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The Cambrian of the Burke River Outlier

by

F. de Keyser

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SUMMARY

The discovery in 1966, by Broken Hill South Ltd, of extensive marine phosphorite deposits in the Cambrian of the Burke River Outlier presented a good opportunity to initiate a long-term programme of research in the geological and environmental characteristics of a major marine phosphogenic province.

This progress report summarizes the results of four months of biostratigraphic mapping of the Burke River Outlier, a small depositional basin roughly 60 miles long by 20 miles wide, which forms an appendix to the main body of the Georgina Basin, and is bounded by faults. The survey was carried out from 12th May to 25th September, 1967, by a combined field party of the Bureau of Mineral Resources and the Geological Survey of Queensland, and the work was assisted by about 2000 feet of stratigraphic scout drilling.

Most of the Cambrian formations in the outlier are restricted to the area contained within the faulted margins of the basin, but a few transgressed beyond the boundary faults.

Perhaps as far back as the Late Upper Proterozoic, the Burke River basin was formed by subsidence in the Precambrian basement, with hinge lines developing along fundamental zones of weakness which became the loci of recurrent episodes of faulting lasting up to Cainozoic times.

The oldest deposits may have been of glacial origin, and were followed by various Lower Cambrian arenite and lutite deposits. They are unconformably overlain by early Middle Cambrian Thorntonia Limestone or its cherty equivalents, which were spread out over the whole area. After a temporary regression, a widespread Middle to Upper Cambrian transgression proceeding from south to north was followed by a general Upper Cambrian regression. The basal lithological units of the transgressive series comprise siltstone, siliceous shale, and some chert; they are followed by calcilutites and marls, and are finally topped by a regressive siltstone series. Time planes transect the lithological boundaries, and the established formations are in reality biostratigraphic units.

The Cambrian deposits were later covered by a regional blanket of Cretaceous conglomerate, sandstone, and siltstone, which has been mostly removed during subsequent erosion. Residuals of Tertiary lake deposits are also known.

The phosphorites occur in the basal part (Beetle Creek Formation) of the transgressive series. The geological conditions were favourable for the development of phosphatic carbonate bank deposits, and it is concluded that phosphatization was brought about by replacement of calcareous matter, not by direct precipitation as postulated by most of the present generation of geologists. Enrichment and concentration of the originally low-grade beds by various processes led to the formation of medium and high-grade phosphorites.

INTRODUCTION

Location and access (Fig. 1). The Burke River Outlier (Opik, 1961) is situated in the Duchess district in north-western Queensland, and is

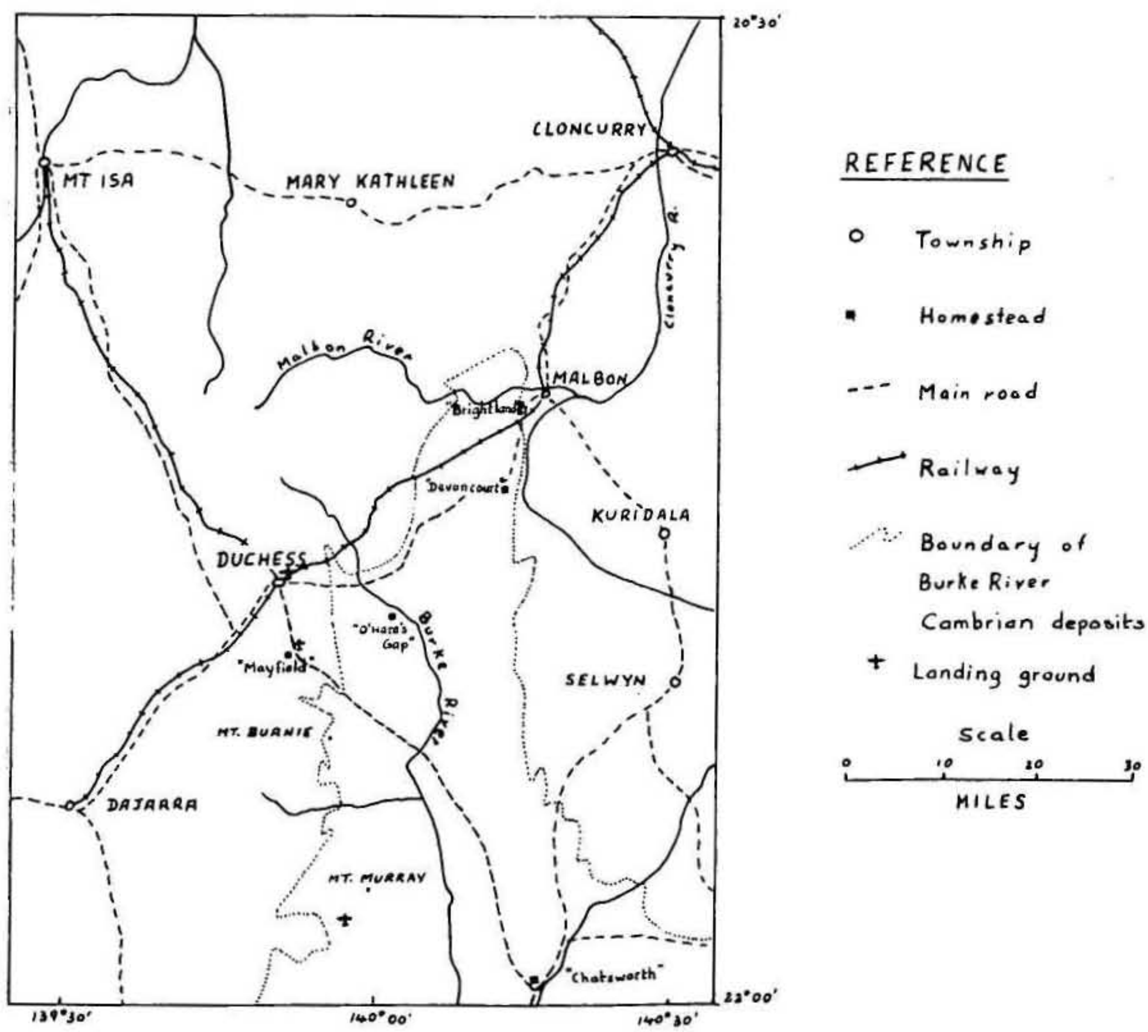

FIGURE 1 — Locality map, Burke River Outlier

contained roughly between latitudes 21°00'S. - 22°00'S., and longitudes 139°55'E. - 140°20'E. Duchess can be reached from Mount Isa (the nearest city of importance) by road (63 miles), by railway, and by charter plane.

The area of the outlier is about 1400 square miles. It is transected in the north by the Duchess - Cloncurry road, and by the Duchess - Chatsworth - Boulia road diagonally across the centre. Both roads are dirt tracks requiring annual grading; they are impassable during heavy rains, and stretches of the Duchess - Cloncurry road deteriorate to tracts of thick bull dust where they are underlain by Cambrian limestone-marl rock formations. The single-track Duchess - Cloncurry railway line passes through the northernmost section of the area. Landing grounds suitable to take small aircraft exist at Duchess and at Mayfield, Devoncourt and Brightlands Homesteads; Broken Hill South Ltd have constructed an additional landing strip at Galah Bore, north of their base camp.

Purpose and scope. The discovery in 1966, by Mines Exploration Pty Ltd (a subsidiary exploration company of Broken Hill South Ltd), of large phosphate deposits in the Cambrian of the Burke River Outlier presented a good opportunity to initiate a long-term programme of research in the geological and environmental aspects of a major marine phosphogenic province, by the newly-established Phosphate Group of the Bureau of Mineral Resources. To that purpose, a combined field party of the Bureau and the Geological Survey of Queensland spent 4½ months in the area, from 12th May to 25th September, 1967. Its main aim was the biostratigraphic mapping of the Cambrian formations, to be assisted by a limited amount of stratigraphic scout drilling. The results of this and subsequent investigations, together with data supplied by the exploration and mining companies and laboratory studies, are expected to lead to a more accurate appreciation of the palaeogeography and palaeo-environment, and to a better understanding of the phosphate genesis, in the Georgina Basin. There is also the hope that the results may throw fresh light on the genesis and deposition of marine phosphorite and provide criteria which will be of value in the search for phosphorites elsewhere.

Method of field investigation. The geological staff of the combined field party consisted of F. de Keyser (party leader), J. Shergold (palaeontologist), C.G. Gatehouse (palaeontologist, April-May), R. Thieme (geologist, from 5th August), and C. Murray (geologist, Geological Survey of Queensland, from 8th July).

The area had been previously mapped on a regional basis by A.A. Opik (1961), but was now mapped in greater detail, with the use of air-phtographs at scale 1:48,000. Much time was also devoted to the collecting of fossils. Attention was directed mainly towards the areas outside the known phosphorite belt, as the latter was already being mapped in great detail by Mines Exploration Pty Ltd in conjunction with an intensive drilling programme. However, frequent visits were paid to the company area, and the company geologists co-operated fully in showing the visiting government geologists over areas of geological interest.

A limited amount of stratigraphic scout drilling was carried out from 24th July to 30th August, using a BMR Mayhew 1000 drill rig.

Visitors. Visitors to the party during the field season included N.H. Fisher, H.A. Jones, J.N. Casey, P.J. Jones, and E. Druce (BMR), W.D. Smith and H. van den Heuvel (M.I.M.), G. Tweedale and D. Wyatt (Geol. Surv. Qld), P. Howard and J. Barrie (I.M.C. Dev. Corp.), P.W. Pritchard (Sydney University), and P. Cook (BMR/U.S.G.S.).

Previous investigations. Summaries of previous geological investigations and history of exploration are given by Carter and Opik (1963) and Opik (1961).

The area was first traversed by Robert O'Hara Burke in 1860. Most of the ensuing geological and prospecting interest was focused on the Precambrian basement rocks because of the signs of mineralization found in them. The limits of the Burke River Outlier were first mapped by Honman (1937), but the Mount Birnie Beds were then considered to be Precambrian. The limestones in the outlier were grouped together as the "Georgina Limestones", to which a Middle Cambrian age was ascribed by Whitehouse (1931, 1936) after examination of fossils obtained from a locality now known to consist of Devoncourt Limestone.

Systematic work on the Burke River Outlier was first carried out by A.A. Opik (1956, 1960, 1961), and the results were summarized in the explanatory Notes to the Duchess area (Carter and Opik, 1963).

Commercial interest in the area rose when, in the wake of the increasing demand for fertilizer raw materials, lithologically promising sequences in the Cambrian of the north eastern part of the Georgina Basin were recognized by the BMR and abnormally high phosphate values were detected in the Thorntonia Limestone in the Morstone bore near Undilla. Broken Hill South Ltd made a systematic examination of the oil-well samples, and confirmed that phosphatization was widespread in the Beetle Creek and Thorntonia Limestone. Particularly high concentrations were noted in the Beetle Creek equivalent in the Black Mountain bore to the south of the Burke River Outlier. This information, combined with regional palaeogeographic considerations, influenced the company in their selection of the Burke River Outlier, where Beetle Creek was shown to outcrop in the published BMR 4-mile geological map, as the first target for field exploration (Russell, 1967). The almost immediate discovery of phosphorite outcrops subsequently made in the field put the crown on a geologically well-reasoned and systematic exploration programme.

By the end of 1967, more than 210 drill holes had indicated large reserves of rock phosphate concentrated in three main sections: "Rimmer Hill", Mount Murray, and "Phosphate Hill" (Fig. 40), and feasibility studies were being undertaken. Further drilling and evaluation is in progress.

Climate and physiography. The Burke River Outlier lies in the semi-arid climatic zone, receiving almost all of its rain during the hot summer half year, while the winter half year is known as the dry season. The mean monthly rainfall figures for the Duchess and Chatsworth recording stations are shown below.

Duchess (Upper Western Rainfall District)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Totals
1.	331	357	196	74	79	58	44	9	22	79	97	212	15.58
2.	294	392	252	76	105	80	48	13	23	72	85	102	16.32
3.	4	5	3	1	1	1	1	0	1	2	2	3	24

Chatsworth

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Totals
1.	239	292	162	54	60	52	43	12	25	72	63	170	12.44
2.	217	345	185	71	71	67	53	15	20	68	61	161	13.34
3.	3	5	3	1	1	1	1	1	1	2	2	3	24

1. = long period average rainfall 1914-1964

2. = standard period 1931-1960 rainfall

3. = standard period 1931-1960 rain days

The mean maximum temperature for the month of January is around 100°F, and the mean minimum temperature in the vicinity of 75°; for the month of July these temperatures are approximately 75° and 47° respectively. There are usually a few frosty nights each winter.

The fairly consistent south to south-easterly trade wind blowing during the winter season gives way in the summer to more variable winds.

The Burke River Outlier represents a fault-bounded sunken block underlain by Cambrian strata which, at the western and northern margins of the outlier, are tilted as a result of faulting, forming cuestas, hogbacks, and hilly outcrops up to a few hundred feet above the adjoining plains. Most of the outlier is occupied by prairie lands of the flat alluvial Burke River Plain, by incised plateaux and mesas of Upper Cambrian O'Hara Shale, and by flat pediments merging with the Burke River Plain.

The general level of the outlier falls from about 1100 feet in the north-western corner, to 900 feet in the north-east, and to 800 feet in the extreme south. The relief is low, the highest points being Mount Birnie and Mount Aplin (altitude 1500 feet above sea level) which both rise 400 to 500 feet above the adjoining plain. Surrounding the Burke River Outlier are the Precambrian ranges and hills with their more rugged and varied relief.

All streams are intermittent. A major water divide (the Selwyn Divide) between O'Haras Gap and Devoncourt Station separates the Gulf of Carpentaria drainage system (represented by the Cloncurry River and tributaries) from the Lake Eyre drainage system (represented by the Burke River).

The vegetation of the outlier consists mainly of tree-less tussock grassland on the Burke River Plain, and open scrubby woodland on the pediments and hills. Spinifex is very common and abundant on the O'Hara Shale plateaux and over parts of the limestone areas; most of the limestone country, however, is characterized by dense "turpentine bush". Phosphorite areas are generally characterized by a grass cover and by a scarcity of trees.

The geomorphology of the headwaters of the Burke River has been discussed by Opik (1961), who described seven morphological divisions in the region, representing three geomorphological and structural classificatory units - depositional plain, plateaux and subhorizontal rocks, and surfaces on deformed or tilted material, including the Devoncourt pediment. The depositional plain (Burke River Plain) is an aggradational, late-Cainozoic surface which is being rejuvenated at its head as a result of the Cainozoic Selwyn Range Uplift. The Devoncourt pediment is an erosional surface truncating the limestone beds, and is pre-Recent but post-Mesozoic. The O'Hara Shale plateaux are remnants of the oldest and topographically the highest erosional surface, of pre-Cretaceous age.

STRATIGRAPHY

Introduction. The Burke River Outlier is a small, meridional basin 60 miles long and 20 miles wide, which forms a south-eastern appendix to the main body of the Georgina Basin. The outlier is bounded by fault systems along its western and northern margins, and to some extent along its eastern border. These fault systems roughly coincide with the original depositional margins, and recurrent movements have taken place along them since the early Cambrian or perhaps even the Upper Proterozoic, and probably until late-Cainozoic times.

The sediments preserved in the outlier are mainly of early to late Cambrian age, and are overlain by Ordovician formations towards the south. Small remnants of a Mesozoic cover are found in places along the margins of the outlier, and Tertiary sediments are exposed in central parts of the Burke River Plain.

Outcrops are mostly found along the margins of the outlier (where the strata are tilted), on the pediments, and in the incised mesas and plateaux. However, the mesas and plateaux are affected by lateritization which commonly camouflages the original composition and structure, and the exposures on the pediments are generally rubbly and confined to competent limestone beds. Relatively fresh, unaltered rocks are found only among the limestone formations.

The measurement of stratigraphic sections is generally impossible because of the low relief and the sub-horizontal bedding; the only satisfactory sections obtained were situated along the margins of the outlier in Mount Birnie Beds (Plate 1).

The Cambrian rocks were subdivided by Opik (1960, 1961, and in Carter and Opik, 1963) into units that are defined by specific fossil assemblages. They are therefore biostratigraphic units, but not, in most cases, lithostratigraphic formations which, in accordance with the Stratigraphic Code, must have definite lithologic composition or succession, must permit observable lithologic separation from adjacent units above and below, and must be traceable from locality to locality. These qualifications are not met by the existing divisions. However, no attempt is made in this report to introduce formal formation names, as the existing unit names are well established and are familiar to all workers on Cambrian stratigraphy. Suffice to say that, over most of the Burke River Outlier, the Cambrian succession above the Thorntonia Limestone can be subdivided in a lower siltstone facies, a middle limestone facies, and an upper siltstone facies. The units composing the lower siltstone magnafacies are not, as a rule, mutually distinguishable, and neither are the various units of the limestone magnafacies. The relationship between these facies units and Opik's biostratigraphic units is shown in Figure 23 (page); most of Opik's subdivisions can be considered as parvafacies units representing portions of one of the three magnafacies units present.

In the following description of the various units, the Mount Birnie Beds are treated in some detail, as they were very little known prior to the survey. The Middle and Upper Cambrian units, however, have been adequately described by Opik (1961), and reference is made to his work and stratigraphic table.

Precambrian. As the Precambrian fell outside the scope of the survey, no attempt was made to map its formations and structure. Details on its geology can be found in Carter, Brooks, and Walker (1961) and in Carter and Opik (1963).

The rocks surrounding the Burke River Outlier belong to half a dozen different Precambrian formations intruded by various granites and dolerite sills. They include acid lava, schist, slate, quartzite, calc-silicate rock and breccia, amphibolite, metabasalt, limestone, dolomite, and conglomerate, and they are strongly folded and faulted. Copper-lead-zinc mineralization is common, and the Precambrian zone adjacent to, and west of, the Burke River Outlier was at the time of the survey actively being prospected and drilled for copper deposits by Longreach Minerals Pty Ltd. A few waterworn pebbles of malachite derived from the Precambrian were found in a creek east of Mount Aplin.

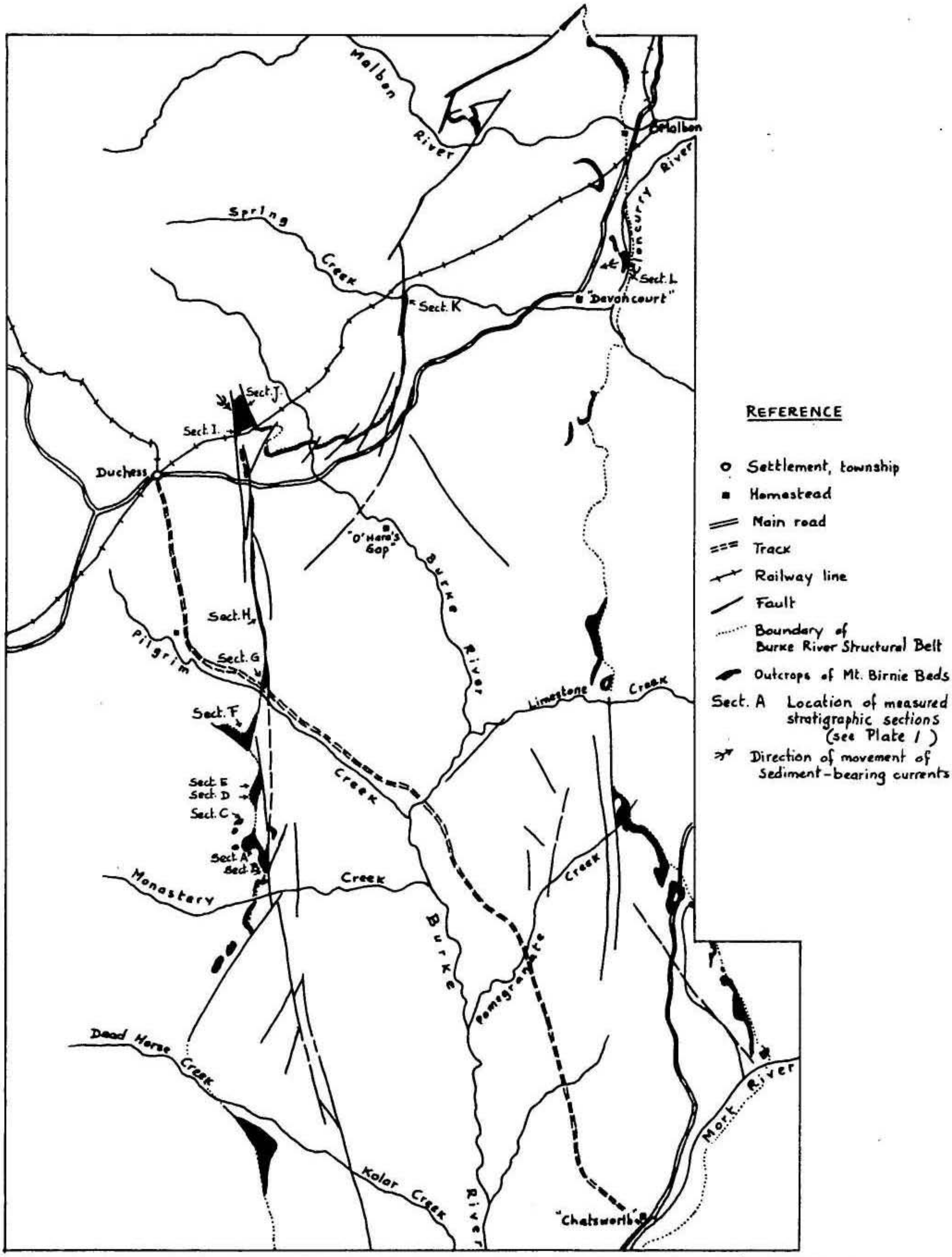

FIGURE 2 - Distribution of Mount Birnie Beds, and location of stratigraphic sections.

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Figure 3: Tilloid, Mount Birnie Beds. Creek outcrop, 6 miles east-north-east of Duchess.

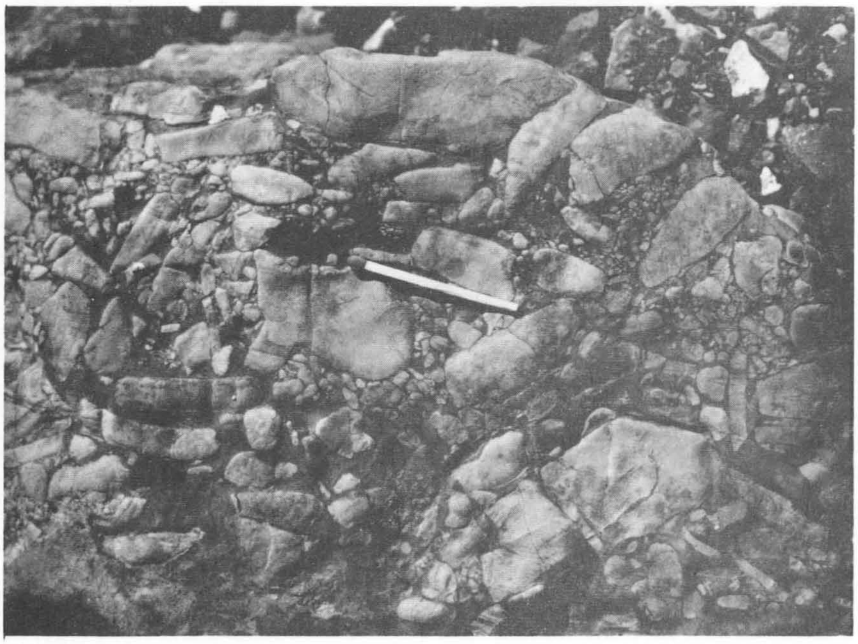

Figure 4: Intraformational conglomerate in dolomite, Mount Birnie Beds, 6 miles east-north-east of Duchess.

