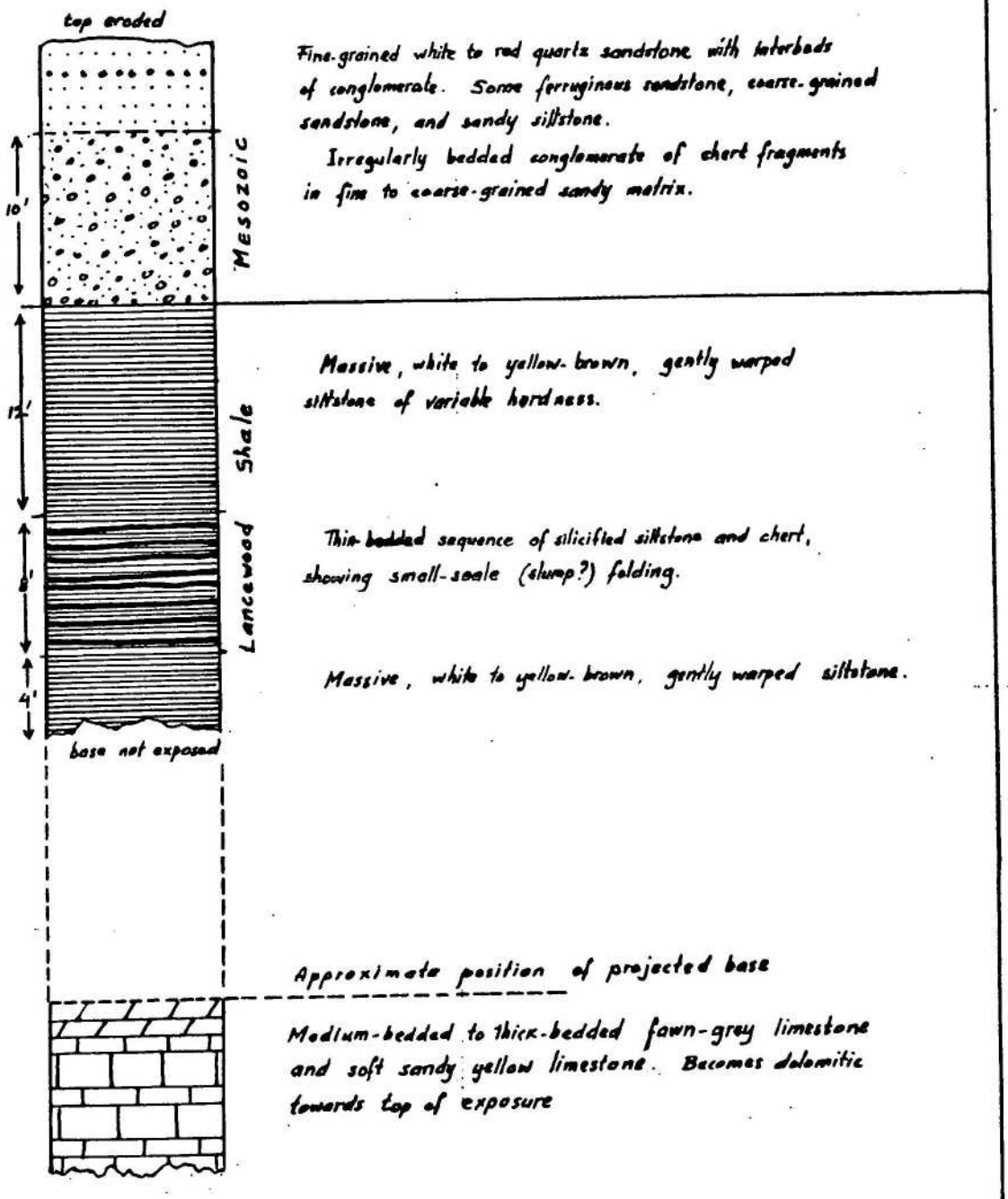


FIGURE 20 – Section of outcrop of Lancewood Shale and Mesozoic, south of Lancewood Creek, 3.5 miles southwest of Highland Plains HS.

If the term "Camooweal Dolomite" is to be retained, it should be re-defined as a unit representing the dolomitized lateral equivalents of Middle(to Upper?) Cambrian limestone formations, with a lower age limit probably somewhere in the post-atavus/pre-punctuosus zone, (or, if the Thorntonia Limestone is included, in the Redlichia zone). The upper age limit is unknown, but extends at least into the laevigate zone, and might even be placed in the Upper Cambrian to Lower Ordovician if a correlation between Ninmaroo Formation and part of the "Camooweal Dolomite" can be proved to be valid.

The thickness of the "Camooweal Dolomite" is unknown, but is hundreds of feet. In BMR No.11 Well (Cattle Creek), west of Camooweal, a section of some 1400 feet of dolomite was penetrated, with an 80-foot interbed of limestone containing Lingula sp. at 1195-foot depth. Interfingering with fossiliferous limestone units is common towards the edges of the "Camooweal Dolomite" province, and is another indication for the unit to be the lateral equivalent of various Middle Cambrian Limestone formation.

Although the "Camooweal Dolomite", does not contain recognizable fossils, thin sections often show ghost remnants of rounded fossil fragment (Fig. 19). This, and the drusy or finely vuggy texture of many dolomites, suggest that the dolomite was formed by dolomitization of original limestone, and is not a primary precipitate. Some regularly wavy laminations may represent algal laminae.

It is pointed out that the "Camooweal Dolomite" strongly resembles the Thorntonia Limestone in this northeastern part of the Barkly Tableland, where the latter formation is developed in a dolomitic facies. Where no fossils are present, the distinction between the two formations in outcrop is impossible. However, in the headwater region of Colless Creek, where both the Currant Bush Limestone and the Border Water Hole Formation cut out towards the south so that the "Camooweal Dolomite" from there on directly overlies the Thorntonia Limestone, the contact between the two units can be fairly accurately traced on the airphotos to a point just north of the old Lawn Hill - Herbert Vale track (see map). Farther south, the contact is camouflaged by a loose thin veneer of disintegrated Mesozoic sandstone, and can no longer be followed.

Facies relationships and palaeo-environment of the Cambrian units.

The facies relationships between the various Cambrian units are diagrammatically represented in Figure 2. Points to note are the interfingering transitions between Border Water Hole Formation and Thorntonia Limestone (which cannot be shown on the geological map), and the apparent disappearance of the bedded chert facies away from the palaeo-shore line.

Although the Cambrian sequence is separated from the Precambrian basement by the Littles Range Fault, it is probable that the original shore line showed embayments comparable to the one represented by the easternmost outcrops of the Colless Volcanics. Here, the volcanics and overlying Thorntonia Limestone and Border Water Hole Formation were deposited in a depression formed by the erosion of the soft core of a Precambrian syncline (Figs. 13, 14). The same applies to the "Mount O'Connor" embayment, similarly situated in the eroded softer core of a Precambrian syncline, and further examples are known from the Thorntonia/Lady Annie areas. In all these embayments the Cambrian deposits lie at a level up to 200 feet or so lower than the surrounding Precambrian ridges that constitute resistant beds in the outer regions of the syncline, and it is obvious that geographically there was a series of small semi-isolated and probably rather restricted basins measuring only a few miles long by a few miles wide. The Dentalium Plateau seems to be the remnant of a much larger restricted basin.

Cross-bedding in the Thorntonia Limestone appears to indicate current directions from eastern through northern to western regions of the compass, which is in line with the presence of a northern shore line. The inconsistency of the current directions was a result of strictly local conditions, and can be considered as further evidence for the close vicinity of the shore line and for shallow water depth. Locally biconulites in coquinites are arranged parallel to current directions inferred from cross-bedding, and the current must have been fairly strong in order to achieve this. Finally, the presence of algal structures in the Thorntonia Limestone is suggestive of a very shallow marine environment.

From the distribution of the chert facies and the carbonate facies, both laterally and vertically (cf. Fig.13), it seems possible to conclude that in general the chert facies was deposited in the shallow zone closest to the shore and that the carbonate facies probably formed farther outside, possibly as shoals, which may have helped in restricting free bottom water circulation between the embayments and the open sea. The effects of traction currents have been noticed only in the carbonates, not in the chert facies, whereas the uneven, irregularly undulating bedding surfaces of the chert sequences may be due to wave influence prevalent along the coast (Fig.15.).

Along the eastern scarp of the Tableland, however, the chert facies appears to have degenerated to the extent that it has not been mapped as a separate unit. Presumably the embayment was represented farther east by the Dentalium Plateau area, being separated from the Barkly sea by the long, straight-lined barrier of resistant Constance Sandstone which forms the eastern edge of the Tableland, and which appears to be associated with a fault.

Farther south, towards Riversleigh, the fault dies out, and, although no B.M.R. mapping has been done here, exploration by Mines Exploration Pty Limited has shown that the chert facies and, with it, the development of phosphorite, has become prominent again.

Mesozoic:

Within the area mapped, Mesozoic beds occur mainly in the area south of Highland Plains Homestead. They consist of fine-grained and medium-grained, in places coarse-grained white to red quartz sandstone with interbeds of pebble conglomerate and some massive siltstone with scattered quartz grains. The conglomerates consist of rounded fragments of chert (derived from the underlying Cambrian) and Precambrian quartzite in a sandy matrix, and occur mainly towards the base of the Mesozoic. The bedding in both the conglomerates and the sandstone is indistinct, and the sandstone commonly grades into siltstone.

A small outlier just southwest of Highland Plains, previously mapped as Precambrian Bluff Range Beds, is composed of sandstone and conglomerate identical to those of the main Mesozoic outcrop area, and is believed to be a Mesozoic valley fill deposit.

The thickness of the Mesozoic section is of the order of several tens of feet, probably increasing towards the south.

The only other Mesozoic deposit visited is found along the old Lawn Hill/Herbert Vale track, in the eastern part of the Tableland. Here, the Cambrian rocks are overlain by fine-grained reddish brown sandstone which is silicified in part. Remnants of massive, billified sandstone and chert conglomerate, forming topographic heights amidst the sandstone, may represent the basal Mesozoic beds on the old erosional surface, and the surrounding sandstone in thet case is a later deposit in-filling the depressions between the tors of billified chert rubble. If not, the billified sandstone and chert rubble form a later deposit overlying the fine-grained sandstone. However, the large amount of Cambrian chert in the former suggest that it is the older of the two. The outcrop is shown as Jurassic on the Lawn Hill 1:250,000 Sheet. Much of the sandstone is disintegrated to form a loose sandy veneer or sandy soil over the area, obscuring the details of the Cambrian geology underneath.

Tertiary

The Tertiary is represented by the Carl Creek Limestone in the area around Riversleigh Homestead, and was most recently described by Tedford (1968). The name was originally introduced by Jack (1895), and although other names were used in later years, e.g. "Verdon Limestone" (Noakes & Traves, 1954), the term was correctly revived after the regional mapping survey by the B.M.R. (Carter & Opik, 1961).

The formation occurs in more than a dozen isolated outcrops in the valley of the Verdon Creek - Gregory River - O'Shannesy River junction, and is also exposed in places along the scarp that forms the eastern margin of the Barkly Tableland near Riversleigh Homestead. It comprises a lower conglomerate unit and an upper clastic limestone unit, with a total preserved thickness of up to 80 feet. The lower unit is a pebble or boulder conglomerate or breccia with a sandy carbonate matrix and containing subangular fragments of Cambrian chert and Mesozoic(?) silicified sandstone, and is overlain by the upper, thick-bedded to massive clastic arenaceous limestone unit composed mainly of intraformational pebbles of Tertiary limestone and rarer, grey pebbles of Thorntonia Limestone set in a sandy limestone matrix. Fossils include remains of fish, crocodiles, birds, and a few mammals, as well as fresh-water gastropods and ostracodes, and the age is estimated as late Oligocene to Miocene. Earlier estimates ranged from Cretaceous to Pleistocene.

According to Tedford, the formation was deposited in a shallow-water, relatively high energy environment, in a trough that was deepest along the scarp and shallowed towards the east. Access to the Gulf of Carpentaria may have been afforded by the narrow valley of the Gregory River along which isolated small outcrops occur over a distance of some 14 miles.

It is probable that the separated outcrops of Carl Creek Limestone are the erosional remnants of a once continuous deposit, as evidenced by the clastic nature of the deposits, which renders unlikely the explanation offered by Öpik (in Carter & Öpik, 1961) that the outcrops represent depositions over sub-aquatic mounds while in the deeper floor of the basin chalky material accumulated. The white, friable chalky or travertinous material is found as far north as Lawn Hill Creek, and is probably a secondary, Recent deposit.

The Carl Creek Limestone is of interest in that its association with the Thorntonia Limestone, which it can resemble, gave rise in the past to incorrect and confused estimates of the age of the Cambrian carbonate deposits of the Barkly Tableland.

Recent

Recent deposits include the black soil plains, slope screes, alluvial concentrations, and probably the travertinous veneers, and need not be treated further.

B. Lady Annie/Lady Jane District (See Fig.2 and Plate 2).

The geology is similar to that in the Lawn Hill district, and involves a basal conglomeratic or gritty, dolomitic sandstone (the "Mount Hendry Formation" of the Mines Exploration geologists), the Thorntonia Limestone, the cherts and phosphorite of the Beetle Creek Formation, and the silt-shales of the Inca Formation. Any younger Cambrian units have been removed by erosion. Outcrops are scarce in the Lady Jane area, where most of the Cambrian is over - lain by Mesozoic sandstone or by alluvial and eluvial sands derived from it.

"Mount Hendry Formation"

At Mount Hendry - a mesa on the east bank of Paradise Creek - folded Proterozoic red micaceous siltstones are unconformably overlain by about 25 feet of a basal conglomerate with sandstone layers. Subangular to subrounded pebbles, comprising Proterozoic quartzite, chert, and siltstone, are embedded in a sandy matrix. They are on the average a few inches across, but may range up to boulder size. Poorly developed imbricate structures suggest current directions from the northeastern quadrant.

Away from this type locality, the thickness decreases and becomes very irregular, and the size of the pebbles smaller.

At Hilary Creek, the formation is a basal gritty to fine-conglomeratic dolomitic sandstone up to 10 feet thick. The top layer is pink and strongly dolomitic and in that sense appears to grade into the overlying Thorntonia Limestone, although the actual contact is sharp. Truely gradational contacts are reported by Mines Exploration geologists to be present in other localities.

In the Lady Jane area, the formation is represented by a few feet (7 or 8 feet were measured in one creek section) of brown ferruginous sandstone, gritty sandstone, and some thin conglomeratic bands. Cross-bedding in the sandstone in the creek outcrop indicates a current direction roughly from the north.

It appears that the palaeo-shore line of the Lady Annie/ Lady Jane basin was not far to the east and north of the outcrop area, in view of the current directions and the generally increasing coarseness and thickness of the "Mount Hendry Formation" in that direction.

Thorntonia Limestone

The Thorntonia Limestone is similar to that elsewhere in the northern part of the Georgina Basin, and is here exposed mainly in the southernmost outliers of the Lady Annie area.