Lower Cambrian. The Lower Cambrian is thought by Opik to be represented by the Mount Birnie Beds, whose outcrop distribution, as shown in Figure 2, is along the margin of the Burke River Outlier. Strong lateral variations in lithology and thickness are apparent in the stratigraphic sections (Plate 1), and it is highly likely that the Mount Birnie Beds are composed of formations of different age, possibly including Proterozoic. The greatest thickness of Mount Birnie Beds was measured in the area 6 miles east-north-east of Duchess. Farther south thicknesses vary greatly, and the Mount Birnie Beds may even be completely absent, but this is mainly due to shearing-out along the Pilgrim Fault. Along the eastern margin of the Burke River Outlier, where faulting has not disturbed the beds greatly, the thickness is fairly consistent and varies from 40 to 60 feet.

(1) Western Margin of the Burke River Outlier

Tilloid member. The oldest unit observed is here described as a "tilloid" in the sense advocated by Harland et al. (1966), i.e., a diamict deposit with tilloid texture but of unknown or doubtful origin. The unit is an unsorted, unstratified and massive deposit of boulder clay, consisting of a red-brown structureless silty mudstone with polymictic fragments, pebbles, and boulders of granite and various metamorphic rocks derived from the Precambrian basement (Fig. 3). The pebbles and boulders range upwards to over a foot in diameter, are rounded to sub-angular, and appear to be quite fresh and unaltered. They have no preferred orientation - in fact, some boulders lie with their longer axes vertical - and commonly have a polished appearance or lustre not due to desert varnish. The thickest and most consistent exposures of the tilloid are found in the north-western corner of the outlier, 6 miles east-north-east of Duchess, where at least 65 feet are present in a creek bed without the base being exposed (Plate 1, Section J). To the south and east, outcrops are scarce and small, but tilloid was recognized along the Pilgrim Fault about 5 miles south of the railway line, and Opik describes a "regolithic purple clay with granite fragments found south-west of Roaring Bore" which possibly represents the easternmost outcrop of tilloid.

The origin of the tilloid is doubtful. The unit may be a massive subaqueous slide deposit, which was triggered off by fault movements or subsidence in this part of the Burke River Outlier. However, a glacial origin is now being favoured. Although positive proof, in the form of striated boulders and striated and polished bedrock, is lacking, the following points are considered suggestive for a glacial origin; the great variety in composition of the pebbles and boulders, and their freshness and somewhat polished appearance; the lack of sorting, grading, and preferred orientation; the thickness of the unit, uninterrupted by bedding structure; and, above all, the remarkable resemblance of the lower Mount Birnie Bed sequence (tilloid - dolomite - ferruginous sandstone - green and red banded shale - thin-bedded sandstone and siltstone) to a similar sequence in the late Upper Proterozoic Duerdin Group in the Kimberley region of Western Australia (Dow, 1965), where the tilloid is recognized as a true tillite (Moonlight Valley Tillite) overlain by a pink or cream dolomite, ferruginous sandstone, green and red banded shale, and thin-bedded quartz sandstone and siltstone (Ranford Formation). There appears also to be some resemblance with the Adelaidean Field River Beds, 180 miles south-west of Duchess (K.G. Smith, pers. comm.), for which a glacial environment has also been contemplated.

If the Mount Birnie tilloid can be proved to be of glacial origin, its age cannot be Lower Cambrian, but would probably be Upper Proterozoic.

Dolomite member. The tilloid is overlain by dolomite, usually pink, less commonly cream coloured. The dolomite has a wider, but laterally much interrupted distribution from north, near Duchess, south to Mount Aplin and beyond. It rapidly disappears to the east. In the tilloid region (Plate 1, Section J) the lower 10 to 15 feet of the dolomite are thin-bedded ($\frac{1}{2}$ inch to $1\frac{1}{2}$ inch beds), and are followed by 30 to 35 feet of medium-bedded (6 inches to 1 foot) dolomite with an intraformational conglomerate at its base (Fig. 4). Locally in this area the dolomite appears to grade laterally into a very thin-bedded sequence of marly dolomite, siltstone, and cherty beds. Elsewhere, beyond the tilloid area, the dolomite seems to form the base of the Mount Birnie Beds, but it is feasible that any pre-existing tilloid may have been sheared out by movement along the Pilgrim Fault.

On weathered surfaces, the dolomite may show indications of cross-bedding (from western directions ?), cut-and-fill structures, and some local intraformational conglomerate.

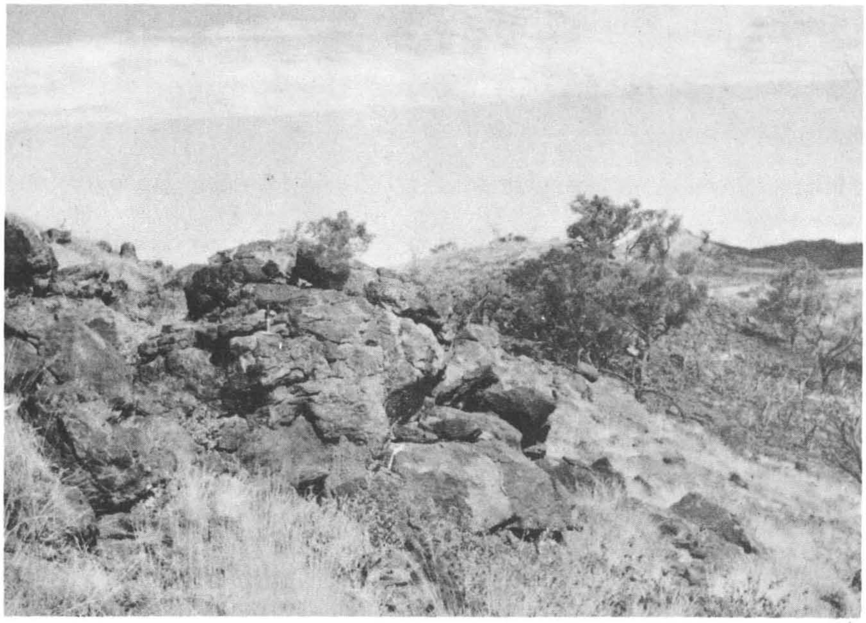

Figure 5: Massive red ferruginous sandstone.
Mount Birnie Beds, Mount Birnie.

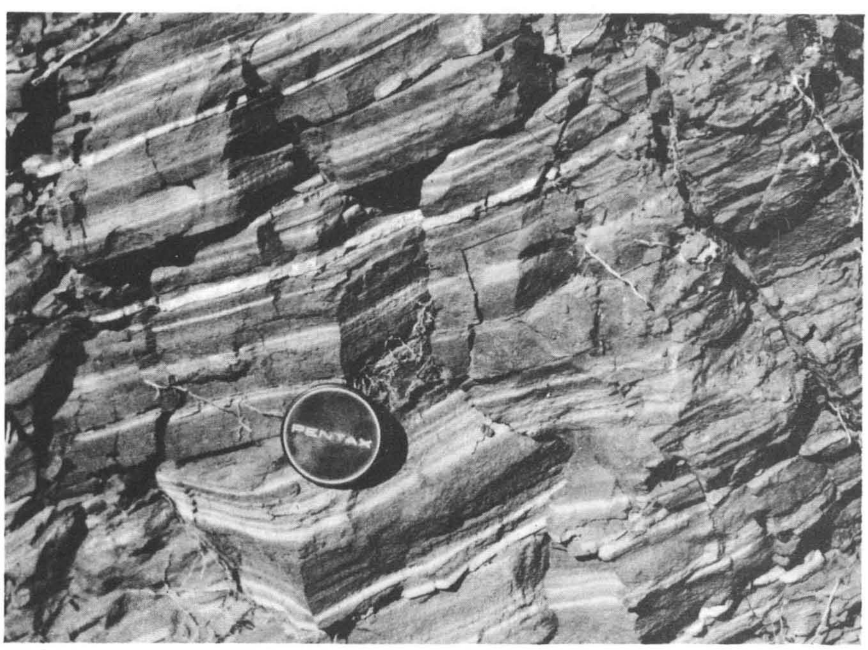

Figure 6: Red and green shale, Mount Birnie Beds.
Creek outcrop, 6 miles east-north-east
of Duchess.

Sandstone member. The dolomite is in turn overlain by massive, dark red-brown ferruginous sandstone (Fig. 5) in which bedding is difficult to detect. Its optimum development of 120 feet is at Mount Birnie, which derives its sombre hue from this dark red-brown sandstone. The sandstone shows rapid and strong lateral variations in thickness and intergradations of bedded silty sandstone and shaly sandstone. In the tilloid region, it is only 10 to 15 feet thick, and grades upwards into flaggy or platy shaly sandstone followed by red and green banded shale.

A thin section of the rock shows the sandstone to be composed mainly of quartz (up to 1.0 mm across) and a few other detrital grains (less than 10 percent of the rock volume) including chert, plagioclase, orthoclase, quartzite and other metamorphic rock fragments, mica flakes, and rare green hornblende, set in abundant limonite cement.

The massive sandstone forms the base of, and also occurs as tongues in, a widely varying ferruginous complex of thick and thin-bedded sandstone, silty sandstone, sandy micaceous shale, red and green fissile micaceous shale, and sandy siltstone. Lateral and vertical intergradations are commonplace, and detailed sections show rapid lateral variations in lithological sequences. In the tilloid region, the red and green banded shale (Fig. 6) is a major unit with a thickness of about 250 feet, and with a few intercalated tongues of sandstone 6 to 12 inches thick. The shale is strongly fissile, crumbling to small fragments in weathered outcrops. It is normally red-brown, but contains greenish-grey bands and laminae probably as a result of reduction; green-grey discolourations also occur along cracks and joints traversing the red rock. In the same area, the shale unit is overlain by about 250 feet of thin-bedded micaceous silty sandstone and sandy siltstone, in which some bedding structures are present, including ripplemarks, cross-bedding, and rib-and-furrow markings. The bedding commonly is uneven, undulating or wavy.

Towards the south, the separation between the shale unit and the silty sandstone unit becomes less distinct, and intercalations of one into the other may occur. Lenses of pink arkose or feldspathic sandstone are also present.

<u>Orthoquartzite member</u>. The ferruginous massive sandstone - red and green shale - micaceous silty sandstone complex is overlain by a 50-foot orthoquartzite - conglomerate unit in the Mount Birnie area. The base of the unit is a quartz pebble conglomerate usually about one foot thick with rounded quartz pebbles up to 3 inches long (Figs. 7, 8). Other lithologies are extremely rare among the pebbles, but a few pink feldspar fragments were noted. The conglomerate is overlain by medium- to thick-bedded medium-grained quartzitic sandstone, composed of recrystallized quartz grains and a little feldspar and rare rock fragments in very little matrix. The sandstone is usually white or light grey, but is in places iron-stained, especially in the upper part of the unit. Cross-bedding is very common (Fig. 7), but the indicated directions of sediment transport are inconsistent and vary even in a single outcrop. Ripple marks are also common, including wave, flow, and interference ripples, and the upper surface of some sandstone beds is characterized by an abundance of worm tracks (Fig. 9).

The conglomerate-orthoquartzite unit can be traced from south-west of the Bundy Bore to Mount Aplin. North-west of Bundy Bore, a 5-foot interval of thin-bedded yellow-brown poorly sorted gritty sandstone with some pebbles perhaps represents the northernmost vestige of the unit.

<u>Massive mudstone member</u>. The top unit of the Mount Birnie Beds is everywhere represented by a massive silty mudstone 10 to 60 feet thick. The mudstone is generally red-brown, with an ochre yellow or even white upper part. When indurated, it has a conchoidal fracture. In places the mudstone unit strongly resembles basal Middle Cambrian mudstone situated above silicified Thorntonia Limestone.

(2) Eastern margin of the Burke River Outlier

The above description of the Mount Birnie Beds applies only to the western margin of the Burke River Outlier. Along the eastern margin the section is different, and neither the tilloid nor the basal dolomite are any longer represented. In the north-east (Plate 1, Section K), the sequence starts off with a fine conglomeratic arkose derived from the underlying Precambrian granite; it is poorly sorted, with pebbles and fragments of feldspar, pink granite, and some quartz up to three quarters of an inch across. This is overlain by a few feet of medium-bedded arkose.

Figure 7: Cross-bedded orthoquartzite overlying quartz pebble conglomerate. Mount Birnie Beds, Mount Birnie.

Figure 8: Quartz pebble conglomerate, bedding view. Mount Birnie Beds, south-west of Bundy Bore.

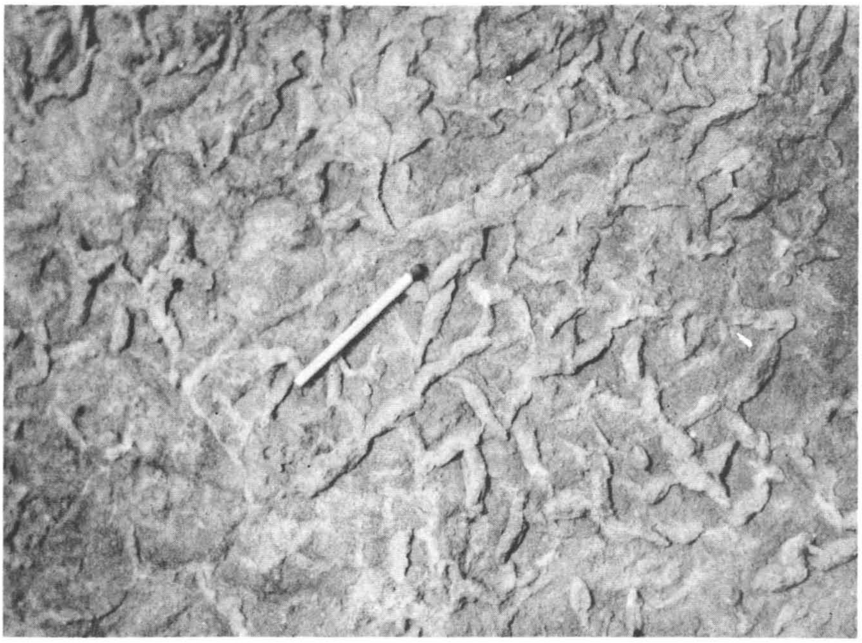

Figure 9: Worm tracks on bedding surface of quartzitic sandstone. Mount Birnie Beds, Mount Birnie.

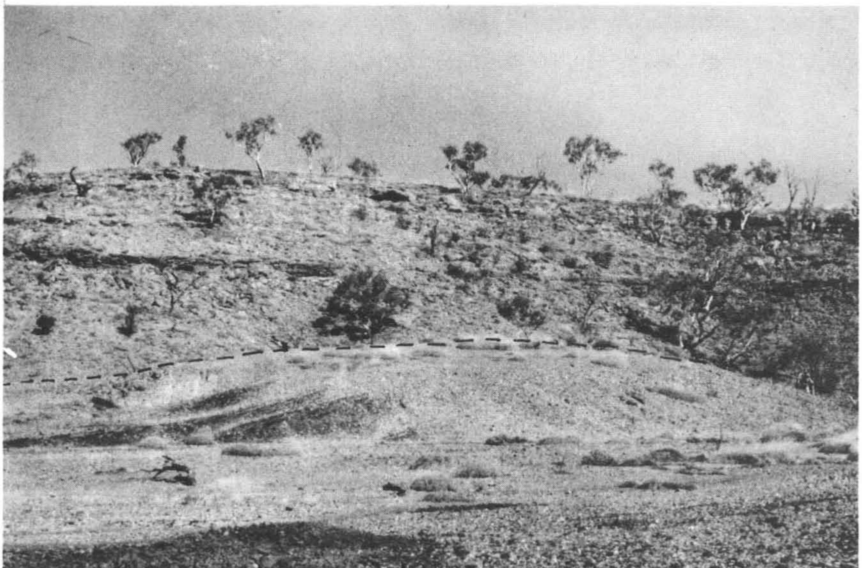

Figure 10: Horizontal Mesozoic sandstone and conglomerate unconformably overlying Mount Birnie Beds. Mesa south of Dead Horse Creek.

Cross-bedding and ripplemarks are common in some of the beds. The arkose is overlain by red ferruginous micaceous coarse- and fine-grained siltstone and sandy siltstone which probably is the equivalent of the ferruginous sandstone-siltstone-shale complex of the western margin. The complex contains lenses of creamy dolomite a few feet thick and several yards long. The top of the sequence is, again, formed by the ubiquitous silty massive mudstone, capped by about 2 feet of a hard ferruginous crust which probably represents a fossil soil.

In the south-eastern area between Limestone Creek and Mistake Creek, the Mount Birnie Beds are represented by a few feet of pink quartzitic arkose containing ripplemarks, which is again overlain by the massive mudstone, here about 40 to 50 feet thick.

Age of the Mount Birnie Beds. It is possible, and quite likely, that the rock units collectively grouped as the Mount Birnie Beds represent separate formations of different age.

As explained above, the tilloid unit may be a glacial deposit of late Upper Proterozoic age. The overlying ferruginous sandstone-shale-siltstone complex, characterized by its red colours and in places by small lenses of dolomite, could be a correlate of the Adelaidean Field River Beds (Smith, 1967). The conglomerate-orthoquartzite unit is clearly and sharply separable from the underlying complex, and represents deposition at a distinctly later stage: note, for example, that whereas the orthoquartzite is preserved in the mesas to the west of the Pilgrim Fault, the ferruginous sandstone complex is completely lacking there. Fossils recorded by Opik (1960), such as Diplocraterion and Crossochorda, are probably associated with the orthoquartzite unit. There is some resemblance to the Grant Bluff Formation from the Huckitta, Hay River, and Tobermory Sheet areas (e.g., abundant worm trails), and the age of the orthoquartzite therefore may well be Lower Cambrian. Finally, the widely distributed massive mudstone unit at the top of the sequence is yet another distinct unit, and its Lower Cambrian age is by inference fairly certain.

Palaeo-environment. The various units in the Mount Birnie Beds are each associated with distinctly different palaeo-environments.

The tilloid may be a genuine tillite, or else a thick subaqueous slide filling a depression formed by local subsidence along the Pilgrim and Roaring Fault zones.

The dolomite and overlying red ferruginous sandstone-siltstone-shale complex are probably evidence of a warm and perhaps fairly dry climate. The rapid lateral facies variations, the cross-bedding and common rib-and-furrow structures, and the mica content, suggest a shallow-water, near-shore, possibly lagoonal-deltaic environment. If the arkoses from the eastern margin of the outlier are correlates of the red sandstone complex, the freshness of the detrital feldspar and the presence of salt crystal casts are further indications of a relatively dry climate. The Burke River Outlier at that time probably formed a small sedimentary basin which was rapidly filled from both sides, as suggested by the directions of sediment-bearing currents.

The orthoquartzite unit, with its mature rock types and transgressive nature, is suggestive of a littoral, stable shelf environment spreading out beyond the (western) limit of the Burke River Basin. No subsidence took place, and streams wandered aimlessly across the area.

Finally, the widespread blanket of massive silty mudstone appears to indicate tranquil transgression over an old land surface of low relief, where the sedimentation energy was no longer capable of transporting arenites and coarser materials.

The area then emerged until lower Middle Cambrian times and a soil profile was formed (ferruginous crust, bleaching and local induration of the top few feet of the mudstone).

<u>Middle Cambrian</u>

The <u>Thorntonia Limestone</u> consists of thick-bedded, usually ochre or yellow-brown dolomitic limestone and dolomite with irregular and patchy chert layers, nodules (Fig. 15), and some siliceous and silicified beds. Outcrops commonly show a slight barren surface. The limestone is preserved in a few places only. Along the Pilgrim Fault the largest outcrop is about 1½ miles long, situated 5 miles north of Mount Murray, and smaller outcrops

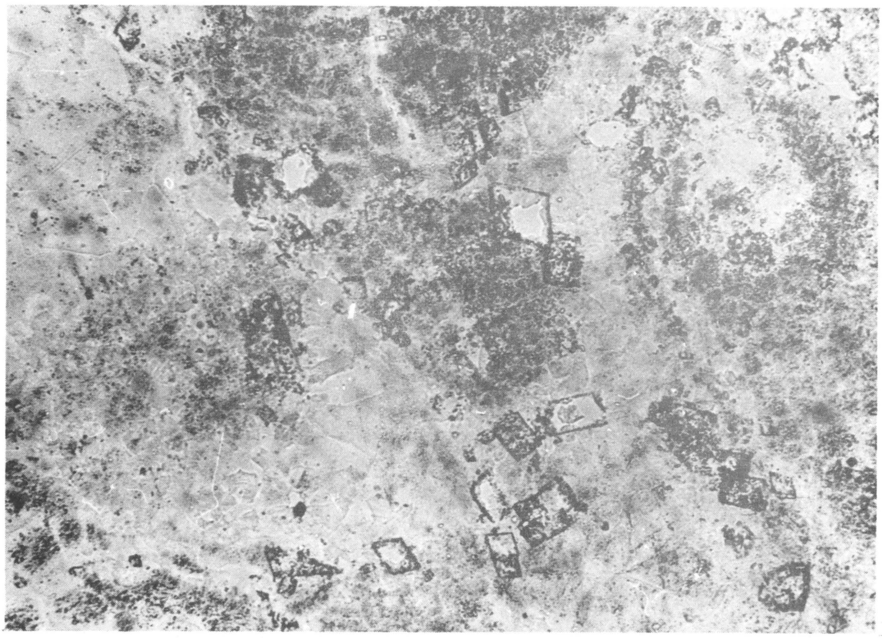

Figure 11: Silicified carbonate rock ("quartzite"), showing limonite(?)-rimmed outlines of rhombohedra in a silicified matrix. Ordinary light. Outcrop east of Mount Aplin. X100

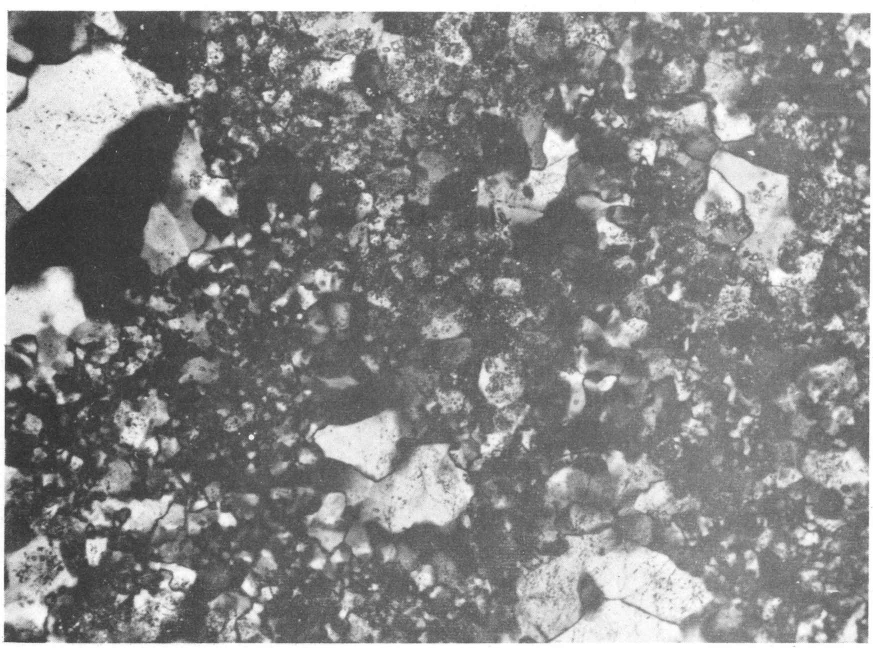

Figure 12: As above, crossed nicols. Note carbonate dust through chalcedony-quartz groundmass. Rhombohedra can still be recognized, with difficulty, by their limonitic rims. X100

are found east of Mount Aplin, 3 miles south of Bronzewing Bore, and 5 miles east of Duchess. One of the results of the survey was the discovery of a large outcrop area in the northernmost tip of the outlier, north of the Malbon River. The rock there is thinner-bedded than usual, and contains flat chert nodules, but is nevertheless unmistakably Thorntonia Limestone directly overlying the Precambrian (and some Mount Birnie Beds in places) via a basal gritty or fine conglomeratic sandy carbonate layer.