In the vicinity of Hilary Creek, the top of the formation represents an old, irregular karst surface with pockets and depressions filled with chert-phosphorite breccias and phosphatic siltstone or silty phosphorite (Figs. 21-23); the bottom and sides of the pockets are lined withan iron- and manganese-rich weathering zone (some samples showing up to 8% MnO_2), in which other metals like Zn, Ni, and Co are commonly also enriched. Elsewhere in the Hilary Creek area, the Thorntonia Limestone is preserved only as small lenses measured in tens of feet, and overlain and surrounded by residual ferruginous and manganese-stained rubbly weathering zones.

It is concluded that before the deposition of the Beetle Creek Formation, the Thorntonia Limestone emerged during a short regression and developed a karst surface, over which the succeeding Beetle Creek Formation was deposited. Part of the pocket fillings probably represent residual phosphate-rich accumulations of silty and weathered cherty material that remained after the dissolution of slightly phosphatic and silty Thorntonia Limestone.

Beetle Creek Formation

The Beetle Creek Formation includes a variety of rock types: uneven-bedded chert, chert breccia and conglomerate, silicified micro-coquinite, white, cream, or yellow phosphatic siltstone or silty phosphorite, and fine sandstone. Away from creek beds, outcrops are usually poor and scarce, and the formation is mainly present as chert rubble covering the slopes and surfaces of the Cambrian residuals. However, it is clear that facies changes are rapid and common.

Fossils found include Redlichia, Xystridura, Lingulella, Hyolithes, Biconulites, and Aluta species.

Ferruginous and manganiferous breccia or rubble horizons again indicate probable periods of regression. One such episode appears to mark the boundary between the Redlichia zone and the Xystridura zone.

The Beetle Creek Formation contains the phosphate deposits, most of which are fine-grained and silty. However, large tonnages of pelletal phosphorite were found by drill holes, mainly in the western part of the prospect area.

An east-west section through the depositional basin in the Lady Annie area shows an asymmetrical bathymetry, the deepest part being in the western half, with the sea gradually shallowing towards the east where the "Mount Hendry Formation" marks the vicinity of the coast line. The western boundary of the basin was probably fault-controlled, the eastern boundary normally transgressive.

Inca Formation.

Regularly bedded, flaggy silt-shale, siliceous shale, and thin even-bedded chert layers of the Inca Formation crop out in the south-western part of the Lady Annie area. They were not mapped separately by the B.M.R. survey party because of the little time spent in the area, but appear to present the typical Inca facies. The unit is distinguished from the Beetle Creek Formation by its regular, flaggy or

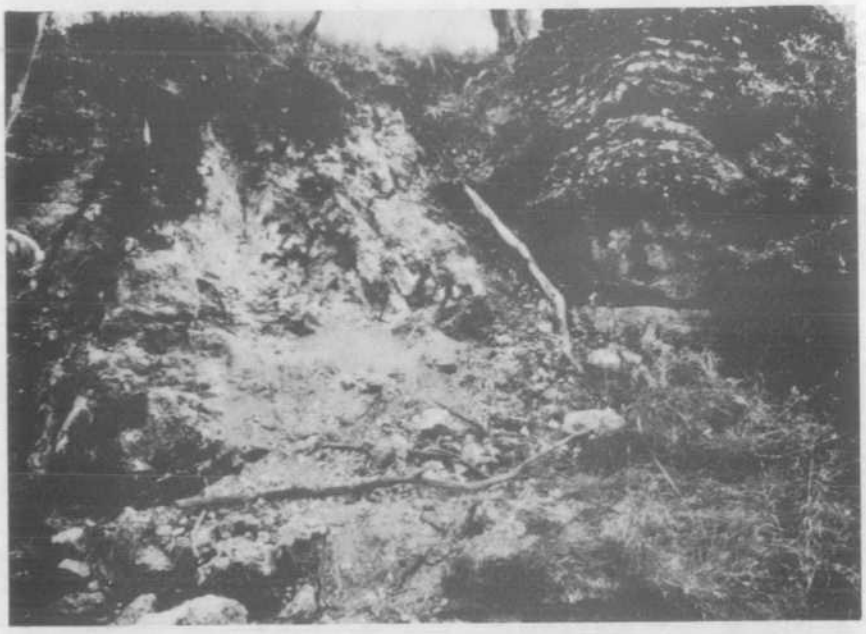


Fig. 21

Pocket of phosphatic siltstone (light coloured) in Thorntonia Limestone (right). Hilary Creek outcrop, Lady Annie area. Neg No. 1788

Fig. 22

Detail of Figure 21 : Thorntonia Limestone with chert layers and nodules. Neg No. 1814

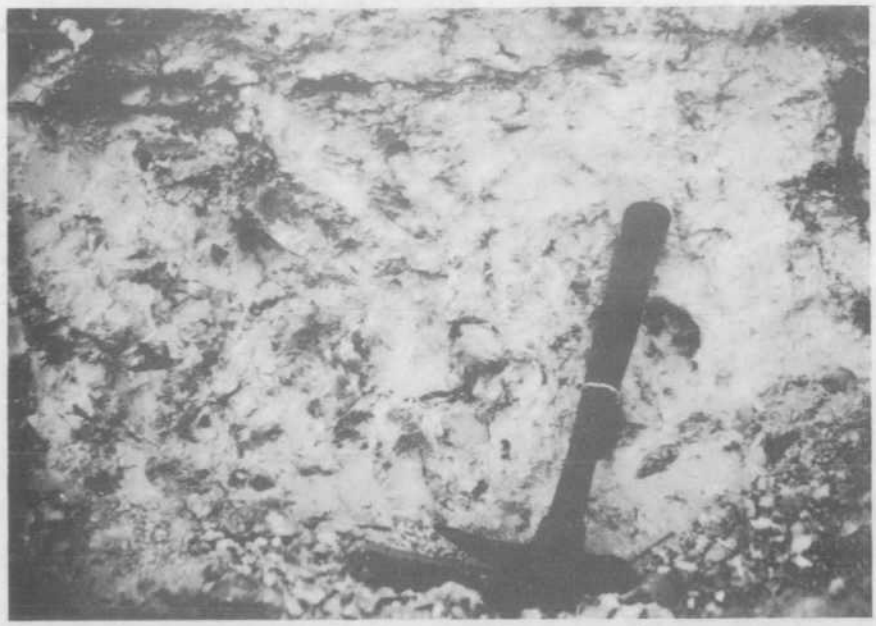


Fig. 23

Detail of Figure 21, showing leached, structureless phosphatic siltstone with weathered remnants of chert fragments derived from the Thorntonia Limestone. Neg No. 1783