The maximum thickness exposed is about 60 feet (Carter and Opik, 1963). Fossils observed include Biconulites sp., Redlichia sp., phosphatic brachiopods, and sponge spicules.

Although the Thorntonia Limestone is preserved only in a few scattered outcrops, a massive grey, slightly vuggy "quartzite" of the same age, and derived by silicification of a carbonate rock, is distributed over the whole extent of the Burke River Outlier. During the field season, the rock was referred to as "silcrete", a term initially used by the company geologist (Russell, 1967) who originally thought the rock to be a silicified Cambrian weathering surface or (paleo-)silcrete.

The "quartzite" has been observed in the field to pass laterally into outcrops of Thorntonia Limestone, which contain more than one similarly silicified beds intercalated with the normal dolomitic limestone. The origin of the "quartzite" is quite clear when suitable specimens of the rock are compared with a specimen of the normal carbonate rock, as microtextures and structures may be identical. Thin sections of the silicified rock (Figs 11, 12) show it to consist of an aggregate of interlocking quartz grains (0.1 - 0.4mm) and granulo-chalcedony (0.02mm or less). A cloud of fine carbonate dust throughout the quartz-chalcedony mass is a pointer to the original composition of the rock, and the presence of rhombohedral outlines thinly rimmed with limonite(?) suggests the former presence of a ferruginous carbonate, possibly ferruginous dolomite, siderite, or ankerite. The unaltered carbonate sample is a dolomite, as shown by a staining test with Magneson solution. Its particle size ranges from 0.04mm to 0.10mm across, the rhombohedral shape being common. In both the silicified rock and the dolomite the crystal size of the rhombohedra is identical. The available evidence therefore suggests that the "quartzite" is a silicified dolomite.

The "quartzite" is a very good marker bed: it is a massive, dark bluish grey to light grey and, in one exposure, pure white rock, with a somewhat saccharoidal and vuggy texture. Its thickness varies from less than a foot to at least 30 feet. It overlies the Mount Birnie Beds, and passes laterally into Thorntonia Limestone. The "quartzite" is distributed over the whole of the Burke River Outlier; however, in the mesas outside the western margin of the outlier it is very thin or is even absent in places, and the old shore line may have been close to the present western limit of the outlier. Fossils found in the "quartzite" include Biconulites sp. and trilobite fragments, and what is probably an algal rock (Girvanella? Fig. 14).

Overlying both the Thorntonia Limestone and the "quartzite" is a bed not definitely known in outcrop, but which is expressed at the surface by a zone of chert rubble of quite characteristic types and structure. The types of chert represented include large rounded and lumpy nodules with creamy yellow and milky surface and with a glazed appearance; black and white banded, commonly convoluted chert (Fig. 15, 16); banded grey lumpy chert; silicified coquina-type rocks (Figs 17, 18); white silicified carbonate rock (Figs 21, 22); and rubble of siliceous silt-shale. A few outcrops of a lightweight, massive, yellow to ochre siliceous mudstone with conchoidal fracture, occur above the "quartzite" and may belong to this horizon. In the south-eastern region of the outlier, the rubble horizon appears to contain sandy beds, occasionally with rare pebbles of rounded quartz, and outcrops in the vicinity consist of residual chert nodule fragments in a soft, weathered, brecciated or conglomeratic siltstone or sandy siltstone. It is also possible that these outcrops may represent an old erosion surface of Beetle Creek or post-Beetle Creek age.

The coquinites consist of well-rounded skeletal fragments, in various stages of silicification, in a ground mass of chalcedonic silica and quartz. Figures 17 and 18 show a stage in which the skeletal fragments are still clearly recognizable, because the phosphatized skeletons are partly preserved. The fragments are up to 2mm long, generally ovoid, and replaced by microgranulo-chalcedony or quartz (up to 0.02mm), whereas the interstices between the fragments are lined with fibrous chalcedony up to 0.01mm long, and quartz up to 0.05 - 0.10mm across. In places the presence of carbonate dust again indicates an original calcareous or dolomitic

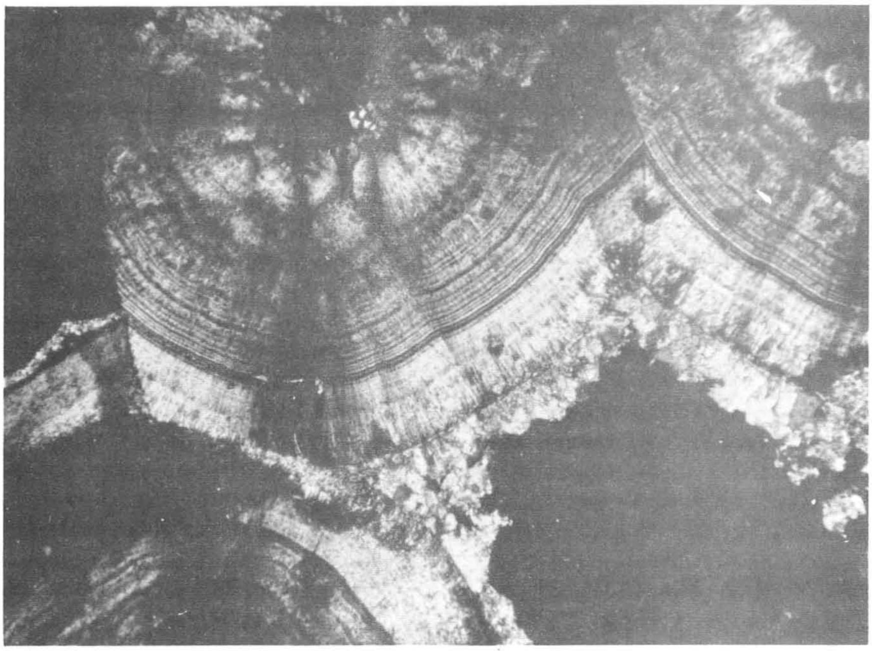

Figure 13: Fibrous chalcedony (crossed nicols), radially orientated but concentrically banded. Granular mass in void is calcite. Altered, leached Thorntonia Limestone with silica infillings in solution cavities. Outcrop east of Mount Aplin. X35

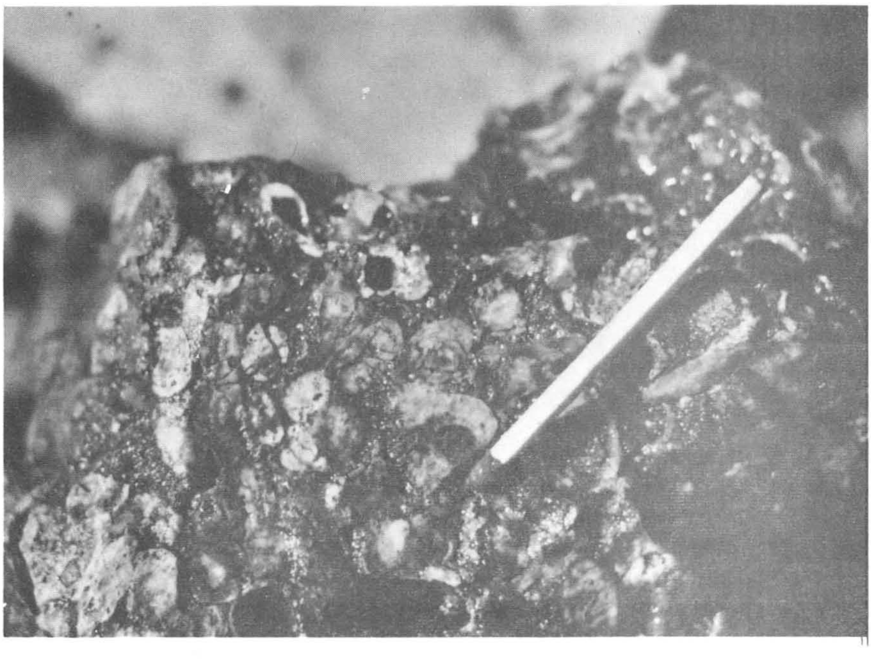

Figure 14: Silicified algal rock ('Girvanella' pudding ?). Outcrop north of Roaring Bore.

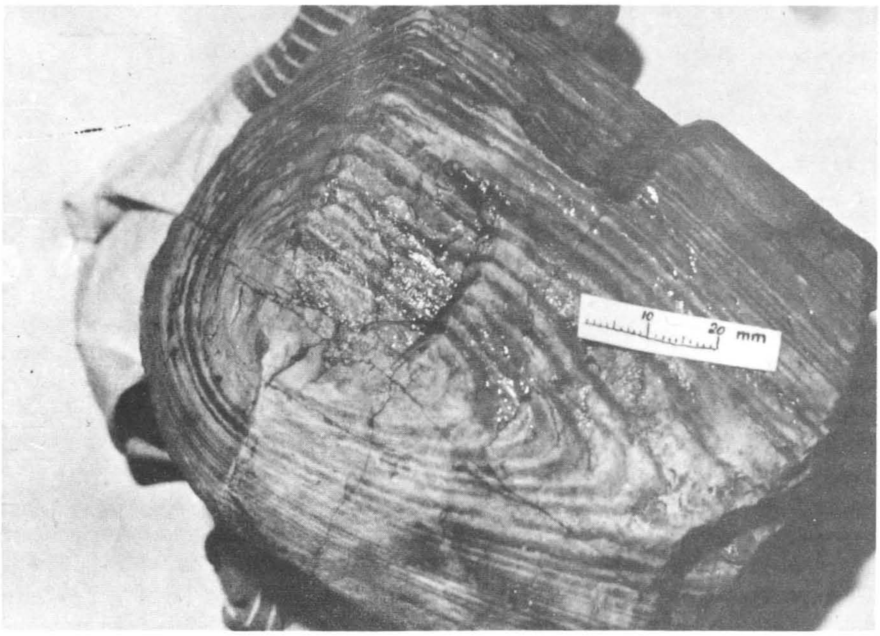

Figure 15: Part of a chert nodule found in Thorntonia Limestone, and commonly present in the unnamed chert rubble horizon.

Figure 16: Convoluted, black-and-white banded chert characteristic of the unnamed chert rubble horizon.

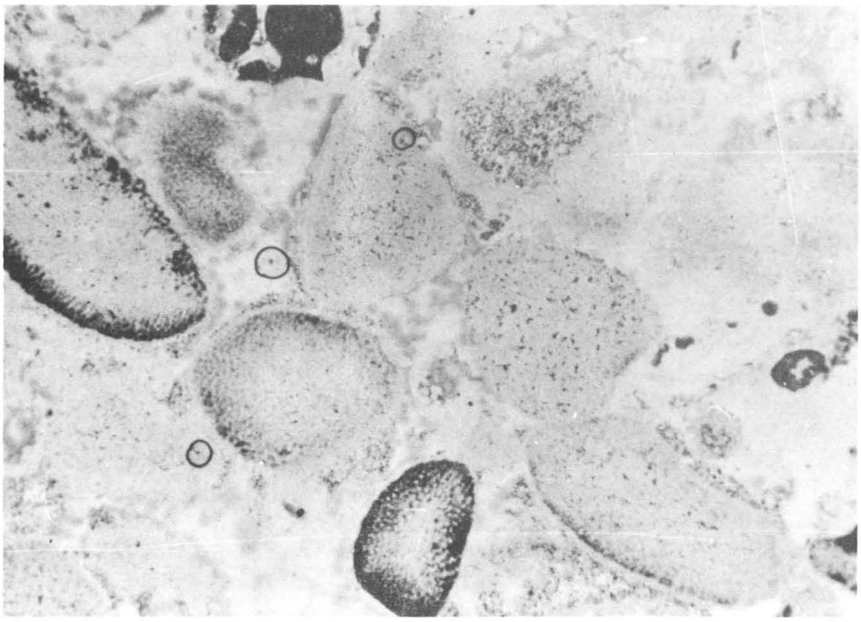

Figure 17: Silicified coquinite from the unnamed rubble horizon. Skeletal fragments still clearly recognizable in ordinary light owing to part-preservation of phosphatized skeletons (dark) and probable organic pigment. Rimmer Hill locality. X35

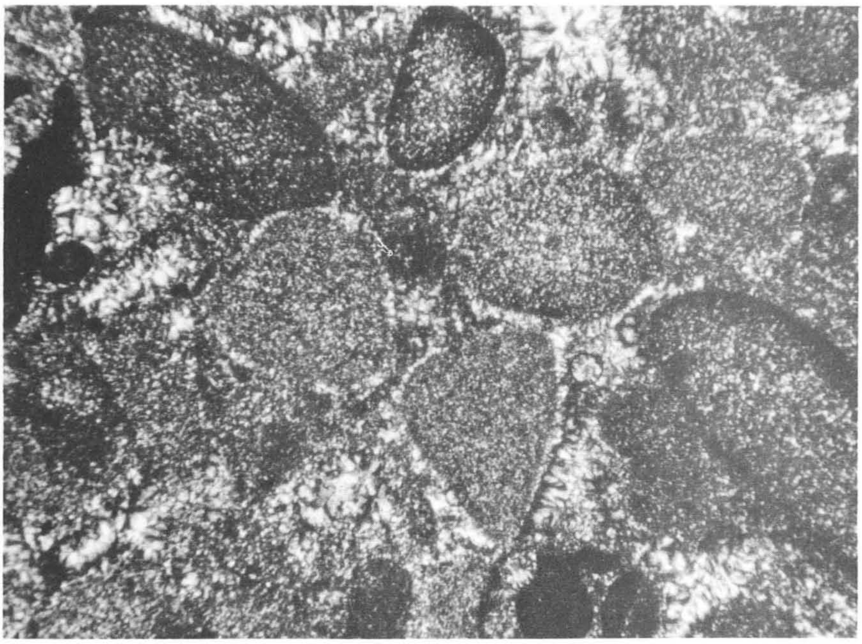

Figure 18: As above, but crossed nicols to show the structure of the quartz-chalcedony aggregate. X35

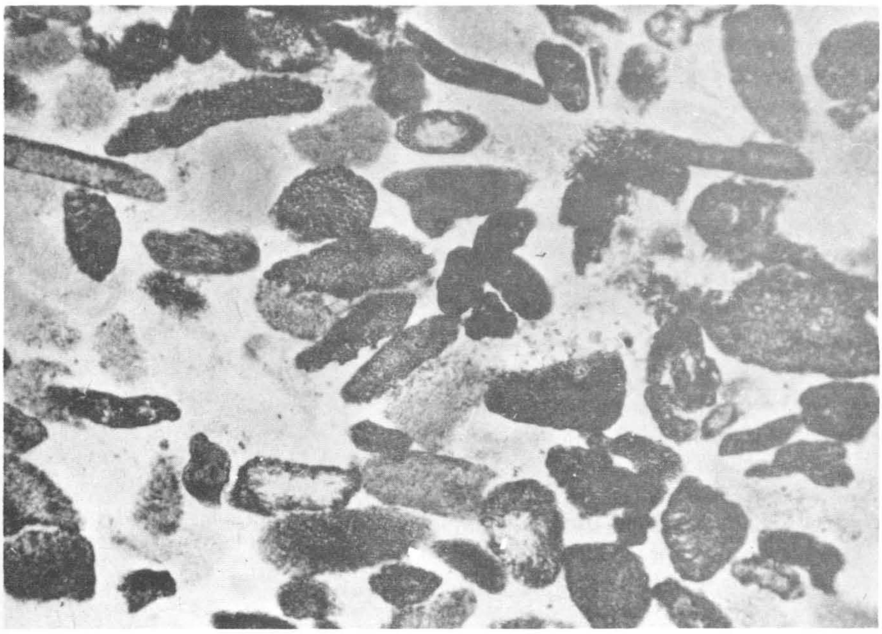

Figure 19: Silicified phosphatic coquinite in Cambrian from the Paradise Creek area, 60 miles north-north-west of Mount Isa. Silicification not as far advanced as on Figures 17 and 20. Organic texture of the rounded phosphatized particles still obvious. X35

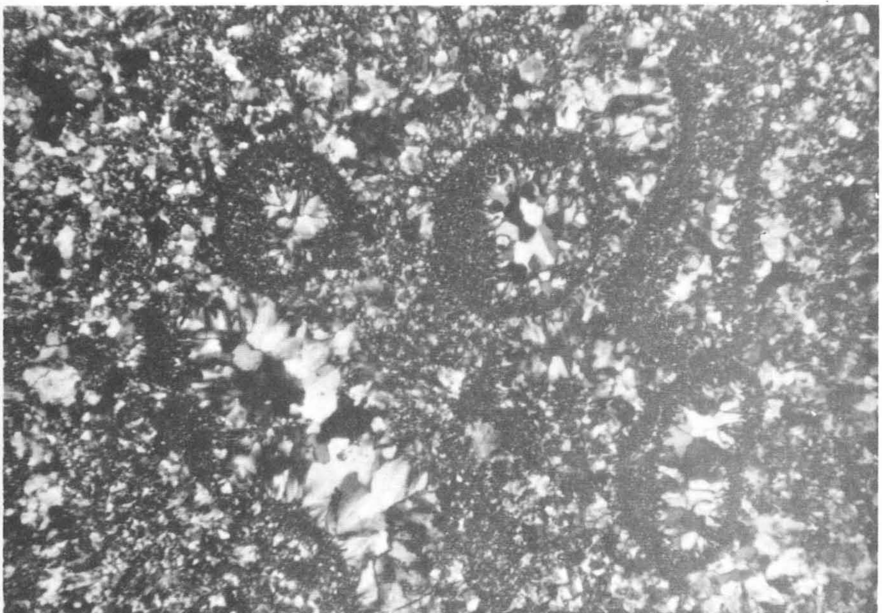

Figure 20: Completely silicified coquinite from 'unnamed chert rubble horizon' 8 miles south-east of Duchess. Crossed nicols to show up ghosts of former skeletal debris. X35

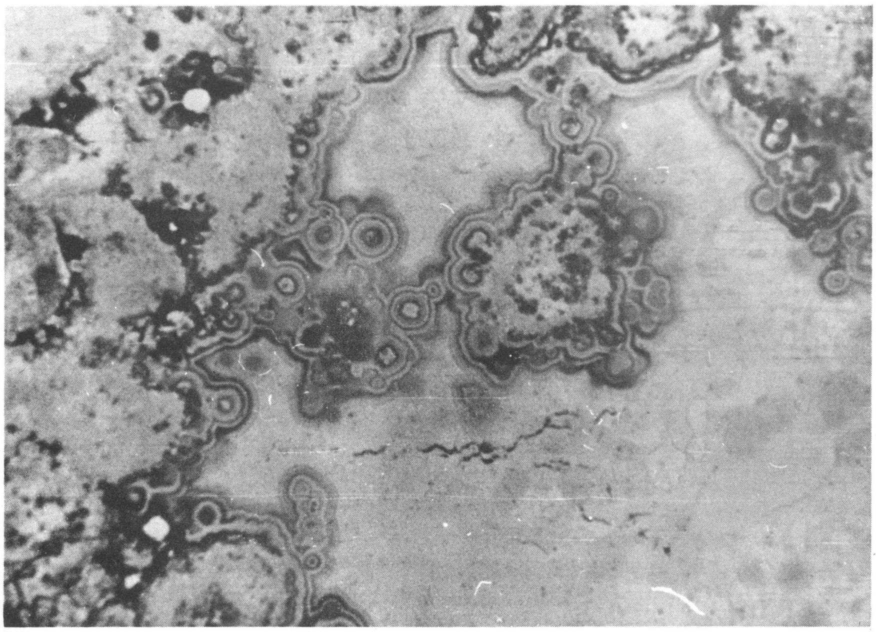

Figure 21: Silicified limestone from 'unnamed chert rubble horizon'. 1.7 miles north-west of Bundy Bore. Colloform chalcedony structures, ordinary light. X35

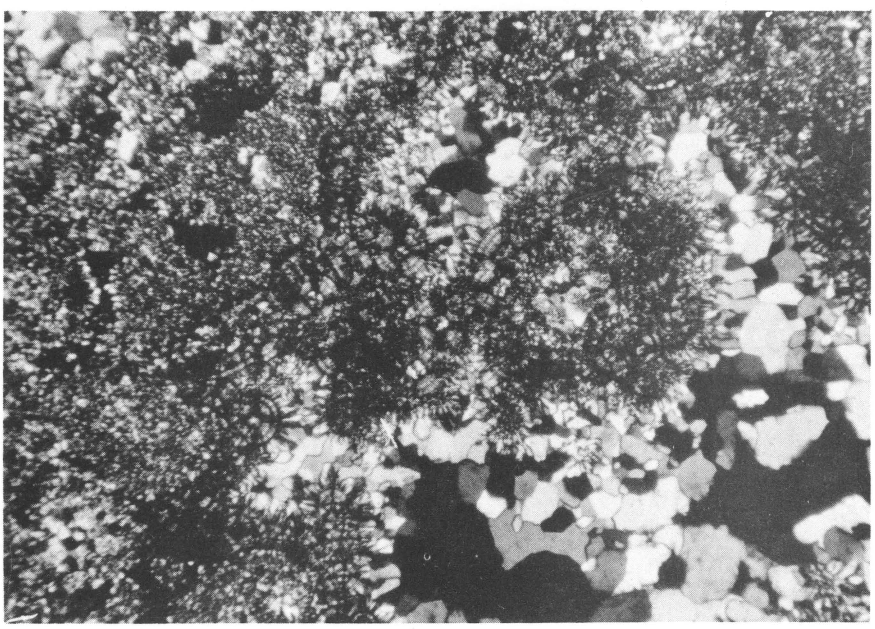

Figure 22: As above, but crossed nicols. Because of the re-crystallization of the silica, the colloform structure is hardly recognizable. X35

composition. Figure 20 shows a similar rock, but more strongly silicified and recrystallized, with the original structure recognizable only under crossed nicols.

Macrofossils observed in cherts of the rubble horizon include Redlichia spp. and Biconulites sp.

The rubble horizon shows some likeness to the 'Yelvertoft Bed(s)' (David, 1950; Opik, 1960), from the Hall's Memorial locality on the Barkly Highway, 55 miles north-west of Mount Isa. Its distribution in the Burke River Outlier is widespread, but not as consistent as the Thorntonia "quartzite" bed, and it appears to be lacking in the mesa sections west of the Pilgrim Fault zone.

The strong rounding of the skeletal fragments in the coquinite indicates a high degree of reworking, probably in agitated shallow waters.

Beetle Creek Formation. The Beetle Creek Formation is, economically speaking, the most important unit in the Burke River Outlier and elsewhere in the Georgina Basin, as it contains all of the most promising phosphorite deposits found since 1966.

The formation consists of siliceous shale, chert, bedded siltstone, phosphatic siltstone, phosphorite, phosphatic limestone, and minor sandstone. Russell (1967) subdivided the formation, from base to top, into a Lower Siltstone Member, a Lower Breccia Member, and a Monastery Creek Member which carries the main phosphorite deposits.

The Lower Siltstone Member comprises thinly-bedded siltstone, black chert, and minor phosphorite, and is limited to the southern part of the Burke River Outlier, from about 9 miles south of "Rimmer Hill". Its thickness is about 170 feet near the southern end of its occurrence.

The Lower Breccia Member consists of brecciated siltstone, chert, or phosphorite, and is very well developed over a 10-mile interval from Pilgrim Creek southwards. Farther north, the Lower Breccia Member is present only intermittently and with decreased thicknesses, and in places it is hardly distinguishable from normal intraformational breccias.