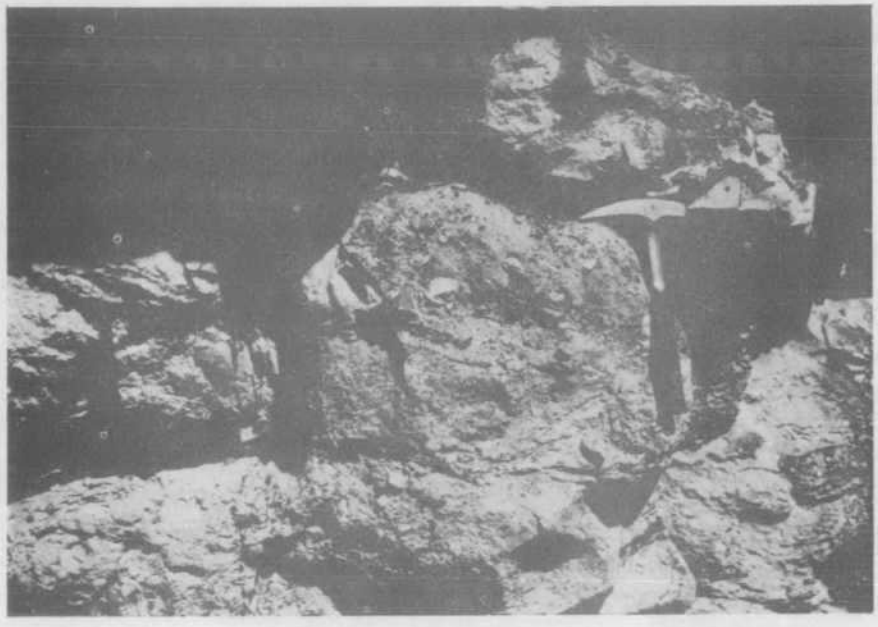


Fig. 24

Basal conglomeratic dolomitic sandstone, Louie Creek area, Lawn Hill district. Locality GP.162. Neg No. 1811

platy bedding, by its thin platy layers of dense chert (as opposed to the lumpy, nodular chert of the Beetle Creek Formation), and by its fossil fauna which is characterized by Ptychagnostus gibbus. The common and persistent presence of sponge spicules is also rather characteristic, notwithstanding the fact that sponge spicules have no diagnostic value in the subdivision of the Cambrian in Queensland, and also occur in, e.g., the Beetle Creek Formation. However, where presence of sponge spicules is coupled with absence of other fossils and with the development of thin-bedded chert, diagnosis of Inca Formation has usually been found to be correct.

Mesozoic

Mesozoic sandstones form a lateritized plateau over the Cambrian formations in the north, and a few small residuals in the Lady Annie area proper. There appear to be two units: a lower, white sandstone and conglomeratic sandstone unit containing plant fossils, overlain by an upper unit of at least 50 feet of yellow fine-grained sandstone with intercalations of ferruginous conglomerate (pebble size averaging 1 inch - 2 inches). The lower sandstone is commonly billified, or elsewhere is superficially altered to a hard quartzite, easily mistaken for Proterozoic quartzite, though the latter is usually more feldspathic. Its age may be Jurassic. The overlying fine-grained, possibly Cretaceous sandstone is lateritized and forms the lateritic plateau in the north.

Cainozoic

Cainozoic deposits include a little alluvium, but are mainly represented by blankets of sand derived by disintegration of the Mesozoic sandstones. The sand effectively covers most of the Lady Jane phosphorite deposits, and the northern portions of the Lady Annie prospecting area.

STRUCTURE

Faulting and, locally, folding have affected the Cambrian formations along the margins of the Barkly Tableland. This is most notable along the Littles Range Fault, where the Cambrian units show dips ranging from vertical close to the fault, down to a few degrees gradually away from the fault; dips in the main body of the dolomites of the Barkly Tableland are virtually horizontal. In places along the Littles Range Fault, the Border Water Hole Formation is crushed and sheared. Another fault zone is found along Lancewood Creek, where Currant Bush Limestone and "Camooweal Dolomite" are off-set against the Border Water Hole Formation and, in part, against each other. This latter phenomenon apparently led to the belief that the "Camooweal Dolomite" was thrusted onto the Currant Bush Limestone, and was the older unit, a theory now untenable.

Dips up to ten or fifteen degrees in the Cambrian along the eastern edge of the Barkly Tableland may be initial depositional dips, but the effect of possible faulting or warping is not to be excluded, especially as north of Lawn Hill Creek the Cambrian on the Tableland lies at a higher level than the Cambrian in the Carpentaria Plain. Towards the south any fault present appears to die out.

The dolomites of the Dentalium Plateau show a structural contrast with the Cambrian elsewhere in that they are folded rather haphazardly, showing vertical attitudes next to almost horizontal dips without any regular fold pattern being obvious. The dolomites form only a thin layer of sediments on the Proterozoic basement, and it is likely that their unexpected structural complexities are due to post-Cambrian faulting in the underlying basement, during which the faults may not have extended to the surface; the Cambrian dolomites compensated for the differential movements by passive, gravitational folding.

That post-Cambrian faulting did indeed occur along Precambrian faults is shown by the Littles Range Fault, along which a pre-Cambrian phase as well as a post-Middle Cambrian phase of movements is known to have occurred. It should also be noted that the Dentalium Plateau is situated in an area where east-west, northeast, and southeast trending fault systems meet each other, which could have given rise to complex block fracturing and splintering (cf. Fig. 2 in Carter & Opik, 1961).

In the Lady Annie area, the most important structural feature seems to be the meridional fault zone separating the Cambrian outlier area from the fault block of Precambrian quartzite to the west. As it appears that the Cambrian sea arm here shallowed to the east, and had its greatest depth in the west, close to the quartzite fault block, it seems reasonable to assume that the fault had already been active before deposition of the Cambrian sediments, and had thereby created the asymmetrical bathymetrical section. Smaller, northwest and northeast trending faults in the Lady Jane area show sinistral movements which, in this case, indicate a generally east-west directed tectonic compression.

PHOSPHORITE DEPOSITS

The phosphorites and phosphatic siltstones are associated with the lower Middle Cambrian chert-siltstone facies of the Border Water Hole Formation and the Beetle Creek Formation, as they are anywhere else in the Georgina Basin. The exploration activities by companies have been centered in the areas around Highland Plains Homestead, "Mount O'Connor", "Babbling Brooke Hill", Lawn Hill ("Mount Jennifer"), Dentalium Plateau ("Phantom Hills"), the eastern margin of the Barkly Tableland northwest of Riversleigh Homestead, and in the Lady Annie/Lady Jane area.

In the Lawn Hill/Border Water Hole area, all activities in the Queensland sector were conducted by Mines Exploration Pty Ltd who first found phosphorite here in 1967, and who in that year put down a total of 9,542 feet of non-core drilling in the first three

areas listed above, as well as 274 feet of core drilling. In 1968, the company completed 9.280 feet of non-core drilling at Lawn Hill, Dentalium Plateau, and Riversleigh. The small sector of Border Water Hole Formation situated across the Northern Territory border was in 1967 held by a consortium including Amad, under the name of Macmine Pty Ltd, and it was reported in February, 1969, that indicated reserves in this sector amounted to 66.5 million tons of 20.9% P_2O_5, and that inferred reserves were of the order of 14.5 million tons of 20.5% P_2O_5. The investigations are continuing.

In the Lady Annie area, Mines Exploration Pty Ltd carried out an intensive grid-drilling programme during 1968, initially at 1000-ft intervals, but later closing to 500-foot intervals or less. The company completed 9,883 feet of non-core drilling 1967, and an additional 64,144 feet in 1968. This work was supplemented by the sinking of thirty-one exploratory shafts, several tens of feet deep, through phosphate-bearing sections in order to take bulk samples for small-scale pilot plant beneficiation tests. The reserves of phosphate rock indicated, on the basis of an 18% P_2O_5 cut-off grade, were estimated at 250 million tons (Chairman's report, November 1968). In the course of the investigations, an additional A. to P. area was taken out adjacent to the northern boundary of the Lady Annie area, and is now known as the Lady Jane area. Here the phosphate deposits rarely crop out, being mostly covered by a thin mantle of Mesozoic beds or their derived sands; they are the sub-surface northern extension of the Lady Annie deposits. In 1968, a total of 2,030 feet of non-core drilling was completed in the Lady Jane area.