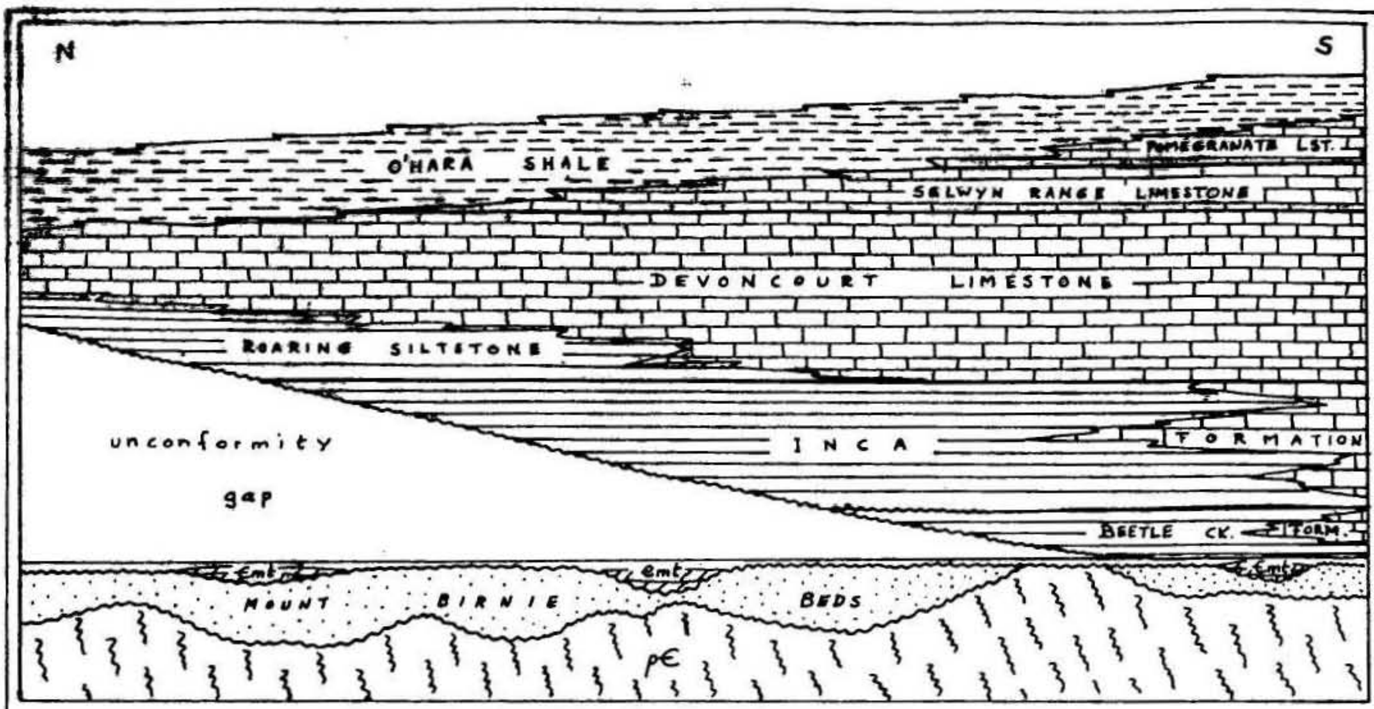

FIGURE 23 - Diagram showing facies and formation relationships of the Lower and Middle Cambrian deposits. Bedding lines represent time planes.

Upper siltstone magnafacies
Limestone magnafacies
Lower siltstone magnafacies
unconformity

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Farther south, the member gives way to the Lower Siltstone Member.

Strictly speaking, the unit has no real stratigraphic definition or meaning, as it is considered highly likely that the brecciation was the result of a post-depositional process, and as a consequence may transgress across time planes. The variations in the composition of the breccia from one locality to the other is therefore as could logically be expected. Usually the breccia consists of poorly sorted and angular fragments of siltstone or silicified siltstone and chert in a comminuted matrix which is quite ferruginous in the Mount Aplin - Mount Birnie area. However, at "Rimmer Hill" the breccia is composed almost exclusively of phosphorite and chert. (Fig. 25), set in a fine-grained collophane matrix, while one mile

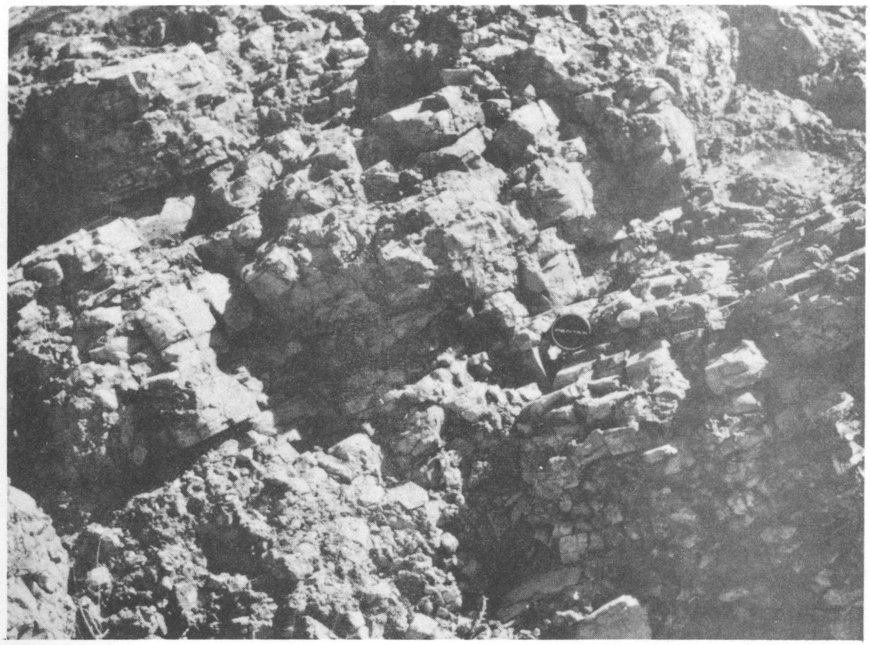

Figure 24: Initial stage of brecciation in "Lower Breccia Member": phosphorite breccia, "Rimmer Hill".

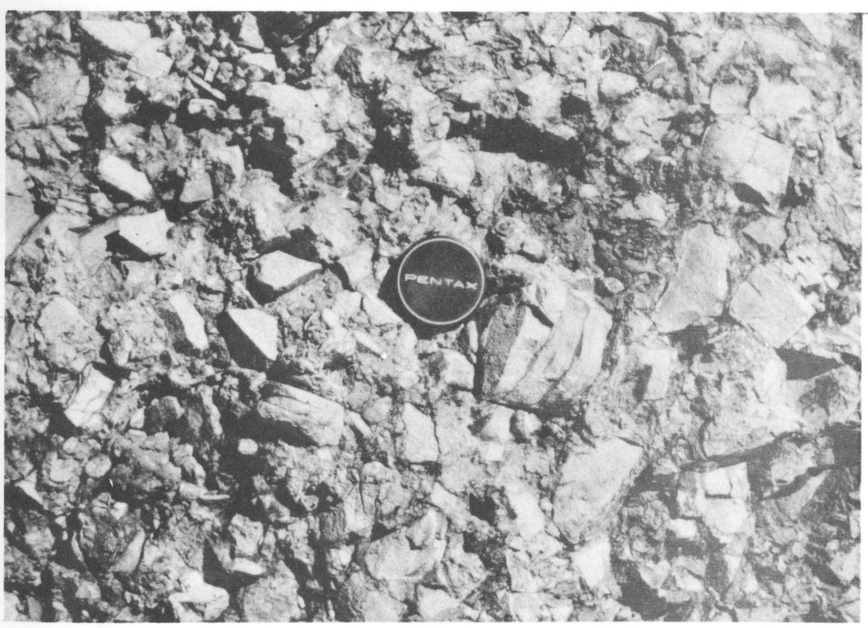

Figure 25: Phosphorite breccia in "Lower Breccia Member", Beetle Creek Formation, at "Rimmer Hill".

farther south the fragments are predominantly phosphatic siltstone and chert in a claystone matrix, with medium-grade phosphorite beds at the top and bottom of the section (Russell, 1967). Rare fragments of phosphorite occur elsewhere in the Lower Breccia Member, as far north as the breccia outcrop on the southern bank of the Burke River, east of Duchess. The breccia even descends low enough in the stratigraphic section in places to incorporate the Thorntonia "quartzite".

The genesis of the breccia is not certain. Various theories have been put forward by visiting geologists. Russell (1967) originally described the breccia as consisting of "reworked basal beds of the Beetle Creek Formation". Others saw the breccia as a product of Cainozoic weathering and alteration, or suggested brecciation due to faulting along the Pilgrim Fault zone. Slumping as an agency has also been popular. De Keyser, noting that the breccia seemed to be mostly absent over outcrops of Thorntonia Limestone, at first thought that it might have formed by the solution-collapse of sediments overlying areas where Thorntonia Limestone had been leached out. This seemed to be able to explain some outcrop features (Figs 26-28), and an initial stage of fracturing without much displacement of fragments seemed to be represented in another outcrop (Fig. 24). However, other outcrop features were less easy to explain, as where breccia overlies, or grades downwards into, undisturbed beds. Possibly brecciation may occur where the carbonate content is leached from cherty limestone or calcareous chert beds. Another likely solution appears to be that of brecciation and sliding on a sloping surface when the deposits were

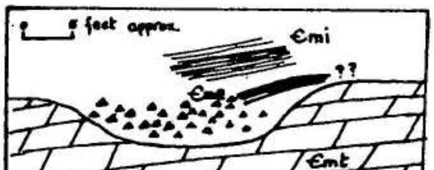

FIGURE 26 — Breccia 2½ miles WNW of Prickly Bush Bore. Phosphorite bed and fragments in black.

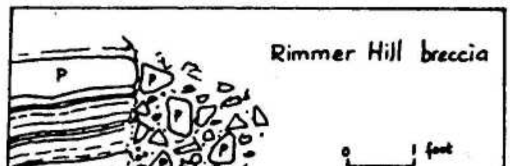

FIGURE 27 — Breccia at Rimmer Hill. P. white massive phosphorite. Left: undisturbed thin-bedded phosphatic siltstone and chert.

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tilted by faulting and flexuring in the belt of the Pilgrim Fault zone. This theory, too, cannot explain all outcrop features. Whatever the general cause of the brecciation, there are some outcrops of breccia that are of different origin, such as fault breccias, and small breccias in axial zones of sharp local folds or flexures.

The Monastery Creek Member is the most persistent member in the Beetle Creek Formation. It comprises phosphorite beds, phosphatic siltstone, phosphatic shale, and chert and phosphatic chert. As will be shown later, there is evidence of de-calcification and silicification of carbonate beds, and at least some of the chert has obviously been formed by replacement of limestone. The phosphatic beds will be described in some detail in the chapter dealing with the phosphorite.

The Monastery Creek Member varies in thickness from 35 to 45 feet, and may attain about 75 feet in the area north of Mount Murray.

The Beetle Creek Formation is restricted almost exclusively to the area south of Pilgrim Creek, but its limits of distribution are not precisely known. Small outcrops of high-grade phosphorite, and the presence of phosphorite pebbles in breccia as far north as the Burke River east of Duchess, suggest that the Monastery Creek Member originally extended at least over that distance, as the overlying younger siltstone formations are not known to be richly phosphatic. An outcrop of high-grade phosphorite only a few square yards in area at the head of Pomegranate Creek on the eastern margin of the Burke River Outlier similarly points to an original extension as far east as there. It is thought that these outcrops are erosional remnants of the Beetle Creek Formation, and not deposits in one of the overlying siltstone formations; the latter are non-calcareous and the genesis of the phosphate is probably closely associated with a calcareous environment, as will be seen later.

In places along the eastern margin of the outlier, and in BMR Scouthole No. 3, the Thorntonia "quartzite" and chert rubble horizon are overlain either by several feet of yellow-brown to red massive mudstone with fragments of chert, altered chert, and siliceous siltstone, and with pockets of coarse arkosic and fossiliferous(?) sand debris, or by coarse impure yellow-brown silty sandstone which in places is crowded with angular fragments of chert and silicified limestone. Small silicified limestone blocks

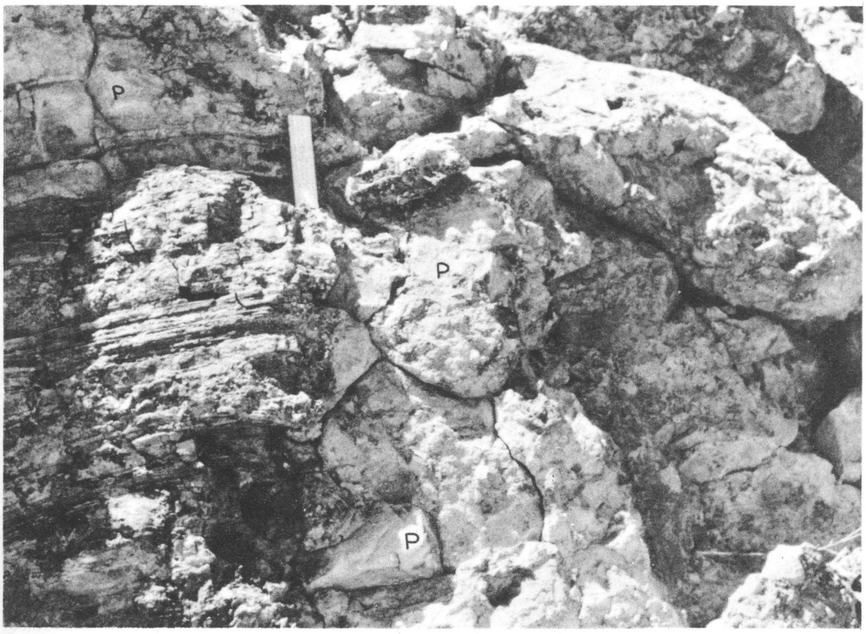

Figure 28: "Lower Breccia Member" at "Rimmer Hill". Undisturbed thin-bedded phosphatic siltstone and chert on the left. Breccia fragments include massive white phosphorite derived from bed on top left. See also Figure 27.

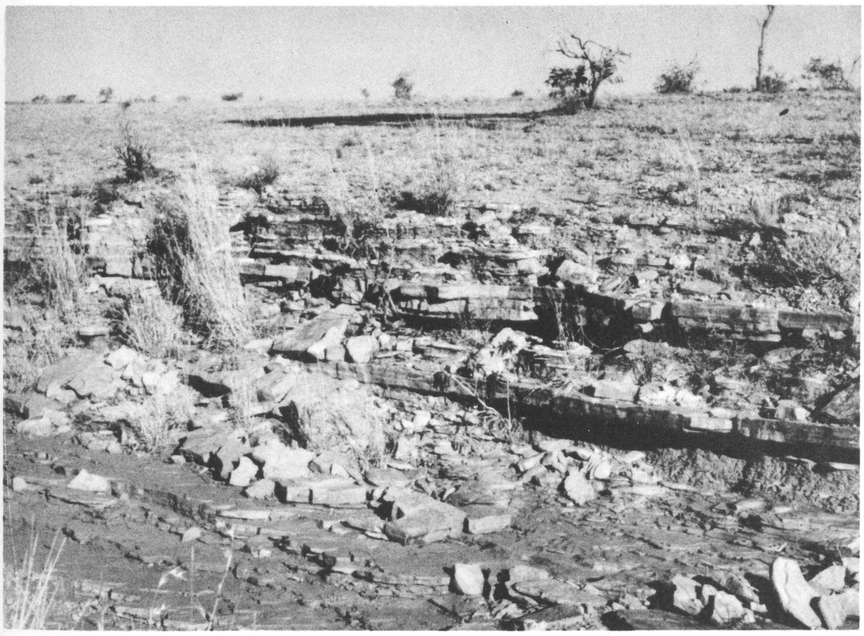

Figure 29: Typical outcrop of Devoncourt Limestone, showing silty calcilutite (hard flaggy beds) with soft marly interbeds (soft crumbly beds, not well exposed). Creek bed on south side of Duchess-Cloncurry road, about 8 miles east of Duchess.

of possible Beetle Creek age are recorded by Opik (1961) from the base of the Roaring Siltstone.

Characteristic of all these deposits seems to be their highly irregular nature and limited thickness, and, although they have not yielded any fossils, it seems likely that they are erosional remnants of littoral deposits of Beetle Creek age or possibly, farther north, transgressively younger.

Inca Formation. The Inca Formation overlies, and overlaps, the Beetle Creek Formation. Its thickness is estimated to be up to 500 feet. It consists of regularly thin-bedded ($\frac{1}{2}$ inch to 2 inches) silt-shale, siliceous shale, minor thin-bedded chert and fine-grained sandstone, and some calcilutite limestone. Russell (1967) subdivides the formation into a Lower Shale Member and an Upper Limestone Member; however, the large mass of bedded limestone west of Prickly Bush Bore is now known, on fossil evidence, to be of Devoncourt Limestone age, so that the "Upper Limestone Member" may loose its validity. Nevertheless,the formation does contain limestone beds of undisputed Inca age. They are commonly dark grey, bituminous and smelly, and thinly to moderately bedded with marly shale intercalations.

The Inca Formation is shown on the map to extend northwards to the vicinity of Pilgrim Creek. Its place farther north is taken by the Roaring Siltstone. There is, however, no lithological break, and the separation is made solely on faunal differentiation; continuous sedimentation from Inca time to Roaring Siltstone time is indicated.

No outcrops of Inca Formation are broken from the eastern margin of the outlier, where the Thorntonia Limestone and erosional Beetle Creek(?) remnants are directly overlain by Roaring Siltstone.

Roaring Siltstone. The Roaring Siltstone consists of laminated siltstone, siliceous silt-shale, and thin bands of fine-grained silty sandstone (commonly fossiliferous). It has been described in detail by Opik (1961) who estimated its thickness to range from 200 to 250 feet. A thickness of some 130 feet was measured 4 miles south of Bronzewing Bore.

Locally the formation contains small lenses of grey smelly laminated limestone, and south-west of Roaring Bore a bed of coarse gritty sandstone is intercalated. Some of the silt-shales are calcareous, especially in the uppermost section.

The formation is the northern continuation of the Inca Shale facies, rests disconformably or slightly unconformably on the Thorntonia "quartzite" and unnamed rubble horizon, and is conformably overlain by, and passes laterally into, Devoncourt Limestone. The recognition of its distribution also in the Mort River area and the head of Pomegranate Creek, has been one of the results of the present survey. In the latter locality it appears to overlie erosional remnants of Beetle Creek Formation.

Devoncourt Limestone. The Devoncourt Limestone, described by Opik (1961), consists of hard flaggy, thin to medium-bedded laminated lutitic grey limestone, fine-grained laminated (not fissile) sandy limestone, shaly limestone or marl and calcareous shale, dark and smelly bituminous limestone, and nodular limestone beds which on weathering leave thick round ellipsoidal limestone discs or nodules up to a foot in diameter. Samples of some of the lithological rock types are shown in Figures 29 to 31.

In the extreme north, where Devoncourt Limestone rests directly on Thorntonia Limestone, the base of the unit is formed by slightly phosphatic silty or fine sandy dolomitic limestone, which in thin section is shown to be composed of a recrystallized sparry carbonate groundmass (grain size 0.05 to 0.10mm) with abundant grains of quartz (0.04 - 0.08mm), limonitized pyrite, mica, and a little glauconite, altered biotite, rare phosphate pellets, some fossil fragments, and occasional tourmaline and zircon. Calcite replaces quartz grains and phosphate pellets along their margins. Part of the carbonate matrix is composed of round grains of micrite which may have been deposited as a clastic constituent.

Bedding structures in the Devoncourt Limestone include some fine cross-lamination (visible only on weathered surfaces) indicating the essentially detrital nature of the limestone beds. The direction of transport of sediments in the area 7 miles east of Duchess appears to have been approximately north-west to south-east.

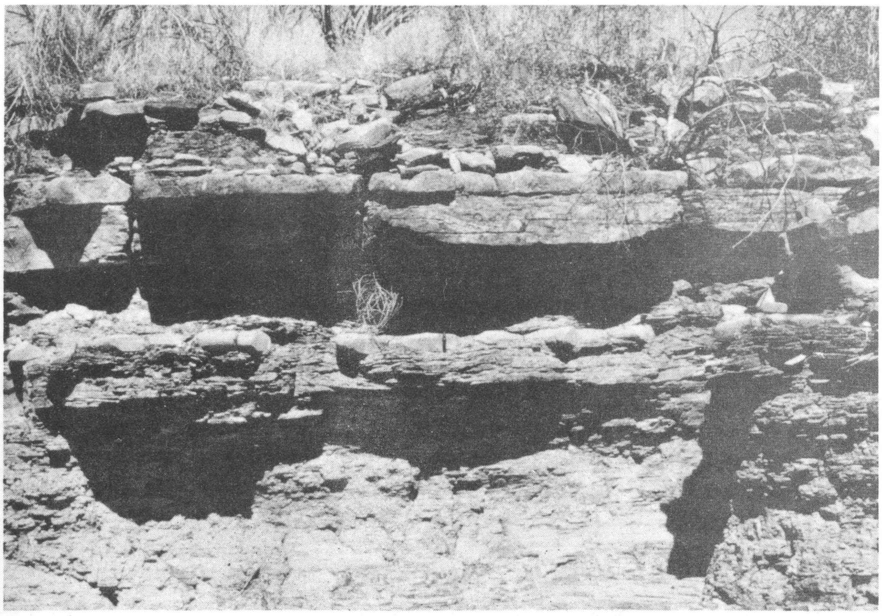

Figure 30: Devoncourt Limestone. Mainly marly limestone, with platy silty calcilutite on top, and nodular limestone bed half-way up. Creek outcrop 7 miles east of Duchess.

Figure 31: As above, showing shape of limestone ellipsoids weathered out from nodular limestone bed.

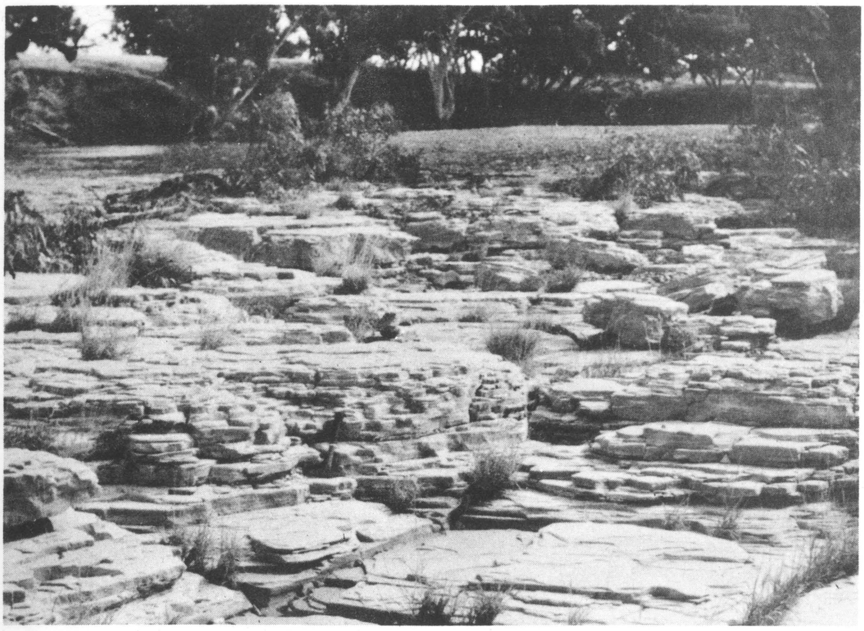

Figure 32: Selwyn Range Limestone outcrop in Burke River, 3 miles south-east of O'Haras Gap Homestead.

Figure 33: Close-up of above, showing laminated calcilutite with chert biscuits.

Thin bands of intraformational breccia are here and there included in the sequence. Characteristic of the Devoncourt Limestone, and of all the other Middle to Upper Cambrian limestone units, is the presence of aggregates of coarse limonite pseudomorphs, presumably after pyrite, though the hopper crystal habit of many of the pseudomorphis is strongly suggestive of halite.

The thickness of the formation varies. Opik (1961) gives a range from 350 feet to 600 feet, the latter in the Roaring Fault zone. A section 7 miles east of Duchess has been calculated to be about 600 to 700 feet thick.

The formation overlies the Inca Formation in the south, the Roaring Siltstone in the central-north, and Thorntonia Limestone in the extreme north-east. It is overlain by Selwyn Range Limestone in the central north, by O'Hara Shale in the extreme north. The lower part of the formation is equivalent in age to the Roaring Siltstone.

Selwyn Range Limestone. The Selwyn Range Limestone consists of hard thin-bedded (1 to 3 inches) fine-grained laminated (not fissile) grey to pink calcilutite (Figs 32, 33), shaly marly interbeds, and occasional brown or white chert layers (about ½ inch thick). Some calcilutites contain flat lens-shaped brown chert nodules (Fig. 33). On some weathered surfaces, fine cross-lamination can be distinguished. Inferred direction of sediment transport in the outcrop shown in Figure 32 is from the north-west.

The Selwyn Range Limestone resembles the other Middle and Upper Cambrian limestones, but it is devoid of fossils, and fine-grained calcilutite strongly predominates. A thin section of a silty calcilutite from the Burke River outcrop reveals a micrite groundmass with small scattered grains of quartz (0.01 - 0.05mm), mica, opaque material, and rare fedlspar. The quartz is, as usual, marginally corroded by carbonate. Spot tests indicate that some bands contain magnesian calcite or possibly some dolomite.

The formation is between 100 and 120 feet thick, overlies Devoncourt Limestone with a gradational contact, and is overlain by O'Hara Shale, locally via a small diastem (Opik, 1961). It is distributed in the central-northern part of the Burke River Outlier. In the area 4 miles south of

Bronzewing Bore, a limestone unit appears to dwindle southwards by the thinning and lensing out of its beds to make place for siltstone beds.

Pomegranate Limestone. The Pomegranate Limestone resembles the Devoncourt Limestone and Selwyn Range Limestone (Fig. 34, cf. 33), but is distinguished by its fossils. The formation includes grey to pinkish laminated (not fissile) thin to medium-bedded silty and sandy calcilutite, grey to pink marl commonly with ellipsoidal lenses of limestone (cf. Devoncourt Limestone), dark or grey smelly bituminous limestone, common intraformational breccias, some hard dark siliceous limestone, subordinate chert beds up to 2 inches thick, and limestone with thin lenses and tongues of chert.

The calcilutites are composed of a partly recrystallized calcitic groundmass (grain size from less than 0.01mm ranging to 0.05mm) with grains of detrital quartz (0.02 - 0.10mm), mica, opaque granules, rare tourmaline, and small round (clastic?) grains of micrite. As in the other limestone formations, the quartz is marginally corroded by calcite. Dolomite rhombs are recognizable in some sections, where spot tests confirm the magnesium content of the rock.

The Pomegranate Limestone crops out between Limestone Creek in the north and the Mistake Bore area in the south. It is overlain by O'Hara Shale via a gradational passage; Opik (1960) has shown that the contact is rising stratigraphically from north to south, and that the two formations interfinger in part.

The Pomegranate Limestone shows a facies change to the east and possibly to the west. In eastern outcrops, near Wangaratta Bore, the limestone beds thin out, and the intercalated marls increase in thickness. At Wangaratta Bore itself, BMR Scouthole No. 6 penetrated calcareous shale and siltstone and highly impure calcilutite in the upper 30 feet of the calcareous section below the O'Hara Shale; the pyritic limestone underlying this may belong to one of the older Middle Cambrian limestone units. In Scoutholes Nos. 5 and 4, no Pomegranate Limestone could be recognized, and the O'Hara Shale rests directly on non-calcareous lower Middle Cambrian and Lower Cambrian rocks. Most likely, movements along the Wangaratta faults during the Cambrian were responsible for the pattern of the Pomegranate sedimentation.

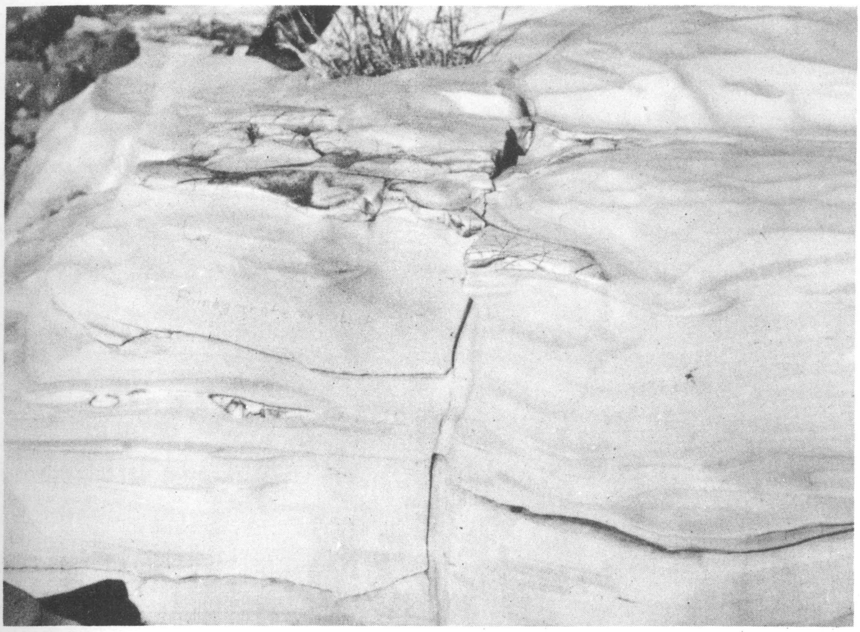

Figure 34: Pomegranate Limestone: laminated calcilutite with disc-like and platy chert nodules. Note similarity with Selwyn Range Limestone of Figure 33. Outcrop in Burke River, 4 miles south-east of Pilgrim Bore.

Figure 35: Mesas of O'Hara Shale resting on pediment of Selwyn Range Limestone and Devoncourt Limestone (foreground). View from Duchess-Cloncurry road near head of Boomerang Creek, towards the south-east.

The thickness of the Pomegranate Limestone is unknown as the base is not exposed. Opik (1963) (and in Carter and Opik, 1963) mentions figures of 60 feet and at least 100 feet. BMR Scouthole No. 6 penetrated a calcareous sequence of about 100 feet, but this probably includes other limestone units. It is certain that the formation thins out towards the east and ultimately disappears.

O'Hara Shale. The O'Hara Shale consists of silt-shale and thin-bedded micaceous siltstone with subordinate bedded chert (half an inch to $1\frac{1}{2}$ inches thick) and fine sandstone. Conglomerate, recorded in Carter and Opik (1963), has not been observed. Some siltstone is slightly calcareous, and the formation also includes ellipsoidal limestone discs in many places except in the north-west. All the sediments are red coloured and ferruginous because of lateritization effects, but in places and rocks are bleached white (pallid zone). Chert is common in the north-western and central-eastern parts of the Burke River Outlier, but is scarce in most outcrops in the region between the Burke River and Devoncourt Homestead, and in the north-eastern part of the outcrop area south of Limestone Creek.

The bottom beds of the formation appear to grade into, and are reported to interfinger with, the Pomegranate Limestone.

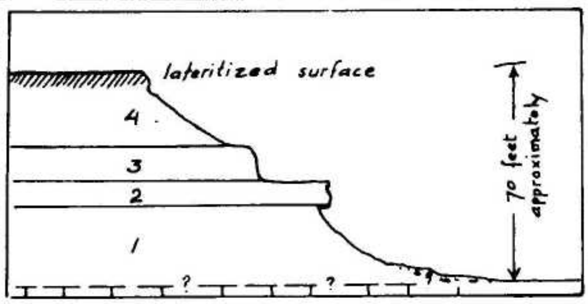

FIGURE 36 – O'Hara Shale.
Cliff section (not to scale)
2½ miles east of Pilgrim Well.

4. Soft siltstone, slightly calcareous in places
3. Platy siliceous siltstone
2. Bedded chert, beds ½"–1½" thick
1. Pink, soft siltstone to fine sandstone. Leached?
Base of Pomegranate Limestone close to surface

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Figure 36 shows a section (not to scale) found east of the junction of Pilgrim Creek and the Burke River. Ellipsoidal calcilutite nodules found scattered on the slope were probably derived from the upper, slightly calcareous siltstone section.

The O'Hara Shale is lithologically very hard to distinguish from the Middle Cambrian siltstone units. It is, perhaps, a little more coarsely micaceous, and its chert is commonly wine red, olive green or brown instead of grey or white. In morphological contrast with the other siltstone units, however, the O'Hara Shale is preserved in incised plateaux and mesas distributed over most of the Burke River Outlier (Fig. 35). These are commonly capped by duricrust ("grey billy"), or by a thin unconsolidated layer of white quartz gravel which is a remnant of disintegrated Mesozoic conglomerate.

The maximum thickness observed was in BMR Scouthole No. 1, where 277 feet of the formation were penetrated before a calcareous unit was reached.

Chatsworth Limestone. The Chatsworth Limestone consists of grey and dark grey, mostly thin-bedded calcarenite and calcilutite, sandy limestone, oolitic limestone, coarse biosparites and coquinites, marly interbeds, and common intraformational breccias. Chert is present in thin layers and as nodules created by the silicification of limestone. Some intraformational breccias consist of calcilutite fragments embedded in an oolitic carbonate matrix which is silicified in places, starting with the oolites. Ripplemarks and cross-laminations have been observed in rare beds, and rod-like limestone fragments with planoconvex cross sections found at the surface in some localities probably represent infillings of large ripple troughs, as the curved bottoms of the "troughs" are crowded with fossil debris.

The thin section of one of the intraformational breccias shows fragments of somewhat micaceous calcilutite in an oobiosparite groundmass. The calcite in the groundmass is recrystallized to 0.1 - 0.3mm size, and contains angular quartz grains (0.04 - 0.1 mm), mica flakes, rounded tourmaline, grains of micrite, and rare feldspar and zircon. Fossil fragments are common, and oolites (about 0.8mm diameter) are abundant but now consist of coarsely divergent-segmented crystalline calcite with one or two concentric rings still preserved. Silicification of the oolites appears to begin from

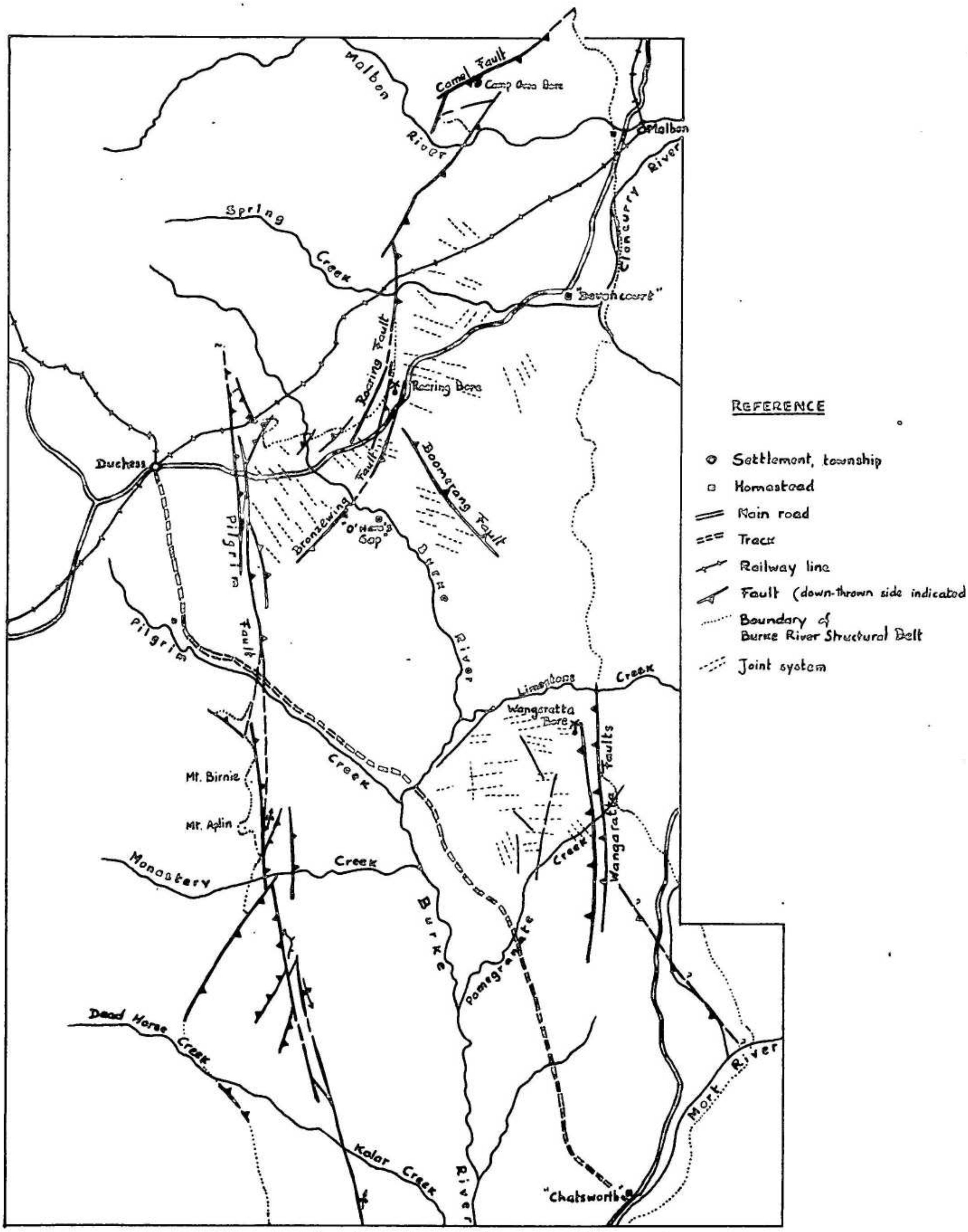

FIGURE 37 - Structural elements in the Burke River Outlier.

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the centre, destroying the original oolitic texture and leaving a shell of calcite. Where silicification progresses into the matrix, chert nodules are formed.

The Chatsworth Limestone is not well exposed in the Burke River Outlier, and its thickness in the area is unknown. BMR Scouthole No. 7 went through 165 feet of limestone without reaching its base, and Opik (1960) mentions a figure of the order of 2000 feet for the whole of the formation, most of which crops out south of the Burke River Outlier. In the area mapped, the formation is found around Chatsworth Homestead, and also east of Mount Murray. Contacts with other formations were not seen, but data from other sources show that the formation overlies the O'Hara Shale, and is overlain by the Ninmaroo Formation.

Ordovician

Ninmaroo Formation. Only the northernmost tip of the Ninmaroo Formation reaches as far as the Burke River Outlier, and is exposed in a ridge on Kolar (or Ibis) Creek. Here, the formation consists of medium- to thick-bedded creamy yellow calcarenite (commonly sandy), calcilutite, intraformational breccia beds, oolitic limestone, dolomitic limestone, and some marly interbeds. Some of the limestone beds, especially oolitic types, are silicified in part, and irregular chert nodules are common. One massive yellow-brown limestone bed (locality D.667) contains an abundant collection of ribeirioid and nautiloid fossils. Cross-lamination is noticeable in some beds, and the current direction is inferred to be from the north.

According to Opik (*in* Carter and Opik, 1963) the Ninmaroo Formation overlies the Chatsworth Limestone in the Duchess Sheet area with a slight disconformity. Its age is given as Tremadocian. An estimated 500 feet is exposed.

Swift Beds. The Swift Beds, of lower Arenigan age, are extremely poorly preserved in the Burke River Outlier, and are limited to the south-western corner of the outlier. The formation consists of sandstone and siltstone with chert, and carbonate interbeds. About 20 to 30 feet are recorded by Opik (*in* Carter and Opik, 1963). No contact relationships with other formations were observed, but the unit is reported to unconformably overlie the Ninmaroo Formation elsewhere.

Mesozoic

Sediment remnants of probable Mesozoic age are preserved as caps on some of the northern mesas of O'Hara Shale, along and adjoining the eastern margin of the Burke River Outlier, and in two places in the south-western marginal area of the outlier.

In the north, along the Camel Fault zone, the Mesozoic deposits consist of a ferruginous basal quartz conglomerate overlain by fine- and medium-grained sandstone (cross-bedded in its upper part) and massive silty mudstone with small ferruginous pisolitic concretions (Fig. 38). A section in the mesas south-west of Camp Oven Bore starts off with 10 to 30 feet of coarse basal quartz conglomerate unconformably overlying steeply tilted Cambrian siltstone; the conglomerate is overlain by about 35 feet of massive silty mudstone, silty sandstone, and occasional gritty layers and lenses and cross-laminated beds. This is followed by a thin layer of shale overlain by more than 5 feet of ferruginous pebbly quartz grit (possibly Tertiary?). The former presence of the basal conglomerate elsewhere on the top of mesas and plateaux is commonly indicated by thin layers of unconsolidated quartz gravel, the remnants of disintegrated conglomerate. Some of the better developed gravels occur on the plateau tops south of Wangaratta Bore.

Along and adjacent to the eastern margin of the Burke River Outlier, the Mesozoic comprises quartz conglomerate at least 20 feet thick and arenites varying from well-sorted medium-grained sandstone to poorly sorted quartz grits. They overlie the Precambrian as well as Mount Birnie Beds, Thorntonia "quartzite", or O'Hara Shale.

A Mesozoic remnant previously unmapped covers the top of the mesa on the south side of Dead Horse Creek, in the south-west. It thickens from a few feet of leached, white lightweight massive chalky-looking rock or porcellanite at the top of the mesa in the north-west, where it is much broken up and rests on a thin irregular layer of ferruginous gritty sandstone, to a sequence of conglomerate, pebbly sandstone, sandstone, and shale, up to about 60 feet thick farther south-east, where it unconformably overlies Mount Birnie Beds (Fig. 10).

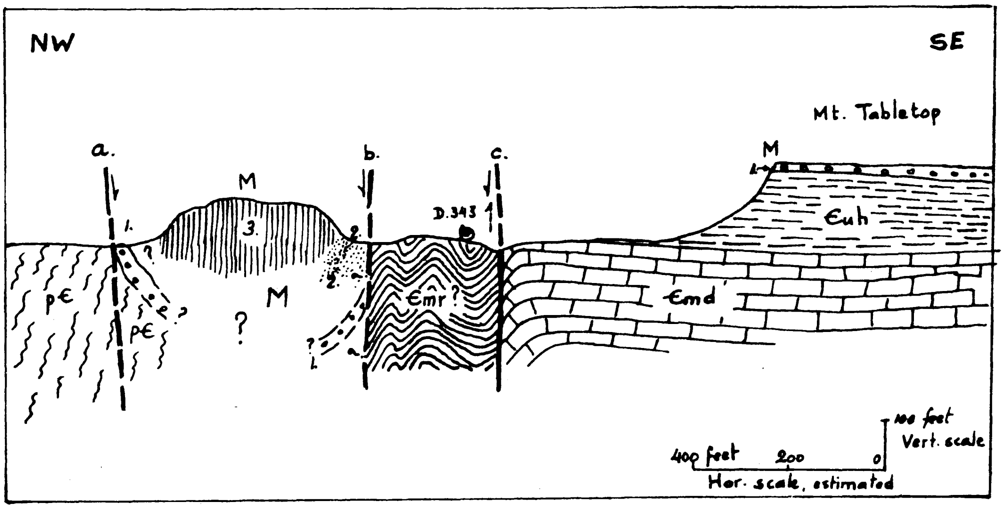

FIGURE 38 — Diagrammatic section across Camel Fault zone, Camp Oven Bore area.

Mesozoic (M) {
3. Massive silty mudstone with pisolitic, ferruginous concretions.
2. Massive sandstone overlain by cross-bedded sandstone.
1. Quartz conglomerate with ferruginous cement

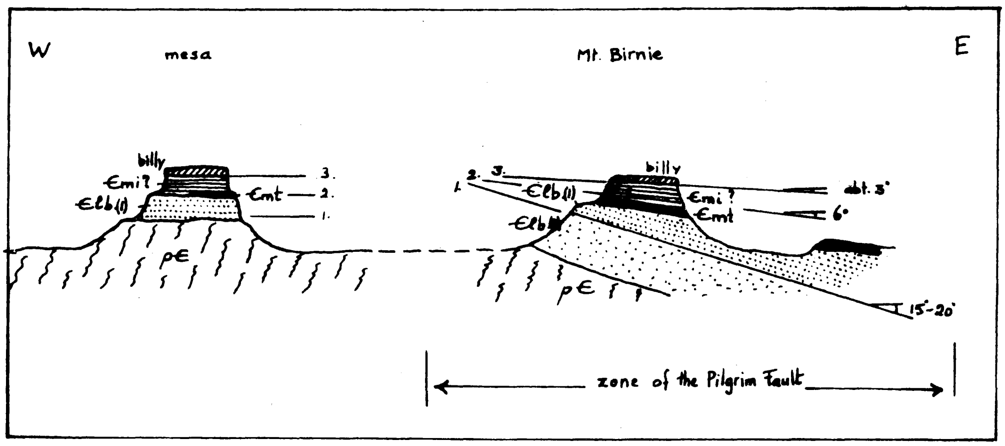

FIGURE 39 — Diagrammatic cross-section, Mount Birnie area, showing the effects of recurrent differential movements in the Pilgrim Fault hinge zone.

1. Lower Cambrian surface, now tilted 15°-20°
2. Middle Cambrian surface, now tilted about 6°
3. Cainozoic surface, now slightly tilted.

Note also the absence of Єlb(2) in the mesa area.

Another Mesozoic outcrop was recorded by Opik from a locality about 2 miles east of Galah Bore in the south-west. The outcrop consists of rubbly chert with shell fragments and pebbles of soft, semi-consolidated siliceous shale. Fossils include lamellibranchiata and silicified coquinites, and the deposit is thought to be a shallow-water inlet deposit.

Skwarko (1966) includes the Mesozoic remnants in the area with the inland deposits of the Cretaceous Mullaman Beds. The latter are subdivided in the non-marine Lees Sandstone (Neocomian? and Aptian) at the base, followed by non-marine siltstone and fine-grained sandstone (Aptian), and completed by disconformable marine Polland Shale (Albian?). A rough correlation with the Duchess sections seems possible.

Tertiary

Tertiary deposits consisting of opaline and chalcedonic silica and siliceous limestone occur in the central parts of the Burke River valley, and are probably the northern extension of the Noranside Limestone exposed in the adjoining Boulia Sheet area. A maximum thickness of about 50 feet is estimated. In the siliceous limestone beds, milky or grey chalcedonic silica is distributed in irregular beds, masses, lumps, and layers.

The age of the deposit is thought to be late Tertiary (Paten, 1960), and it is probably of lacustrine origin.

A previously unmapped deposit of Tertiary age was found between Pilgrim Creek and Maiden Creek to the west of the Pilgrim Fault, and overlying the Precambrian. The outcrop consists of low-density white porous sinter-like siliceous sediments, milky opaline silica, and bedded, relatively compact but low-density, grey silica. They may be spring deposits.

The high-level gravels found scattered around the margins of the outlier, are also considered to be of Tertiary age.

Another Tertiary feature is the lateritization. As a result of lateritization, a duricrust ("billy" or "grey billy") was formed over large parts of the O'Hara Shale plateaux, that is, over an old and exhumed pre-Cretaceous land surface. Other effects are the strong ferruginization and red-colouring of the siltstones, leading to the alteration of the original composition and obliteration of the structure of the sediments near the top of the plateaux; in places, a leached white pallid zone is also exposed. Limestone formations are usually unaffected except for a few specific beds which may be turned into concretionary-ferruginous beds from which all traces of carbonate have been removed.

Quaternary

Quaternary alluvial deposits are widespread in the Burke River valley, forming the Burke River Plain. They include alluvial soil, sand, and gravel, and are up to several tens of feet thick. The lower beds are probably of Tertiary age.

STRUCTURE

Opik (1960) defined the Burke River Outlier as the northern segment, surrounded by Precambrian basement rock, of the Burke River Structural Belt. He described the outlier as a sunkland or graven bounded by faults in the north, east, and west, and by a trough in the south. The total thickness of Palaeozoic rocks in the outlier increases from about 1000 feet in the north to an estimated 5000 feet in the Chatsworth area (Carter and Opik, 1963).