The phosphorites in the Lawn Hill and Lady Annie districts are commonly in the form of phosphatic chert breccias, in which the matrix usually is a creamy to yellow-brown earthy phosphate rock, or a dense, at least partly secondary, microcrystalline apatite cement. The latter is generally found at the base of the phosphatic section, but may also occur in certain horizons higher up in the sequence. Manganese and iron staining is quite prominent in places, especially in basal phosphatic chert breccias as in the "Babbling Brooke Hill" area.

At "Mount O'Connor", the best phosphorite appears to occur near the base, in places in the upper part of a basal manganese-stained earthy siltstone up to about 10 feet thick, overlying the Colless Volcanics (Fig. 12). In the phosphatic chert breccia (some 75' thick) between"Mount O'Connor" and the Ridgepole copper prospect also, the P_2O_5 values appear to increase towards the base, where chert fragments (and some Proterozoic quartzite pebbles) are commonly cemented by a dense iron-stained secondary phosphate matrix. Locally the lower-most basal layer is a massive, ochre to yellow, silty bed without chert, and is ferruginous and, in part, silicified.

Obvious pelletal phosphorite varieties such as are found in the Duchess district (Russell, 1967; de Keyser, 1968 unpubl.) were not observed at the surface. However, drilling in the Lady Annie area by Mines Exploration Pty Ltd revealed the presence of pelletal phosphorite in the subsurface mainly in the western and northern portions of the A. to P. area, and pelletal phosphorite was also reported from a few creek outcrops by the company geologists.

There appears to be a gradual change in the phosphorite facies from the Duchess area in the south, via the Lady Annie and Thorntonia regions, to the Lawn Hill district in the north, in so far that the pelletal phosphorites, which are strongly predominant in the south, are overshadowed by the earthy, silty phosphorites in the Lady Annie area, and seem to be virtually absent in the far north. Among the factors that could have contributed to this distribution pattern may be mentioned a greater intensity of attrition by reworking in the northern regions, and a greater percentage of residually accumulated and precipitated fine-grained phosphate derived by leaching of weakly phosphatic carbonate rocks. Both factors could have been the result of a sea depth that was slightly shallower in the northern regions than in the southern Duchess district, thus giving rise to more frequent episodes of emergence and creating environments of higher wave-energy. Evidence of a reduced sea depth in the north includes the greater abundance of manganese-iron stained rubble zones and of chert breccias;

the fact that pelletal phosphorite in the Lady Annie area appears to be associated with the deeper parts of the local depositional basin, whereas many of its silty and earthy fine-grained phosphorites are found over the eroded surface of the Thorntonia Limestone, partly filling the depressions in a palaeo-karst topography in this unit; and lastly the typical development of uneven-bedded thin chert sequences with wavy bedding surface, which probably is the result of wave action. It seems likely that the phosphorite deposits in the Duchess area in the south were deposited in a slightly deeper sea, vide the scarcity of stained rubble horizons, the regular bedding of the cherty Beetle Creek Formation, and the pre-dominance of pelletal phosphorites and the preservation of original biopelsparites. In accordance herewith the fine-grained silty phosphate facies in this area is concentrated closer to the palaeo-shore line. It is possible that the fine-grained phosphate was originally formed by intense attrition in turbulant coastal waters, and was subsequently carried away to be deposited in a quieter environment.

The sediments associated with the phosphorites are mainly chert and chert breccia and some limestone and siltstone. At least part of the chert is silicified limestone and silicified micro-coquinite; and much of the chert conglomerate and chert breccia probably represents a lag-product residually accumulated during the leaching of cherty carbonates. Similarly, any phosphate originally present in the limestone would have been residually concentrated and precipitated in the remaining silty matrix. It is noteworthy that the limestones and dolomites are often slightly phosphatic (though generally containing less than 1 percent P_2O_5), so that leaching of the carbonate could have led to appreciable concentration of phosphate.

From the evidence accumulated (see chapters on palaeo-environments, physiography, etc.) it seems clear that the palaeogeographical conditions during the lower Middle Cambrian generally involved:

(a) the presence of embayments, estuaries, lagoons, shallow flats studded with islands or submarine banks. A ria-type coast prevailed.

(b) a shallow water depth, probably less than 200 feet.

(c) clear water with a negligible supply of land-derived detritus.

(d) a good supply of nutrients derived from the adjoining land, and supporting an abundant fauna and flora.

(e) oscillations of the sea level leading to recurrent short periods of regression.

The genesis of the phosphate deposits in the Georgina Basin is discussed in some detail in another report (de Keyser, 1969 unpubl.), the conclusion reached being that the phosphorites are mainly biogenic replacement deposits formed in very shallow water in semi-enclosed basins, estuaries, etc. Enrichment of originally low-grade phosphatic sediments took place by means of reworking during sedimentation, followed in places by early-diagenetic concentration as a result of carbonate leaching, and later, occasionally, by residual concentration during short periods of regression. There is very little likelihood that upwelling currents have played a role in the formation of the phosphorites, as the palaeo-environment was not suitable: the seas were too shallow over too greatly extended areas. The Camooweal Dolomite, for instance, which occupies a very large area of the Barkly Tableland and has a considerable vertical range from lower Middle Cambrian to probably Upper Cambrian, was "...deposited on intertidal mud flats, in saline lagoons connected with the sea and possibly in shallow impermanent saline lakes not connected with the sea" (Brown, 1968, p. 22).

Finally, it is possible that penecontemporaneous as well as post-depositional submarine fumarolic exhalations may have contributed to some of the processes of silicification and the alteration of collophane to Al-Fe-phosphates, at least in the Duchess district (de Keyser, 1969 unpubl.).

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APPENDIX

LIST OF FOSSILS DETERMINED BY J. SHERGOLD

Locality

GP 116 — 10 miles east of Highland Plains homestead.

Peronopsis sp. undescribed.
Ptychagnostid of the Euagnostus opimus group.
Nepeid new genus
Dolichometopid undetermined.
Phosphatic brachiopod undetermined.

Age:- Middle Cambrian, late atavus Zone or younger but pre-punctuosus Zone.

GP 116A — Locality as GP 116, chert fragment.

Pagetia sp. indet.

Age:- Middle Cambrian, Zone uncertain.

GP 117A — 11 miles east of Highland Plains homestead

Diplagnostus sp.
Peronopsis sp. undescribed.
Ptychagnostid of Euagnostus opimus group.
Acrothele sp.

Age:- Middle Cambrian, late atavus Zone or younger but pre-punctuosus Zone.

GP 117B — Locality as GP 117A.

Xystridura sp.

Age:- Middle Cambrian, Xystridura fauna (?).

GP 117C — Locality as GP 117A.

Undetermined ptychoparioid trilobite, n. gen. (?)

Age:- Middle Cambrian, Zone uncertain.

GP 123 — 16 miles east of Highland Plains homestead.

Diplagnostus sp.
Peronopsis sp.
Ptychagnostid of the Euagnostus opimus group.

Age:- Middle Cambrian, late atavus or younger but pre-punctuosus Zone.

GP 125 16 miles east (east-south-east) of Highland Plains homestead.

Peronopsis sp. undescribed.
Diplagnostus sp.
Ptychagnostus ex gr, atavus
Dolichometopid new genus
Nepeid new genus
Phosphatic brachiopod undetermined.
Sponge spicules

Age:- Middle Cambrian, Zone of Ptychagnostus atavus.

GP 130 22 miles east (east-south-east) Highland Plains homestead.

Peronopsis sp.
Ptychoparioid trilobites undetermined., 2 undescribed genera.
Dolichometopid new genus
Tonkinella sp. undescribed.
Phosphatic brachiopod undetermined.