Faults. Figure 37 shows the major fault zones with their relative displacements, the main joint systems, and a few folds due to drag along the faults. Compared with Opik's diagram of faults, and with the existing Geological Map of the Duchess 4-mile Sheet, a few slight changes have been made; some faults are extended, or are now known to be more complicated, a few more faults have been added, and several faults in the extreme north and north-east for which no justification could be found have been deleted. Names given by Opik (1961) have been retained, and two more added.

The net effect of the faulting has been the formation of a graben. Differential movements have been more intense along the western fault zone than in the eastern fault belt, resulting in more pronounced tilting and even in the development of largely anticlinal folds. Opik (1961) estimated, on stratigraphic grounds, that the vertical displacement is not less than 1000 feet along the Pilgrim Fault, and up to 700 or 800 feet along the northern part of the Roaring Fault. The combined displacement along the Wangaratta Faults is at least 230 feet, as shown in Figure 66. In the Camel Fault zone, the post-Mesozoic displacements total at least 160 feet, while earlier stages of faulting must have produced displacements of more than 700 feet.

The character of the faulting was probably that of very steep overthrusting. Opik (1961) concluded that slickensided fractures across Devoncourt Limestone beds indicate thrusting from the east. Minor thrust faults found during the present survey about 3 miles north of Mount Birnie suggest that the Pilgrim Fault zone is a steep fault thrusting from the west.

Apart from stratigraphical evidence for the faulting, the physical aspects are demonstrated by shearing, crumpling, brecciation, steep tilting, minor folds with sharp crests, fracture cleavage, the wedging-out of beds and lenses, the presence of slivers of one lithology within another, and the granulation and strain shadows observed in thin section. Such deformation is much rarer and less pronounced in the eastern fault zone than in the western.

The vertical component of the faults thus being established, the question arises whether any horizontal component is present. This is not as easy to ascertain. The attitude of one or two small, north-east plunging anticlinal folds adjoining the Pilgrim Fault as a result of drag, would suggest that some sinistral lateral movement was present. Perhaps some dextral component is hidden in small compensatory faults south-west of the Roaring Fault, but minor structures in the disturbed Roaring Siltstone along the Roaring and Camel Faults are all sympathetic with vertical movements, and no indication has been found for lateral movements. It is therefore concluded that the faults have no significant lateral components.

It is probable that some of the faults served as channels for hydrothermal solutions, thus explaining the presence of alunite, fluorite(?), possibly even that of turquoise, as these minerals have been found only in outcrops close to the major faults along the western margin. Another side effect may have been the leaching and complete removal of those limestone beds that had been steeply tilted and therefore made more accessible to solutions. This possibility is suggested by the presence of small, flat-lying outcrops of Thorntonia Limestone restricted to the western side of the northern end of the Pilgrim Fault; there are no outcrops of the limestone east of the fault, but the "unnamed chert rubble horizon" there does contain a fair amount of spherical, concentrically banded grey and white chert nodules identical with the nodules found in the limestone on the west side, and they may therefore represent the insoluble residue of the limestone.

Away from the margins of the Burke River Outlier, the disturbing effects of the faulting fade out rapidly, and the Cambrian strata are sub-horizontal or show very gentle domes and folds with dips not more than a few degrees. These structures are best recognized on the airphotographs.

Joints. Some main joint patterns are shown in Figure 37. Opik (1961) in discussing the joint systems in the northern areas, stated that the Devoncourt Limestone is characterized by a joint direction of N 145° E, whereas in the Selwyn Range Limestone the direction is N 105° E. This opinion cannot be corroborated, for both formations show the 145° direction in the area south-west of the Burke River. Rather, the joint directions appear to be tectonically determined, for example, the joints to the west of the Bronzewing Fault (or its northern extension) strike N 145° E, while those to the east strike N 105° E.

Age of the faulting. There is ample evidence that the major fault systems have known several recurrent phases of activity, dating from the Precambrian, and extending into the Cainozoic. There are also strong indications that the Burke River Outlier has been a genuine depositional basin from the outset, and that its present (faulted) boundaries are not very much different from the original basin margins during at least some of the Cambrian sedimentary episodes. It is thought that at least the meridional boundary faults are positioned along fundamental zones of weakness acting at times as hinge lines for the subsidence.

The strongest arguments for repeated episodes of faulting are found at Mount Birnie and in the Camel Fault zone at Camp Oven Bore. The evidence at Mount Birnie is presented in Figure 39, and is self-explanatory. Note also the absence of the lower part of the Mount Birnie Beds, the degeneration of the Thorntonia "quartzite", and the possible absence of Beetle Creek Formation in the outside mesas.

At Camp Oven Bore (Fig. 38), a narrow graben appears to be present. Mesozoic strata are downfaulted, and drag effects in the Devoncourt Limestone strongly suggest down-faulting on the north-western side of fault "c". The very much disturbed and folded siltstones on that side were therefore thought to be O'Hara Shale, and the picture not too complicated. Although BMR Scouthole No. 12 penetrated the siltstone to a depth of 240 feet without bottoming; the last few feet were slightly calcareous and this was taken as evidence that the underlying Devoncourt Limestone was being approached. However, fossils collected from D343 appear to identify the siltstone as Roaring Siltstone, which forces one to assume that subsequent to an initial down-faulting along fault "c", the sense of movement was reversed at a later stage and brought up the Roaring Siltstone. This reversal might possibly account for the strong folding of the siltstone in the graben. Post-Mesozoic movements along faults "a" and "b" down-faulted the block containing the Mesozoic segment.

The recurrence of faulting is also clearly expressed in a mesa south-west of Camp Oven Bore: here, Mesozoic conglomerate is tilted up to 45° along the fault, and unconformably overlies almost vertical Cambrian siltstone beds.

An argument for faulting going as far back as the Precambrian is based on the presence of quartz-filled fault lines (at The Brothers) alongside and in the same general fault zone as the Pilgrim Fault. Furthermore - if the lower section of the Mount Birnie Beds is Upper Proterozoic - there is a case for an Upper Proterozoic phase of subsidence, if not faulting.

A number of episodes of faulting and flexuring (subsidence) are inferred with greater or lesser certitude:

Episode:	Evidence:
1. Precambrian	Quartz-filled faultlines in same zone.
2. Upper Proterozoic ?	Lower Mount Birnie Beds within outlier, not beyond Pilgrim Fault.
3. Early Middle Cambrian	Beetle Creek Formation confined.
4. Upper Cambrian	See Figures 66 and 38.
5. Post-Cretaceous	Faulted Mesozoic.
6. Late Cainozoic	Tilted billy capping at Mount Birnie.

THE PHOSPHATE DEPOSITS

General. The phosphorite deposits are contained in the Beetle Creek Formation, which has been subdivided by Russell (1967) into a Lower Siltstone Member, a Lower Breccia Member, and a Monastery Creek Member. The latter is characterized by the thick and highest-grade phosphorite sections (Fig. 41), while a few thinner and lower-grade phosphatic beds occur in the Lower Siltstone Member. Some parts of the Lower Breccia Member also contain high-grade phosphorite, but the member is not a true stratigraphic unit.

The Beetle Creek Formation crops out over approximately 100 square miles, centred about 30 miles south of Duchess. Detailed data on the stratigraphy and structure of the units in this area have been obtained by the company during their drilling and mapping programme, but the information is confidential.

Isolated very small (though very high-grade) deposits of phosphorite occur at the base of the Roaring Siltstone east of Duchess, and at the headwaters of Pomegranate Creek, but these outcrops probably represent eroded remnants of Beetle Creek Formation. The Thorntonia Limestone and the base of the Devoncourt Limestone in the extreme north where the latter directly overlies the Thorntonia Limestone are slightly phosphatic. The base of the Inca Formation is also reported to be phosphatic (Russell, 1967).

Field characteristics. Although phosphorites are usually unobtrusive rock types of varied colour and lithology, the Duchess phosphorites are rather distinctive once one has become familiar with them. They can be recognized firstly by their typical and common pelletal texture (Fig. 42), the pellets

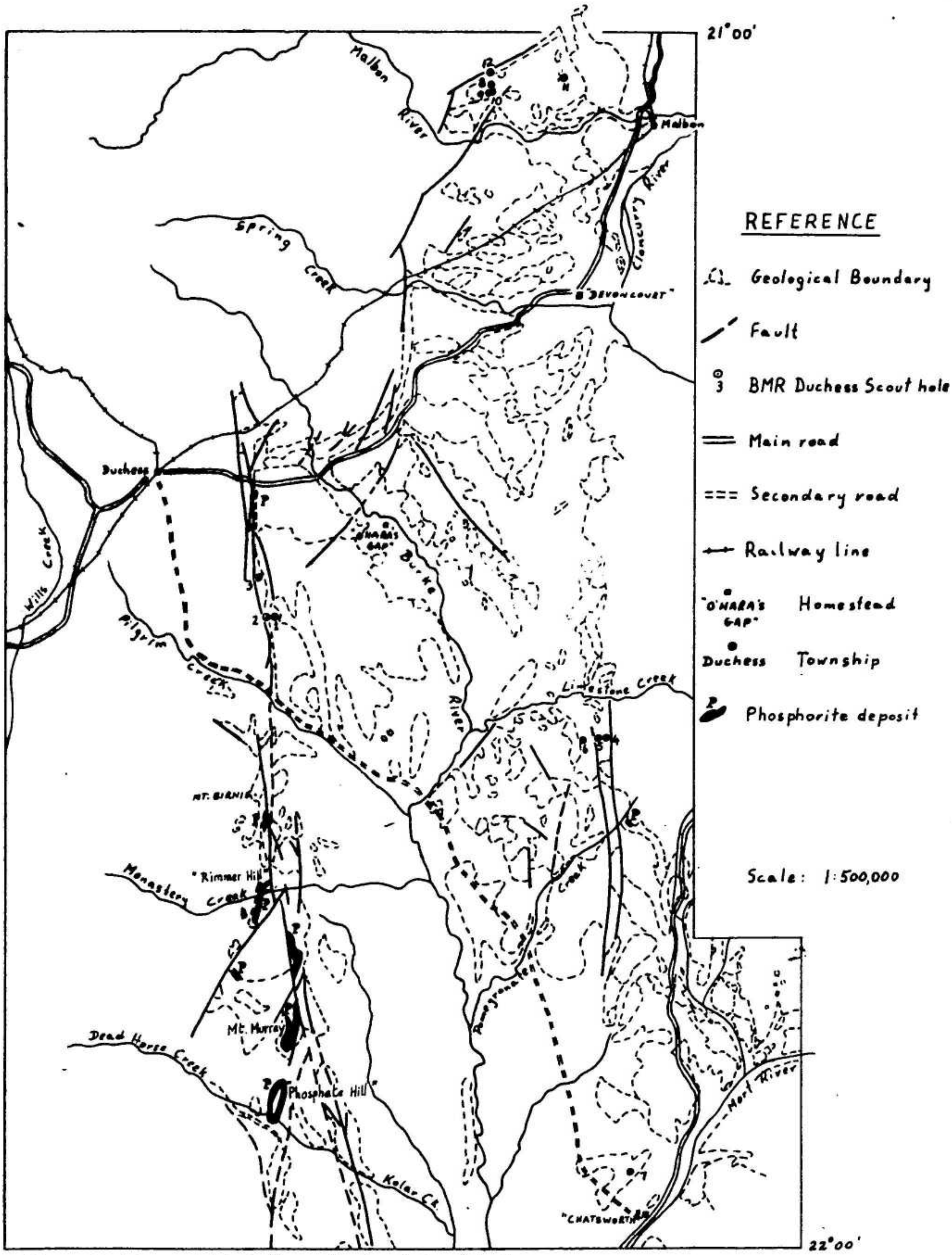

FIGURE 40 - Distribution of phosphate deposits ; Location of BMR Scout holes

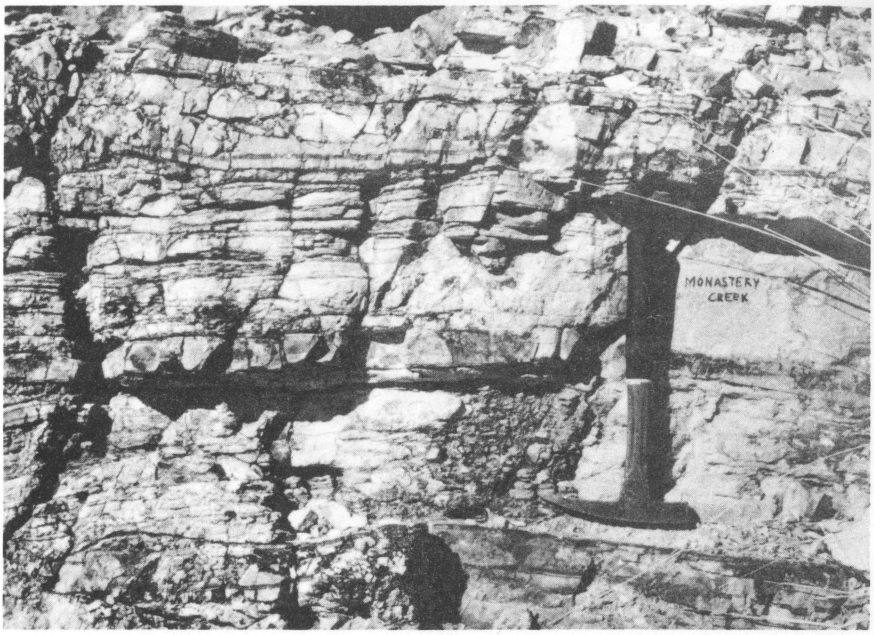

Figure 41: Phosphorite section in Monastery Creek. Beds of phosphorite, phosphatic siltstone, and thin laminae of chert. 'Monastery Creek Member', Beetle Creek Formation.

Figure 42: Typical pelletal phosphorite. Area 2 miles north of Mount Murray.

ranging in size from 0.06 to 0.60 mm across. Other features include: a high specific gravity; a faint bluish to purplish light-grey phosphatic "bloom" on some weathered surfaces; a typical "brain" texture etched on weathered surfaces of high-grade material; and a grassy vegetation in combination with a scarcity of trees and often the presence of a certain type of scrubby plant species over the outcrop. It is also reported that "poisonous gidyea" favours phosphatic soils.

Chemical tests. The ultimate test for phosphate is the ammonium molybdate test, by which a rock is stained yellow in the presence of even small quantities of phosphate. The test is purely qualitative and has its drawbacks: it may give a strong positive reaction even where very little phosphate is available, especially when the sample is calcareous, and in cold weather the reaction may be very slow. In addition, some types of high-grade rock seem to give a deceptively weak or slow reaction while on the other hand some of the cherts associated with the Duchess deposits react strongly. It is possible that this may be caused, or at least strengthened, by precipitation of yellow silica molybdate. This is suggested by the observation that barren Tertiary opaline silica in places reacted positively to the test, and that some altered silicified Thorntonia Limestone did the same although in thin section not a trace of a phosphate mineral could be detected. It could also explain the fact that the test solutions deteriorate much faster in glass bottles than in plastic containers. It seems that only opaline and chalcedonic silica are reactive, while quartzose rocks are inert.

Semi-quantitative tests can be made with the Shapiro method. It is, however, advisable to prepare new standards each time a fresh solution is made up: the results obtained in the field with old standards applied to fresh solutions subsequently proved to be consistently 20 to 40 percent below the assayed values.

Lithology. The composition of the phosphorites ranges from dense pelletal rocks consisting almost exclusively of francolite ("collophane") to siliceous and calcareous phosphorite, phosphatic chert, phosphatic siltstone, and phosphatic biopelsparite. These beds are associated and intercalated with bedded chert, siltstone, and biosparite including encrinite limestone and glauconitic varieties. Photomicrographs of some of the sediment types are shown in Figures 47-50 and 52-61.

The surface colours of the phosphorite are creamy, white, grey, or brown. Some brown phosphorite has bleached rims. The cherts are caramel brown to grey, the siltstones red, and the limestones light grey. Below the zone of oxidation, the phosphorites siltstones and cherts are black, as indicated by a drill-hole in the Monastery Creek area.

The strata are thin- to medium-bedded, and thick beds are subordinate (Figs 28, 41, 44). In many places, small-scale cut-and-fill structures and cross-lamination are common (Fig. 43). Some chert layers may contain cracks filled with clastic pelletal material (Figs 60, 61). Whether these cracks are desiccation cracks or a feature formed as a result of a volume decrease following the silicification of the rock, the fact that they are filled with collophane grains and other material swept-in from the overlying layer shows that the process must have taken place before the consolidation of the overlying rock. This is also indicated by the presence of cut-and-fill structures in tough, splintery chert layers.

Highly fossiliferous beds occur in the Mount Murray area and to the north of Mount Murray, and include encrinite limestone, beds rich in sponge spicules, and beds with a mixed fauna of agnostids and other trilobites, sponge spicules, phosphatic brachiopods, and bradorinid ostracodes.

Secondary processes. Some of the originally calcareous beds and limestones were silicified to chert beds. This is displayed in Figures 44-46. However, it is difficult to decide whether all chert beds in the Beetle Creek Formation represent silicified carbonate beds. Of particular significance is the outcrop shown in Figures 44 and 45. The original rock was obviously a phosphatic limestone which became silicified to a cherty phosphorite in which the traces of the original bedding were destroyed. During the process, part of the carbonate was leached out and lost without being replaced, and because of the resulting decrease in rock volume the collophane pellets were residually concentrated resulting in an increase in phosphate content from 6.8 percent to 20.6 percent P_2O_5. There was no active phosphatization of the silicified bed, and in both rocks the pellets appear to be identical in every respect.

Figure 43: Cross-bedded pelletal calcareous phosphorite. Area 2 miles north of Mount Murray. (Arrow in lower right corner about 1 inch long).

Figure 44: Silicified phosphorite bed, with two nodular remnants of unaltered original phosphatic limestone bed still showing initial bedding structure. See also Figure 45. Bed is about 9 inches thick. Costean south of Mount Murray.

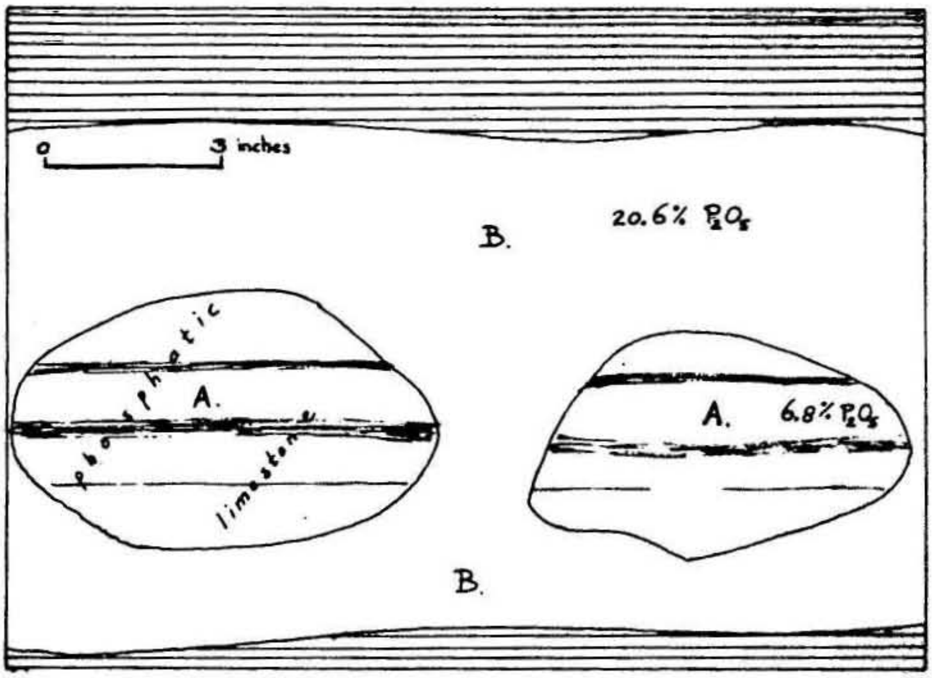

FIGURE 45 – Silicification of a phosphatic limestone bed (A.) produces a siliceous phosphorite (B.). Decrease of volume is suggested by relative enrichment in P_2O_5 in the silicified rock (see text).

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FIGURE 46 – Silicification of limestone produces chert. Laminae of phosphate pellets remain unaffected and undisturbed.

.... trail of phosphate pellets.

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An added peculiarity in this outcrop is the presence of a thin alunite zone along the junction between the limestone and the chert. The alunite (identified by optical and X-ray diffraction methods by C. Murray) replaces the collophane pellets only, whereas both the calcite and the chert matrix remain unaffected. As the mineral is usually thought to be formed in the presence of sulphuric acid and commonly under conditions of high temperature and pressure, it is suggested that hydrothermal solutions associated with the Pilgrim Fault zone may have been responsible for its formation. Reasoning along the same lines, it seems feasible that in this case the silica may also have been of hydrothermal origin. Another possible explanation for the formation of the alunite suggested by C. Murray is that the necessary sulphuric acid was derived from the oxidation of pyrite present in the limestone.

Alunite also occurs in the Mount Murray area as coarse fibrous semi-radiating aggregates with fibres up to an inch long.

At Monastery Creek, a light grey to white bed near the base of the Inca Formation was found (by X-ray work) to consist of quartz, alunite, and muscovite.

Turquoise and variscite occur locally in the Mount Murray area and in several other places.

In two thin sections - one from a quartzitic fragment in the core of BMR Scouthole No. 3, the other from a pelletal cherty phosphorite at Mount Murray - idiomorphic rhombs of a colourless isotropic mineral with fair relief and with an R.I. lower than that of Canada balsam were noted. Except for the crystal form, these properties suggest that the mineral is fluorite(?) (Figs 62, 63). In both sections it is associated with secondary silica.

Other processes of replacement observed in thin section include:

a. phosphatization of calcitic fossil fragments and probable lime mud.
b. silicification of calcitic fossil fragments and of matrix calcite, commonly beginning in the centre of cystoid fragments. Also rare silicification of collophane fragments.
c. calcification of chalcedony, detrital quartz grains (marginal only), clauconite, and collophane pellets.

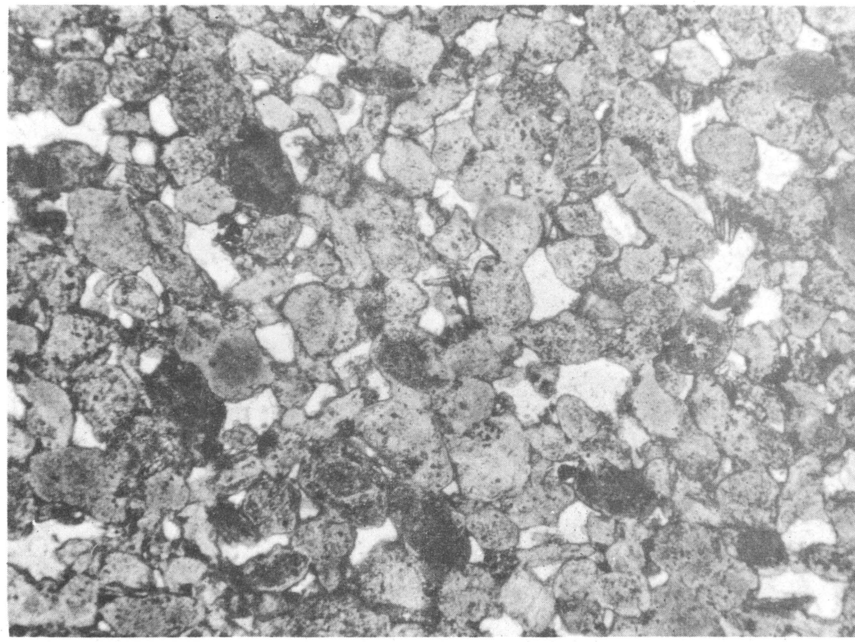

Figure 47: High-grade pelletal phosphorite, Mount Murray area. High concentration probably due to winnowing, or possibly to leaching of original calcareous matrix. X100

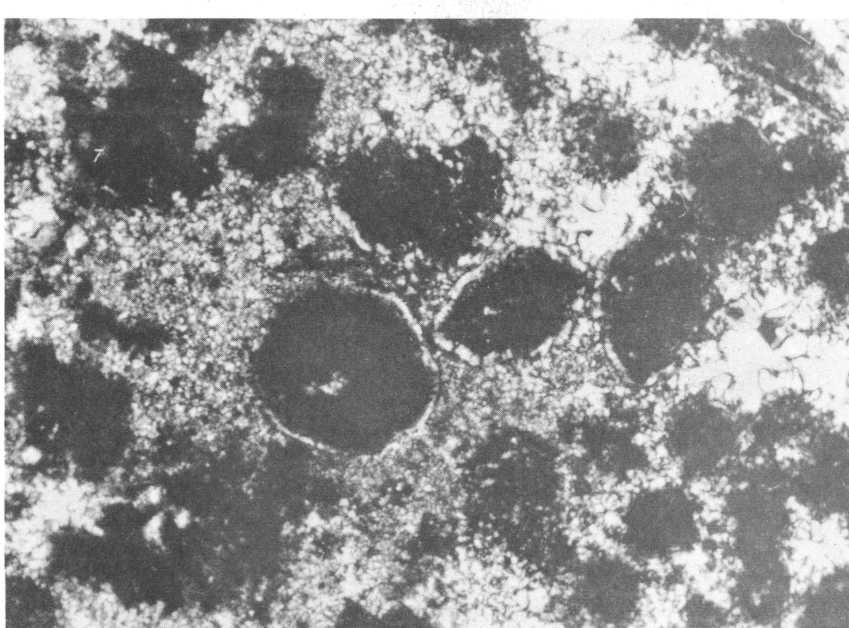

Figure 48: Collophane pellets thinly rimmed by dahllite(?), in chert matrix (crossed nicols). Rimmer Hill. X100

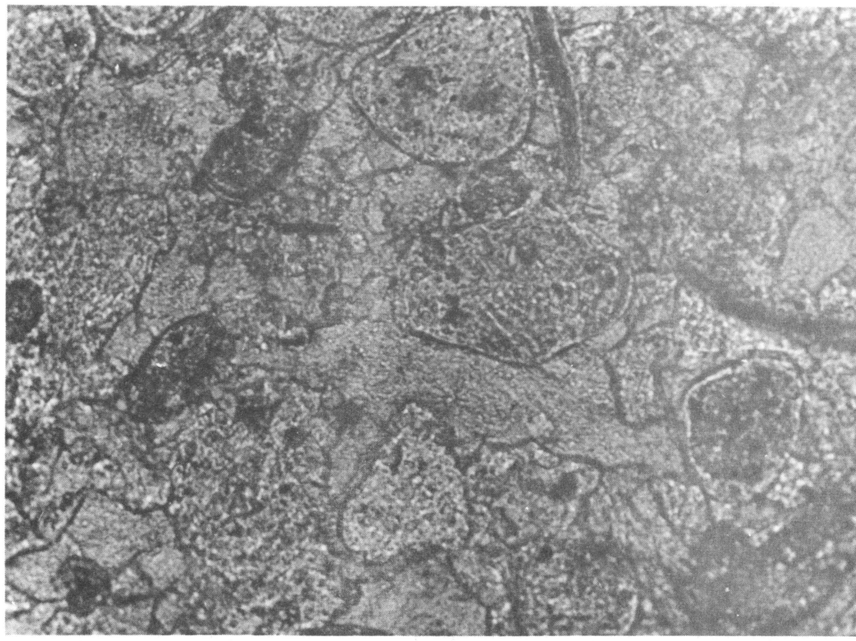

Figure 49: Biopelsparite, phosphatic. Collophane pellets and fossil fragments in sparry calcite. Area 2 miles north of Mount Murray. (Ordinary light). X100

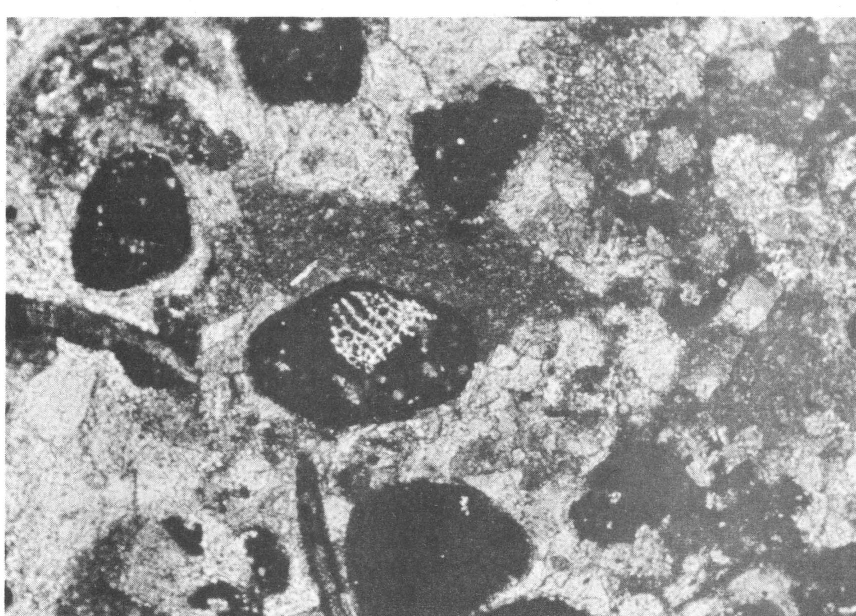

Figure 50: As above, but crossed nicols. Remnant of a skeletal structure (calcitic) clearly visible in central pellet. X100

These processes are usually incomplete and do not lead to wholesale alteration and replacement of a rock. Also, reversal of a process in a given rock is sometimes obvious, for instance where a phosphatized or partly silicified fossil fragment is in turn replaced by coarse idiomorphic crystals of calcite. The order of replacement may vary, but in general phosphatization of calcite takes place before silicification, and marginal replacement by calcite, where present, occurs last.

Diagenetic recrystallization of calcite to a crystal size up to 0.5 and even 0.8 mm is commonplace in the limestones, especially in the fossil-rich types.

The phosphorites. The phosphorites are composed of:

- a. collophane pellets and pseudo-pellets (Figs 47-50)
- b. phosphatized fossil fragments (Figs 19, 54-57)
- c. phosphatized mud (Fig. 52)
- d. composite lumps or aggregates

The pellets range in size from 0.06 to 0.60mm across, and are usually spherical, ovoid, or well-rounded slightly irregular forms. They consist of isotropic or weakly birefringent "collophane", which is generally yellow to dark brown, but may be colourless when oxidized. Some pellets are thinly rimmed by a slightly more strongly biregringent mineral, possibly dahllite, which is oriented with its fibres at right angles to the pellet surface (Fig. 48).

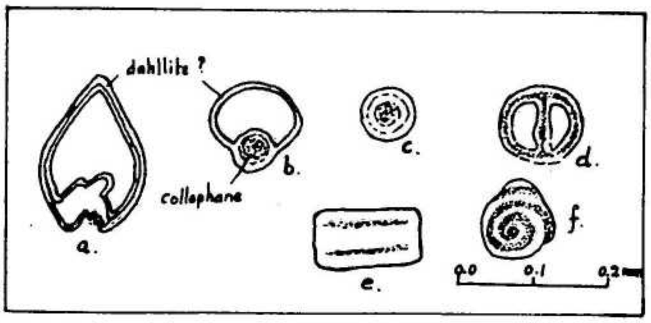

FIGURE 51 — Some of the more uncommon forms of phosphatized organic matter found in thin section. e may be a faecal pellet.

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The pellets are of different origin, but in most cases this is no longer recognizable. Some are phosphatized fossil fragments, rounded by abrasion and attrition (cf. Figs 17, 19, 51, perhaps also 50), or they may be phosphatized carbonate pellets or oolites. Others are faecal pellets (Fig. 51e, f ?), fragments of phosphatized carbonate mud, lumps or aggregated pellets (discernible only under crossed nicols), and possibly also algal pellets where they contain much organic pigment. Most of the pellets are probably faecal pellets, notwithstanding the scarcity of internal structures (which are easily destroyed anyway). Some pellets contain very fine-grained clastic material (about 0.01 to 0.02mm), usually quartz and sericite, showing rolled-about orientation (faecal origin? minute mud balls?) or, in larger fragments, a bedded orientation (fragments of a lime mud layer). Other pellets are clear and devoid of detrital material. Clastic material may be present in pellets even in calcareous rocks in which clastic quartz and sericite are rare or absent.

All the above pellet varieties may occur together in the same rock, which proves that they had been transported from elsewhere, and have behaved like normal sediment particles. No evidence whatsoever could be found for direct chemical precipitation. On the contrary, all observations point to an origin by replacement of calcareous material, whether organic or inorganic. Figure 52 shows a thin collophane layer in a biopelsparite; the layer contains minute particles of quartz and sericite, and also patches of remnant calcite, and it seems clear that the layer was a fine-grained lime mud subsequently phosphatized. Elsewhere in the same section, angular as well as rounded fragments of the same material were evidently derived by the flaking off of such a mud layer. Continued reworking and attrition would eventually produce rounded pellets. Elsewhere in the rock, large fossil fragments still contain similar phosphatized lime mud material in their cavities where the mud was protected against removal by washing-out. This is to some extent shown in Figure 55, but much better examples are also found.

Upgrading of the original phosphatic sediments. Assuming that biopelsparites such as shown in Figures 29-50 and 52-57 are the original sediments in which phosphate is mainly present in the form of phosphatized lime mud, fossil fragments, and faecal pellets, enrichment to medium and high-grade phosphorite could then take place along the following lines:

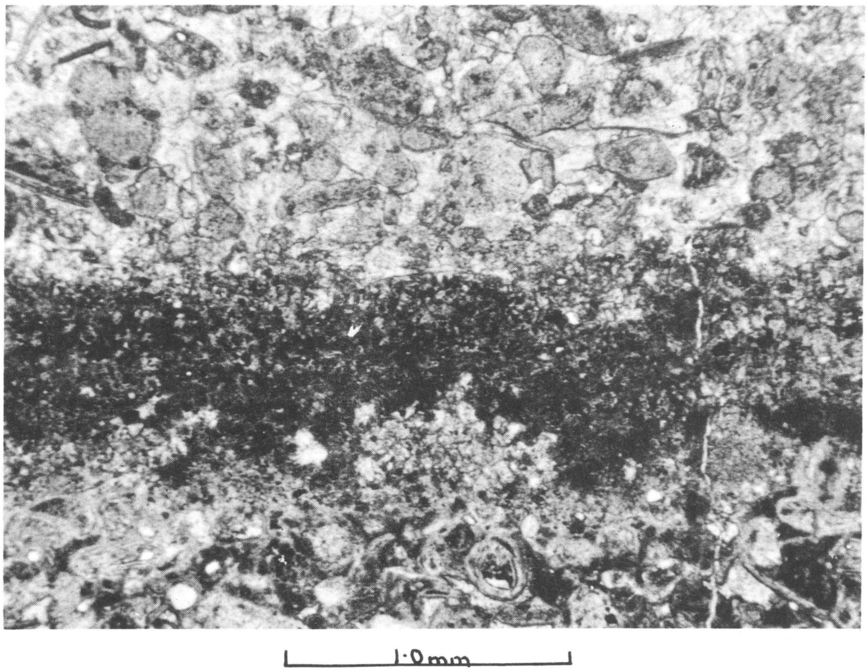

Figure 52: Phosphatic biopelsparite with dark layer of collophane. Area 2 miles north of Mount Murray. (Ordinary light). X35

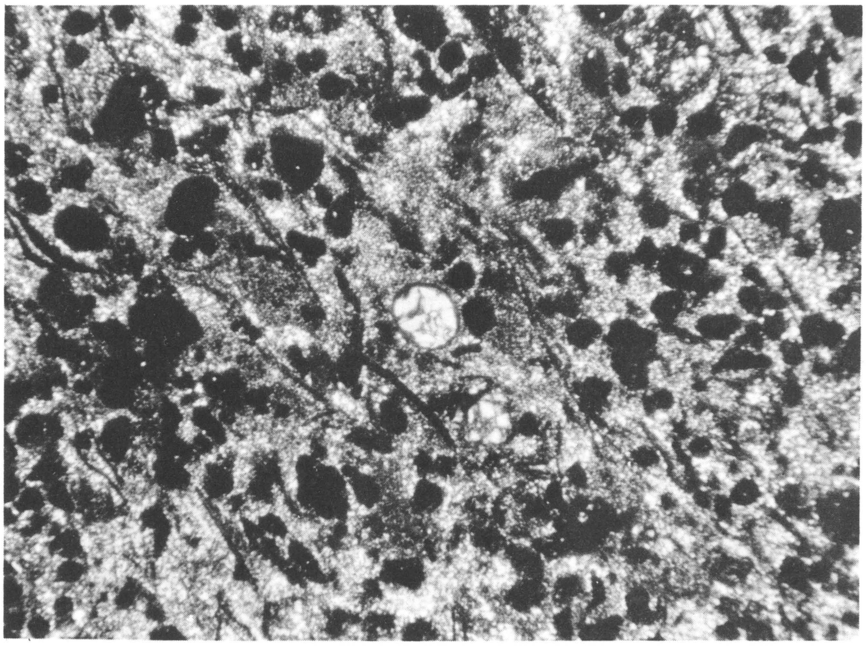

Figure 53: Fossiliferous pelletal cherty phosphorite (silicified biopelsparite). Fossil fragment in centre is filled with chalcedony. Monastery Creek section. Crossed nicols. X35

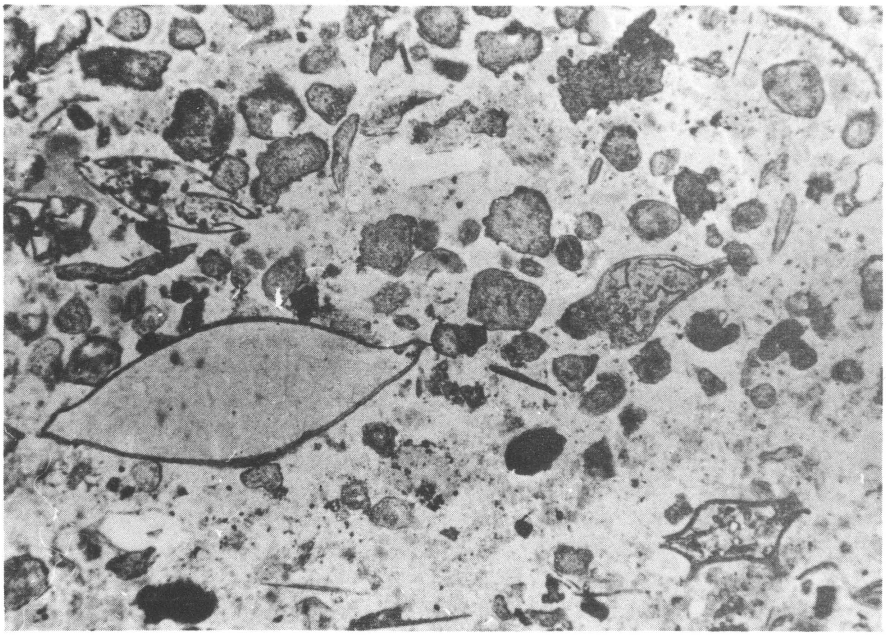

Figure 54: Fossiliferous phosphatic chert (silicified phosphatic biopelsparite), same thin section as Figure 53, Monastery Creek. Ordinary light. Collophane pellets (dark grey), and phosphatized fossil fragments in light grey chert matrix. X35

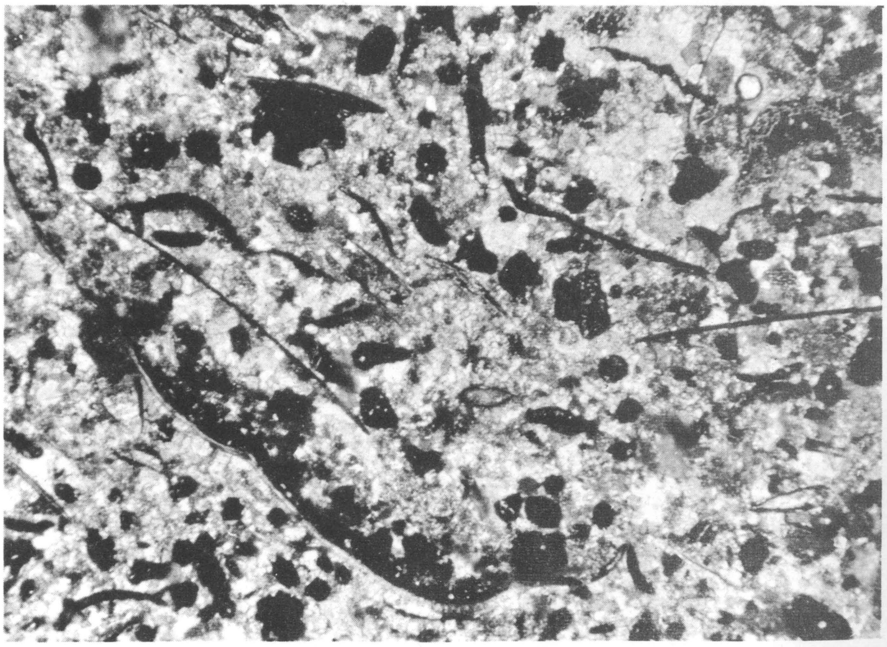

Figure 55: Phosphatic biopelsparite, area 2 miles north of Mount Murray. Crossed nicols. Collophane pellets and phosphatized fossil fragments (black) in sparry calcite matrix. Large fossil fragment in the lower left is filled with collophane and some remaining calcite. X35

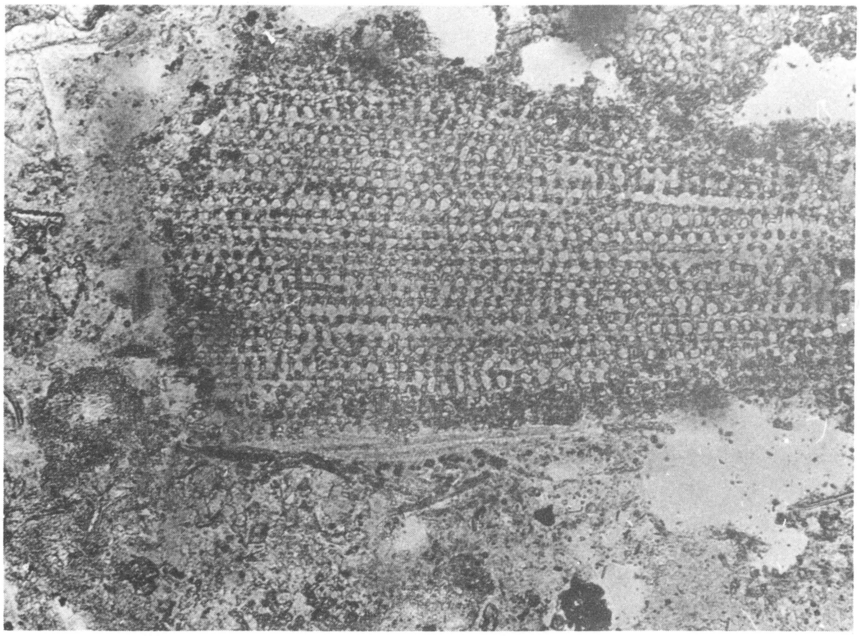

Figure 56: Fossil fragment in biopelsparite, area 2 miles north of Mount Murray. Ordinary light. Skeleton is partly collophane, partly calcitic. X100

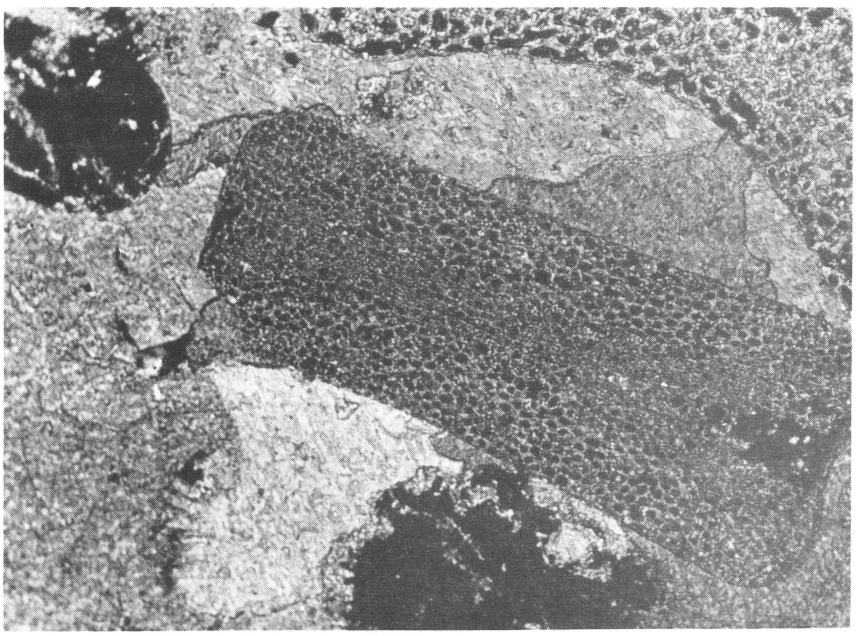

Figure 57: Fossil fragments in biopelsparite, area 2 miles north of Mount Murray. Crossed nicols. Skeletons are partly collophane (black), partly calcite (grey). Black collophane pellet in lower right-hand corner partly replaced and crossed by calcite. X100

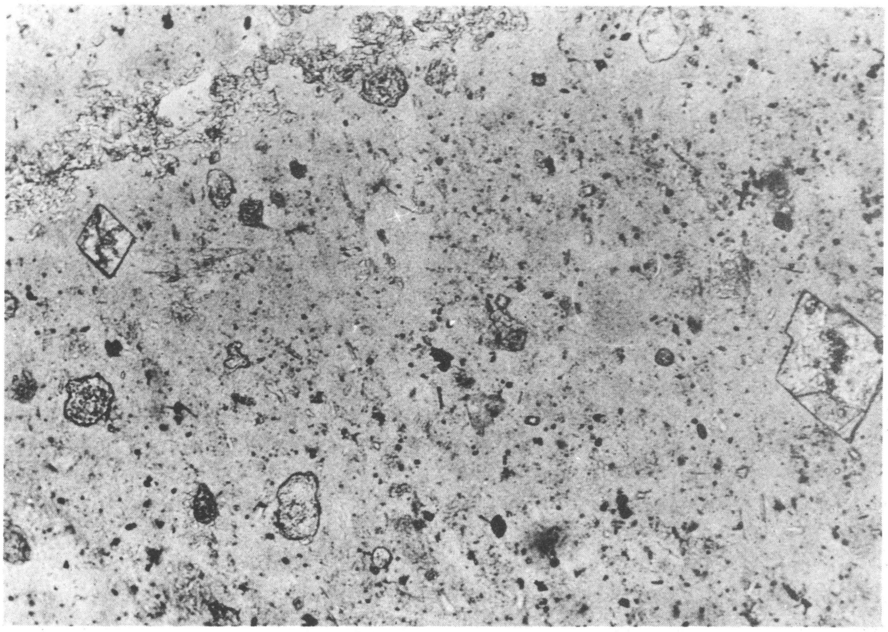

Figure 58: Phosphatic chert with few phosphate pellets and two rhombohedrons of dolomite. Ordinary light. Area 2 miles north of Mount Murray. X100

Figure 59: Phosphatic biopelsparite (encrinite limestone). Cystoid and other fossil fragments and some phosphate pellets. Ordinary light. Area 2 miles north of Mount Murray. X35