Age:- Middle Cambrian, possibly atavus Zone.

GP 132 24 miles east (east-south-east) Highland Plains homestead.

Ptychoparioid trilobite, gen. undescribed.

Age:- Middle Cambrian, Zone uncertain.

GP 133 28 miles east (east-south-east) Highland Plains homestead.

Pagetia sp.
Xystridura sp.
Redlichia sp.

Age:- Middle Cambrian, basal Xystridura fauna (?).

GP 149 14 miles at 239° from Lawn Hill homestead.

Xystridura sp indetermined.
Pagetia cf significans

Age:- Middle Cambrian, Xystridua fauna

GP 150 15 miles at 237° from Lawn Hill homestead.

Redlichia sp indeterminate
Ptychoparioid gen indeterminate

Age:- Middle Cambrian, Redlichia fauna

GP 151 17 miles at 237° from Lawn Hill homestead.

Ptychoparioid similar Lyriaspis sp.

Age:- Middle Cambrian, zone uncertian.

GP 152 — 17 miles at 236° from Lawn Hill homestead.

Dolichometopid new genus

Age:- Middle Cambrian, post-*gibbus* but pre-*punctuosus*

GP 161 — 15 miles at 202° from Lawn Hill homestead.

Nisusia sp.
Xystridura sp. nov.
Pagetia significans (?)

Age:- Middle Cambrian, *Xystridura* fauna (?)

GP 163 — 22 miles at 195° from Lawn Hill homestead.

Girvanella sp.

Age:- Middle Cambrian, *Redlichia* fauna (?)

GP 398 — 3.5 miles east of Highland Plains homestead.

Acrotreta sp.
Dolichometopid new genus
Nepeid new genus
Peronopsis sp.
Pagetia sp.

Age:- Middle Cambrian, post *atavus* pre *punctuosus*

GP 399 — 0.25 miles southeast of locality GP 398

Fuchouia sp.
Nepeid new genus
Lingulelloid brachiopod
Acrothele sp.

Age:- Middle Cambrian, *atavus* Zone (?) (based on the dolichometopid).

GP 403 — 3.75 miles east-south-east of Highland Plains homestead.

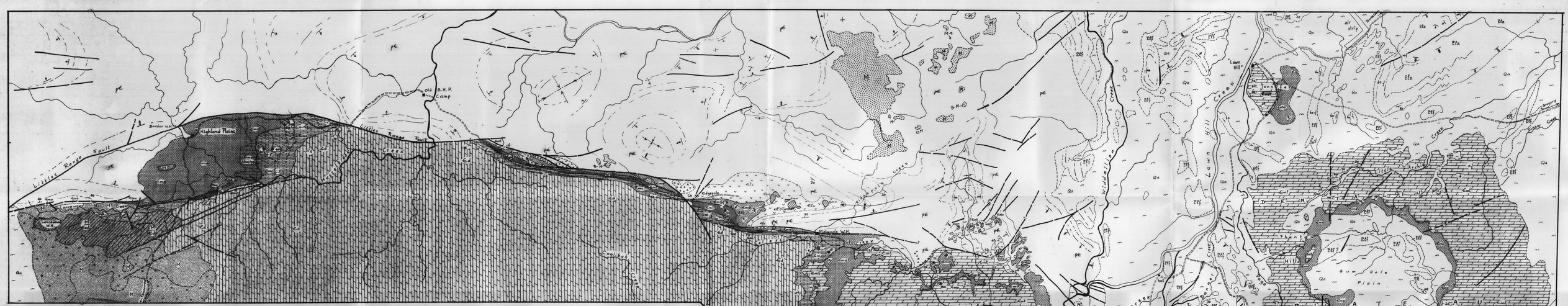
Fuchouia sp. (?)
Nepeid new genus
Pagetia sp.
Acrotreta sp.
Lingulelloid brachiopod
Sponge spicules

Age:- Middle Cambrian, post *atavus*, pre *punctuosus* (?)

GP 404 0.25 miles east of locality GP 403

Fuchouia sp.
Pagetia sp.
Peronopsis sp. (?)
Diplagnostus sp.
Euagnostus ex gr opimus (?)
Acrotreta sp.
Linguleiloid brachiopod
Acrothele sp.

Age:- Middle Cambrian, post atavus, pre punctuosus



Geology, 1968, by F de Keyser and R Thieme

CAINOZOIC
- Qa — Soil, black soil, alluvium, travertine
- Lateritized formations

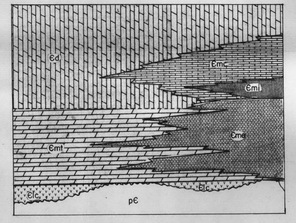
MESOZOIC
- Sandstone, conglomerate
- Mesozoic and Lancewood Shale
- Mesozoic and Camooweal Dolomite

MIDDLE CAMBRIAN
- Camooweal Dolomite: thin-bedded to massive dolomite
- Currant Bush Limestone: thin-bedded grey limestone with chert lenses and interbeds of marl, sandy and gritty dolomite, and rare dolomite
- Inca Formation: laminated silt-shale and chert
- Border Water Hole Formation: chert, siltstone, chert breccia, phosphorite
- Thorntona Limestone: thin-bedded to massive dolomite and dolomitic limestone

LOWER CAMBRIAN ?
- Gaiess Volcanics: vesicular basalt, some intermediate volcanics; lenses of quartzite

PRECAMBRIAN
- pE — Undifferentiated: sandstone, siltstone, iron ore, some conglomerate
- Dun — Constance Sandstone: sandstone, some conglomerate
- Elf — Lawn Hill Formation: impure sandstone, siltstone, folaite
- Etz — Roughed Mountain Beds: sandstone, quartzite, conglomerate, acid and basic volcanics

- dip and strike, measured
- horizontal beds
- tread lines
- dip and strike of beds, dip ≤15°
- dip and strike of beds, dip 15°–75°
- dip and strike of beds; dip >75°
- anticlinal fold axis, with plunge
- synclinal fold axis, with plunge
- fault (broken where approximate) with relative sense of displacement shown
- fossil locality with locality number
- mine
- track
- fence
- homestead "Lawn Hill"



RELATIONSHIP DIAGRAM OF THE CAMBRIAN UNITS
Horizontal lines are time lines, except at the basal unconformity

0 1 2 3 4 5 miles approx.
0 1 2 3 4 km

CALVERT HILLS	WEST MURPHY LAND	BURKETOWN
MT. DRUMMOND	LAWN HILL	DONOR'S HILL
RANKEN	CAMOOWEAL	DOBBYN

INDEX TO ADJOINING SHEETS

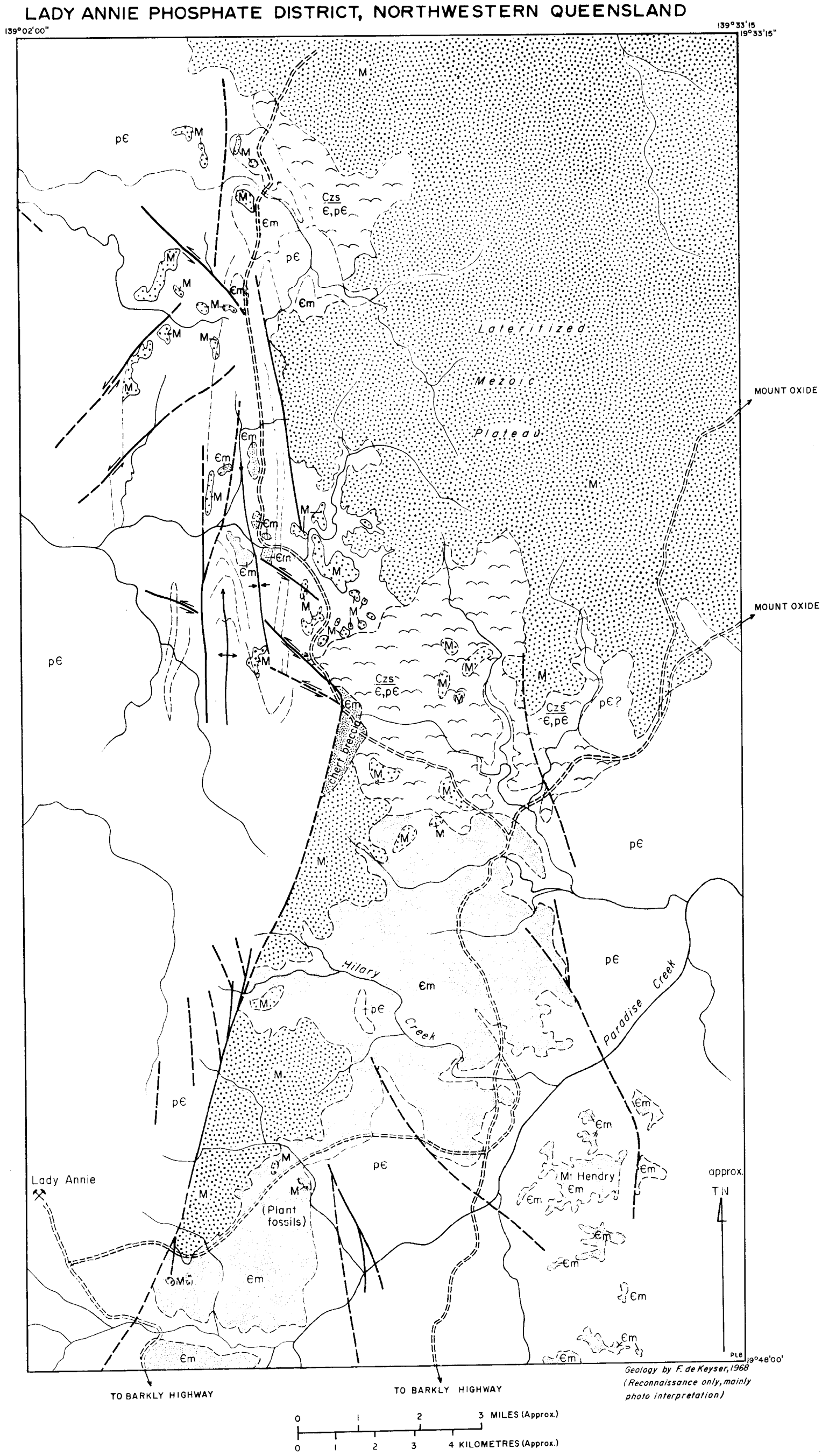
PLATE I. CAMBRIAN GEOLOGY OF THE BORDER WATER HOLE LAWN HILL AREA, NORTHWESTERN QUEENSLAND

To accompany Record 1969/147

E54/A9/28

CAMBRIAN RECONNAISSANCE GEOLOGY OF THE LADY ANNIE PHOSPHATE DISTRICT, NORTHWESTERN QUEENSLAND

PLATE 2



Geology by F. de Keyser, 1968
(Reconnaissance only, mainly photo interpretation)

Cainozoic	Czs	*Sand, derived from Mezoic sandstone*
Mesozoic	M	*Ferruginous sandstone, grit, white quartz sandstone, Subordinate conglomerate. Generally laterized*
Middle Cambrian (undifferentiated)	εm	*Inca Formation: laminated silt-shale and bedded chert* *Beetle Creek Formation: chert, siltstone, phosphorite* *Thorntonia Limestone: massive yellow-brown dolomite* *"Mount Hendry Formation**: *basal sandstone and conglomerate, commonly with dolomitic sandy matrix*
Precambrian	pε	*Undifferentiated dolomite, quartzite, siltstone and chert*

Fault, with direction of relative displacement

Anticline, showing plunge

Syncline showing plunge

==== *Track*

* *Unofficial formation name used by Broken Hill South Ltd*

To accompany Record 1969/147

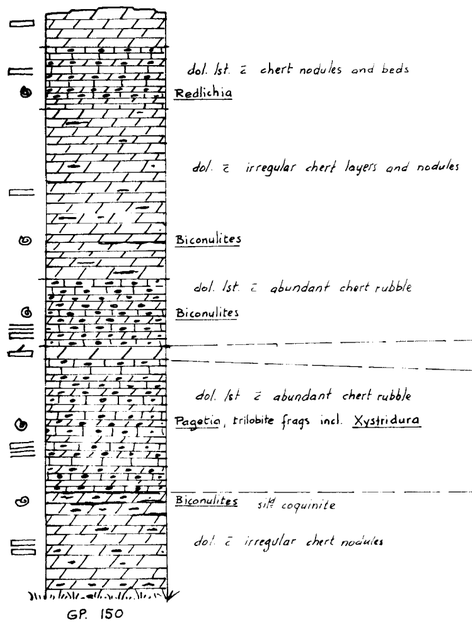
E53/A13/16

PLATE 3

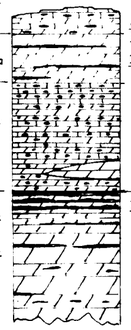
REFERENCE

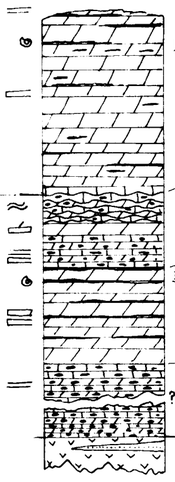
- dolomite
- dolomitic limestone
- chert nodules / irregular chert stringers
- silicified coquinite or dolomite
- basal dolomitic conglomeratic sandstone
- very thick-bedded (> 40 inches)
- thick-bedded (12–40 inches)
- medium-bedded (4–12 inches)
- thin-bedded (0.4–4 inches)
- cross-bedded
- undulate bedding
- slumping
- macro fossils

Vertical scale : 1 inch = 50 feet

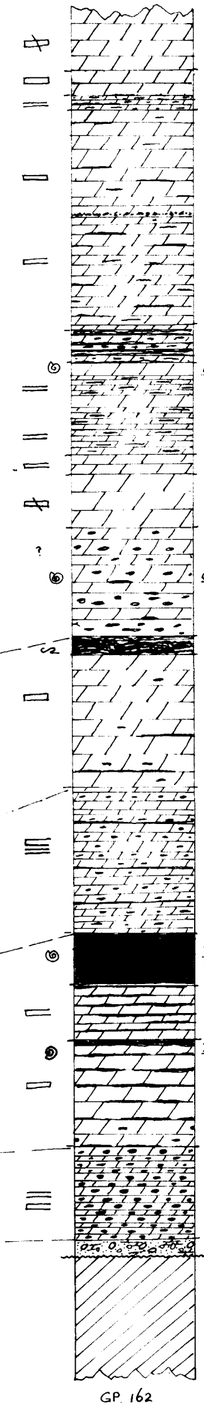


GP. 150





GP. 135



GP. 162

Outcrop Sections
LAWN HILL DISTRICT

to accompany Record 1969/147

E54/A9/29

PLATE 4

CAMBRIAN GEOLOGY
OF THE
THORNTONIA PHOSPHATE DISTRICT
NORTHWESTERN QUEENSLAND

0 1 2 3 4 miles (approx)

0 1 2 3 4 km

Geology, 1968, by F. de Keyser and R. Thieme

CAINOZOIC
- Qa — *Soil, black soil, alluvium*
- *Laterized rock*

JURASSIC
- J — *Sandstone*

MIDDLE CAMBRIAN
- Ɛmp — *Split Rock Sandstone: fine-grained sandstone, siltstone*
- Ɛmh — *Chummy Bore Formation: thin-bedded siltstone, dolomitic limestone, chert*
- Ɛmv — *V-Creek Limestone: thin-bedded calcilutite, silty calcilutite, marl, some chert*
- Ɛmc — *Currant Bush Limestone: thin to medium-bedded calcilutite with silty and marly interbeds*
- Ɛmi — *Inca Formation: laminated silt-shale fine-grained sandstone, bedded chert*
- Ɛme — *Beetle Creek Formation: chert, siltstone, silicified coquinite, phosphorite*
  Basal breccia member
- Ɛmt — *Thorntonia Limestone: thin-bedded to massive dolomite, dolomitic limestone*

PRECAMBRIAN
- pƐ — *Undifferentiated chert, dolomite, quartzite, siltstone*

dip and strike of bedding

airphoto interpretation:
- *horizontal bedding*
- *trend lines*
- *joint pattern*
- *strike and dip of bedding, dip < 15°*
- *ibid, dip 15°–75°*
- *ibid, dip > 75°*
- *anticlinal axis showing plunge*
- *synclinal axis showing plunge*

fault; broken where approximate

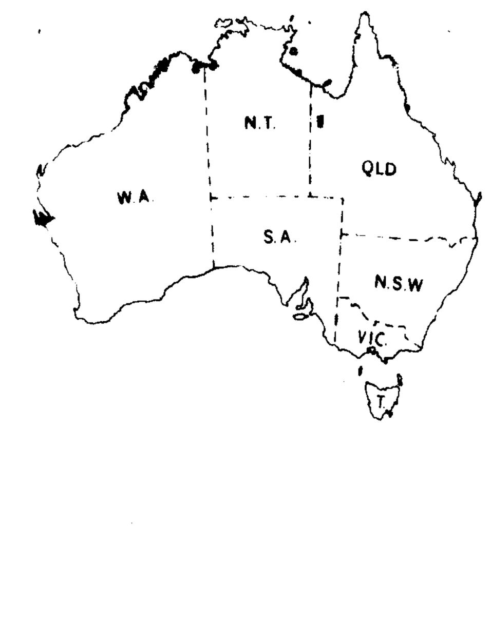
fossil locality with locality number (252)

mine

water bore

track

homestead ("Thorntonia")



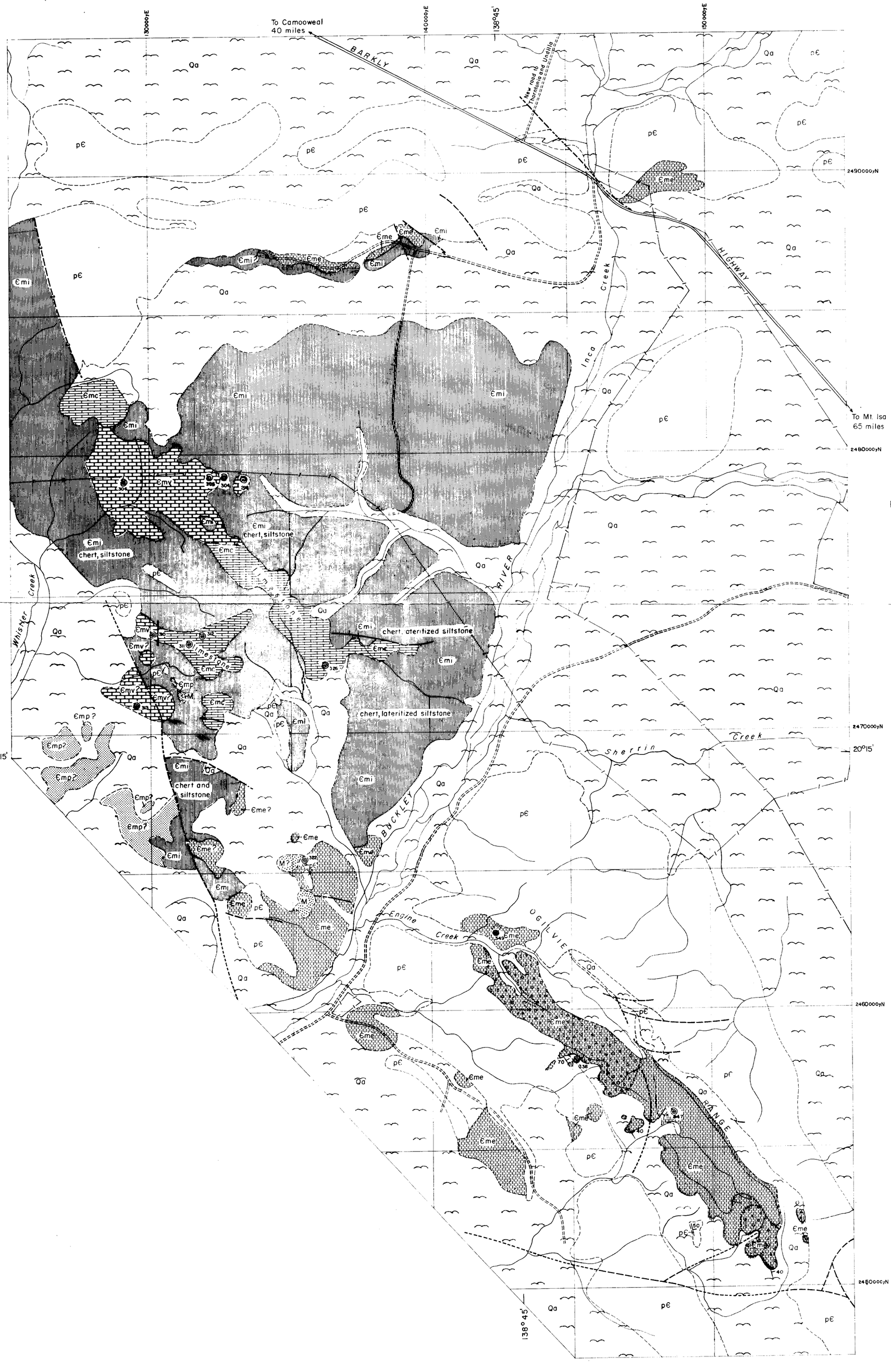
To accompany Record 1969/147

E54/A13/17

PLATE 5

CAMBRIAN GEOLOGY IN THE AREA WEST OF YELVERTOFT, NORTHWESTERN QUEENSLAND

Geology by R. Thieme, 1968
(Mainly airphoto interpretation with check-traverses)



CAINOZOIC
- Qa — Soil, alluvium
- Qa — Laterized rock

MESOZOIC
- M — Quartz sandstone, silicified chert breccia

MIDDLE CAMBRIAN
- Emp — Split Rock Sandstone: sandstone (interitized)
- Emv — V-Creek Limestone: grey thin-bedded limestone
- Emc — Currant Bush Limestone: grey thin-bedded limestone
- Emi — Inca Formation: silt-shale, chert
- Eme — Beetle Creek Formation: chert, siltstone, silicified coquinite; Basal sandstone and conglomerate member

PRECAMBRIAN
- pε — Precambrian, undifferentiated: quartzite, siltstone

- 70 — Strike and dip of bedding
- Fault, inferred
- 305 — Fossil locality with locality number
- Water bore
- Fence

0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

LOCALITY MAP

To accompany Record 1969/147

F54/A1/1