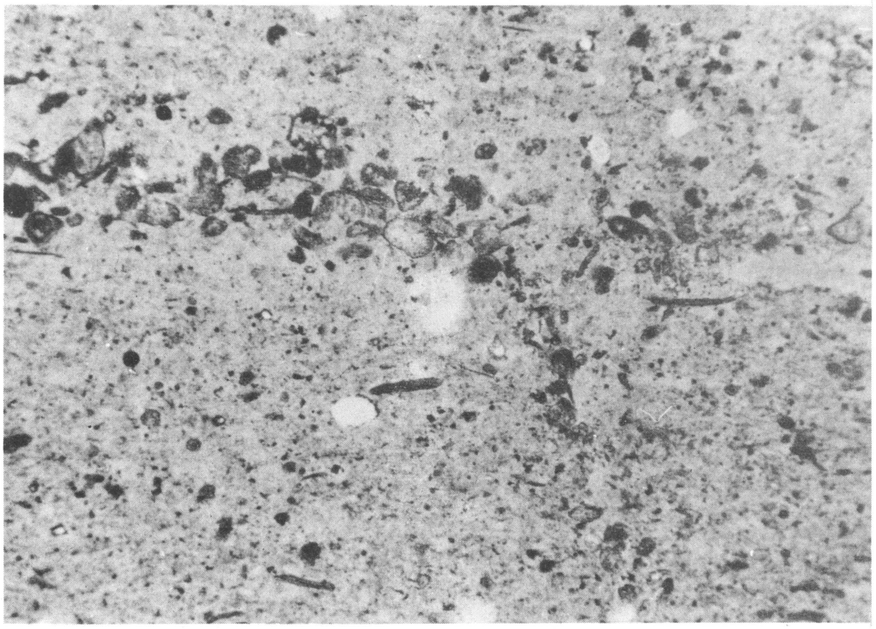

Figure 60: Phosphatic chert with thin layer of collophane pellets. The chert below the layer is cracked, and pellets have been swept into the joint. Area 2 miles north of Mount Murray. Ordinary light. X35

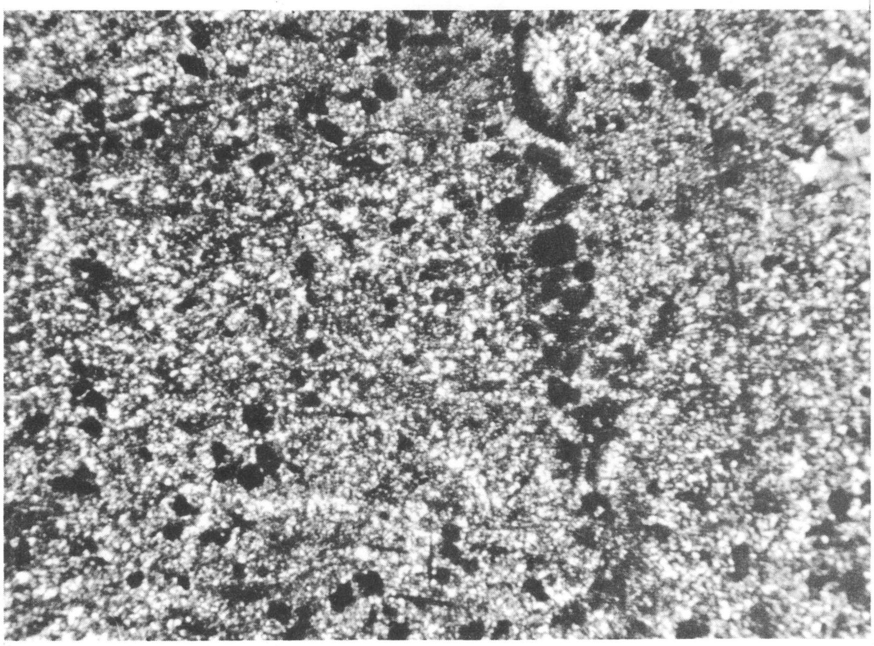

Figure 61: Same rock as above, but slightly below it. Crossed nicols to accentuate the collophane pellets. Concentration of pellets in the continuing crack (see above) clearly shown. X35

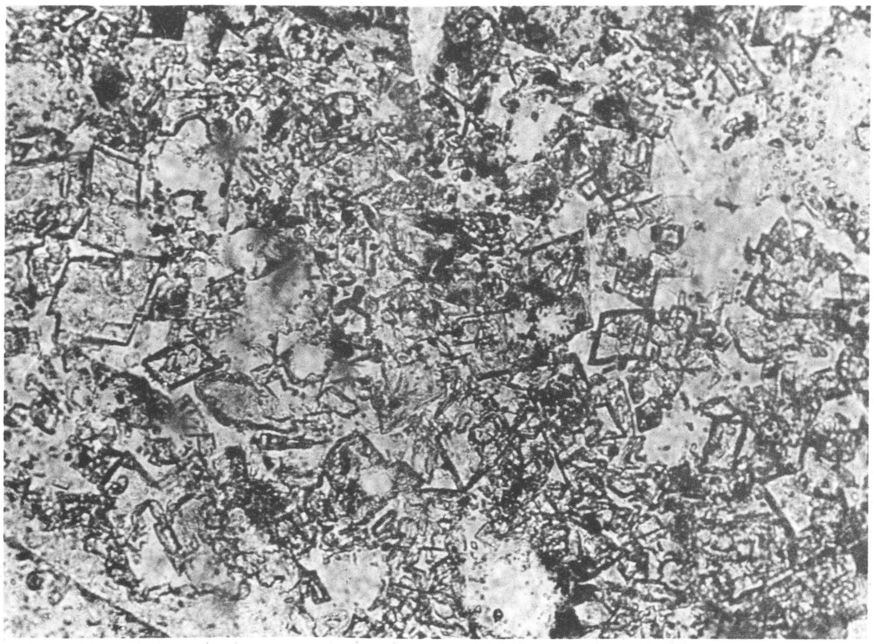

Figure 62: Fluorite (??) crystals in quartzitic matrix. The mineral is colourless, isotropic, has fair relief with a R.I. lower than the Canada balsem. Fragment in sandy siltstone matrix. Core from BMR Duchess Scout hole No. 3, at 33' depth. X100

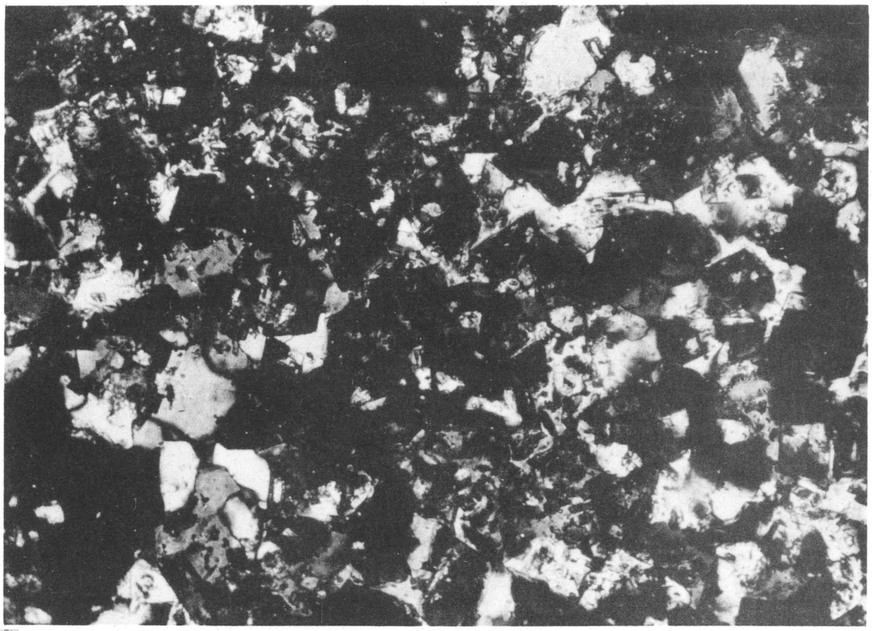

Figure 63: As above, but with nicols crossed. The fluorite (??) crystals are isotropic, or birefringence colours of underlying quartz comes through. X100

a. calcite was lost in solution whenever the pH of the environment was sufficiently lowered. This was commonly accompanied by silicification but at any rate the resulting decrease in rock volume led to a residual enrichment in phosphate content (Figs 44, 45). A rock almost entirely consisting of collophane pellets (Fig. 47) could conceivably be the end result of carbonate leaching; however, in this case at least the absence of large phosphatized fossil fragments rather suggests that the rock was produced by other menas.

b. the sediments were reworked and carried away by currents to other areas of deposition where a natural sorting process separated coarser fractions (to become coquinites) from finer ones (pellet rocks); final high-grade concentration was obtained in the pelletal rocks by the winnowing out of the fine mud fraction. Figure 47 shows a probable example of such a rock type. The contact surfaces between individual pellets usually shows a concentration of sericite left behind and trapped during the process.

c. a third method of enrichment may have consisted in the reworking (without long transport being involved) of unconsolidated sediment by wave action and currents; the phosphate pellets, with their high specific gravity, became concentrated in seams and thin layers in the same way heavy minerals are normally concentrated.

Mineralogy. X-ray work by C. Murray showed that the "collophane" consists of francolite. Dahllite could not be detected, although in some rocks many of the pellets are thinly rimmed by a slightly more strongly birefringent fibrous apatite mineral, which in this report is conveniently referred to as dahllite. Wavellite and variscite were identified in an unusual specimen consisting of silica with small globules of these mainerals. Turquoise has already been mentioned. According to Russell (1967), crandallite is common in the basal section of the Inca Formation.

Chemistry. Thirty phosphorites and phosphatic rocks were analysed in the BMR Laboratory for their content of P_2O_5, Fe, and the trace elements Mn, Cr, Ni, Co, Cu, Pb, Zn, and Cd. The results are given in Table 1. The iron content is very low (except in the Little Phosphate Hill specimen), a quality of importance in the beneficiation of phosphate rocks. Further work is contemplated, and any speculations on the above results would be premature.

Palaeo-environment and genesis of the Duchess phosphorites

All evidence found so far strongly indicates that the Beetle Creek phosphorites were formed in biopelsparite sediments by the replacement of calcite in fossil fragments and lime muds, and were subsequently upgraded by processes of leaching, reworking, sorting, and winnowing. Whilst there is no general agreement on the precise conditions controlling the formation of phosphate, it seems likely that the conditions required for the phosphatization are: a pH higher than 7; a PO_4^{-3} concentration of more than 0.1ppm; an environment of slow deposition, and a water depth most favourably between 100 and 500 meters; the presence (according to some workers like Ames, 1959, and as confirmed in this report) of calcareous material, and a Ca-saturation of the sea water with respect to the HCO_3^- content.

These conditions appear to have been satisfied in the Mount Murray area, where there was an abundance of organisms (indicating the water was rich in nutrients) the water depth was not very great (abundance of cut-and-fill and cross-lamination, and repeated facies changes), sedimentation was slow, and the pH high. The Mount Murray area was probably the site of a carbonate bank association of sediments, characterized by biopelsparites, low rate of sedimentation, presence of glauconite, high to moderate energy, high pH, mostly positive Eh, and a littoral to infralittoral environment. Such associations are found on stable as well as unstable shelfs, in this case probably the border of the shelf. North of the Mount Murray carbonate banks were areas of slightly deeper water where silts and shales were slowly deposited in a quieter environment. The black colour of the fresh rocks here, the presence of pyrite, and the bituminous nature of the limestone lenses, suggest that water circulation could have been restricted at least partly in the Burke River basin. The abundance of trilobite fragments in the Beetle Creek Formation south of Dead Horse Creek suggests possible episodes of mass mortality when the organisms coming from the open sea were trapped in stretches of poisonous water of the Burke River Basin (and hydrothermal solutions may have added to the water poisoning). Southwards, the Mount Murray area probably faced the open ocean where the water gradually deepened.

TABLE 1

	P_2O %	Fe	Mn	Cr	Ni	Co	Cu	Pb	Zn	Cd
			parts per million							
Monastery Ck "A"	33.4	0.42	190	55	15	7	75	18	103	2.5
" " "B"	14.8	0.49	180	166	15	4	80	11	68	3.5
" " "C"	23.1	0.75	660	177	34	26	115	11	97	2.0
Phosphate Hill "A"	36.5	0.69	160	59	18	4	25	24	46	<1
" " "B"	37.2	0.73	600	51	24	11	20	18	32	<1
Mount Murray "A"	20.8	0.60	70	39	24	4	43	12	79	1.0
" " "B"	5.9	0.06	45	260	26	4	46	5	36	<1
" " 67632022/1	6.8	0.11	115	3	13	<4	20	35	30	<1
" " /2	20.6	0.27	60	66	15	4	27	12	37	<1
Little Phosphate Hill	35.5	>5	1900	63	15	15	154	18	82	1.5
Duchess 623	37.5	0.30	2200	39	29	30	136	20	100	12.5
" 624	37.2	0.80	160	63	18	8	83	34	68	3.0
" 626	36.4	1.24	520	75	36	46	320	24	114	3.5
" 627	38.1	0.48	60	66	9	<4	38	9	68	1.5
" 640 "A"	19.2	0.48	20	79	9	4	27	11	48	<1
" " "B"	16.9	0.22	40	17	10	4	23	12	26	1.5
" " "C"	21.1	0.92	40	110	12	4	61	12	126	1.0
" 663	23.2	0.34	20	51	13	<4	31	10	64	1.5
" 675 "A"	38.2	0.42	40	55	15	<4	27	38	600	16
" " "B"	37.8	0.26	40	21	9	<4	25	43	800	17
" 687 "A"	36.4	0.72	140	79	12	8	80	34	76	4.0
" " "B"	35.3	1.04	60	96	15	8	80	48	60	4.0
Urandangi "1A"	36.4	0.30	140	79	15	<4	15	14	26	<1
" "1B"	34.6	0.42	160	39	15	4	25	6	30	1.5
" "1C"	38.0	0.26	40	55	9	<4	29	12	24	1.5
" "1D"	38.4	0.20	40	28	6	<4	20	12	22	1.5
" "1E"	37.0	0.48	160	35	18	<4	27	12	30	<1
" "1F"	22.2	0.58	60	83	12	4	29	9	126	2.5
"Rimmer Hill"	35.8	0.20	40	63	9	<4	29	58	112	2.5
Camooweal (i) 1	31.6	5.60	550	98	78	38	18	25	235	<1
Detectability limit				2.5	2.5	3.5	1.5	6		

In reconstructing the development of the phosphorite deposits, it is assumed that upwelling currents rich in phosphorus sustained a healthy population of various organisms in the Mount Murray area and farther south. The phosphorus, accumulated by these organisms, was upon their death and decay released and concentrated in the bottom muds of areas where the conditions were favourable for the subsequent replacement of calcite by phosphate. The processes of upgrading already described then led to the formation of medium to high-grade phosphorite deposits, as shown diagrammatically in Figure 64. As can be expected, deposits at greater distances

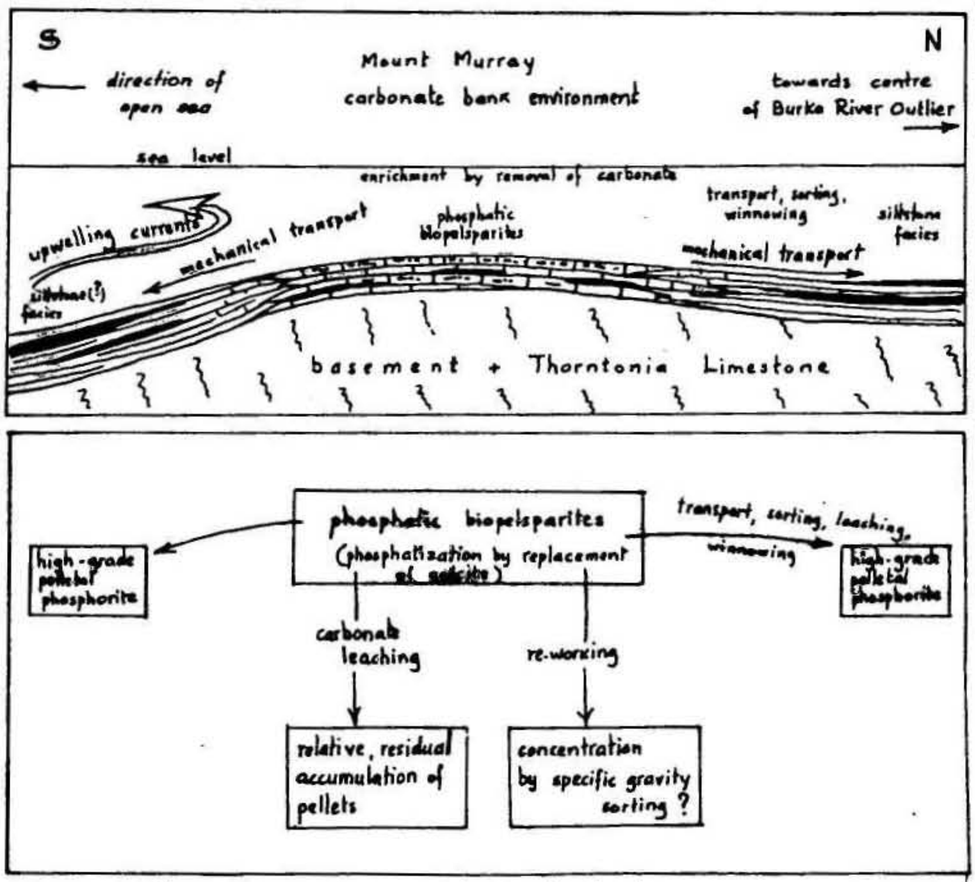

FIGURE 64 - Suggested model of phosphorite genesis, Duchess phosphorite deposits.

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from the original area of phosphatization are commonly very high-grade, as it is here that transport, sorting, and winnowing have had their greatest effect. And although not enough data are available to prove this statistically, there seems to be a tendency for a slightly smaller average size, and a better sorting and rounding of phosphate pellets in those fringe areas, compared with a greater range of pellet sizes in the source area at Mount Murray. The information, received while writing these pages, that Broken Hill South Ltd have drilled new large, thick, and rich deposits in the area south of Phosphate Hill is completely in line with the theory here developed. It is also reasonable to assume that good-grade deposits extend eastwards from the Mount Murray area, though of course underneath a prohibitive thickness of Middle and Upper Cambrian sediments and Recent alluvium.

GEOLOGICAL HISTORY

Probably as early as the Precambrian, the Burke River Outlier formed a small depositional basin bounded by fundamental zones of weakness along which recurrent differential vertical movements took place by faulting and by warping.

The first deposits may have been late Upper Proterozoic glacial sediments, followed by a red ferruginous sandstone and shale sequence with dolomite lenses, which rapidly filled the basin. During the Lower Cambrian, a littoral orthoquartzite and conglomerate sequence topped by massive mudstone transgressed over the area and extending over the Precambrian borderland. All these units have been grouped together under the name of Mount Birnie Beds.

During the early Middle Cambrian, deposits of Thorntonia Limestone or its cherty equivalents, all characterized by a Redlichia and Biconulites fauna, were laid down as a thin layer over the whole of the Burke River Outlier and, in the east, beyond its margin.

After a temporary regression, the Burke River basin was inundated by a Middle to Upper Cambrian transgression moving from south to north and east. The basal sediments were the siltstone, siliceous shale, fine sandstone, and chert of the Beetle Creek Formation, and conditions were favrouable for the deposition of phosphorites. The Beetle Creek Formation suffered some

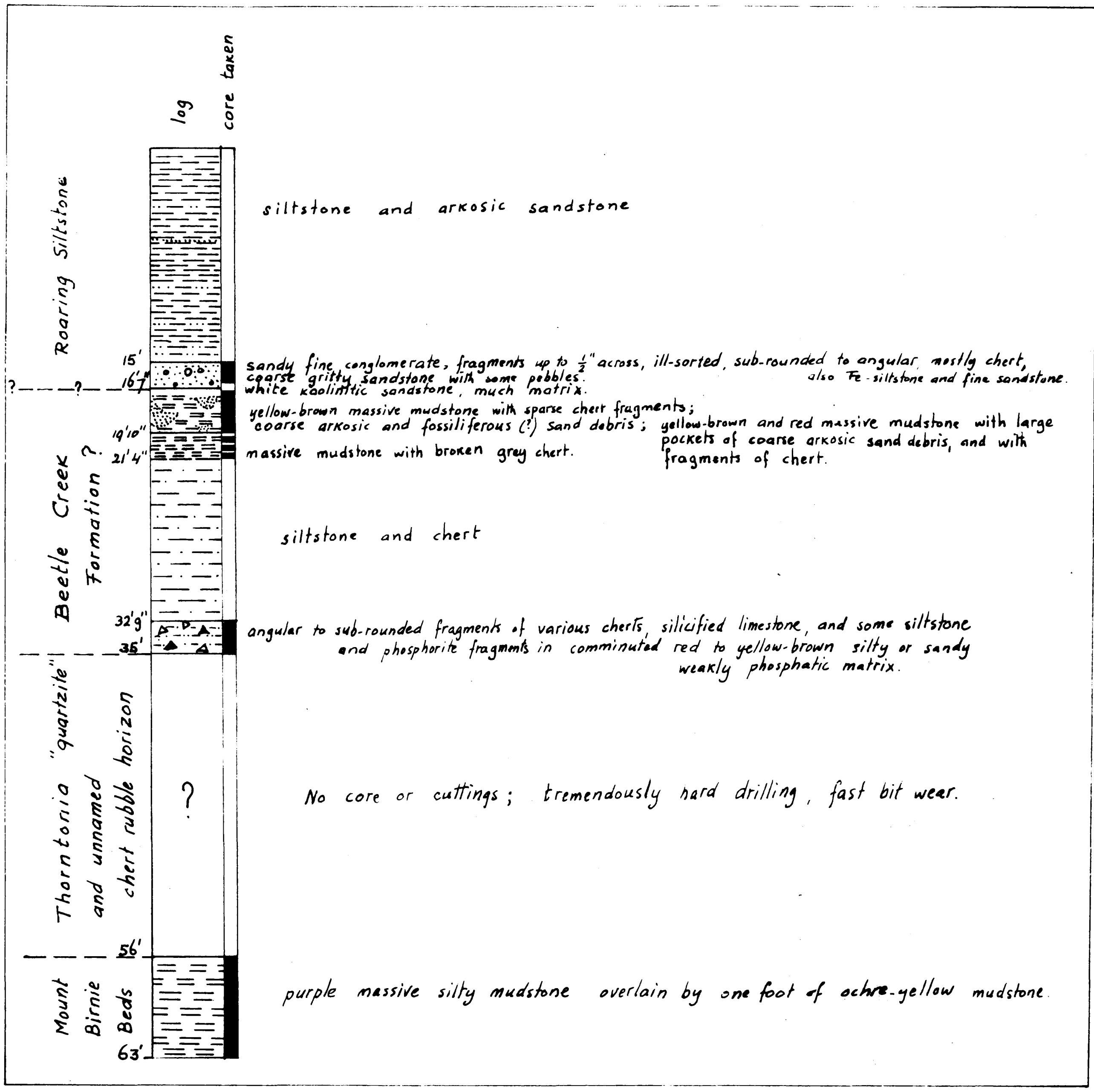

FIGURE 65 – Section of BMR (Duchess) Scout hole No 3

marginal erosion during a short slight regression, but then the transgression continued northwards, depositing siltstone sequences along the shores, and grey calcilutites and marls more in the centre of the depression, possibly at some stages in a near-evaporitic environment. Free water circulation was impeded to some extent, probably owing to low limestone banks acting as barriers between the Burke River basin and the open sea to the south. Sedimentation was slow and quiet.

At the beginning of the Upper Cambrian, the transgression was halted and gave way to a general regression during which the O'Hara Shale and Pomegranate Limestone were deposited. The youngest Palaeozoic rocks are Lower Ordovician deposits outcropping in the extreme south of the outlier.

According to Opik, the main deformation of the Burke River Structural Belt, of which the Burke River Outlier is but the northernmost sector, took place during the Ordovician.

The long period between the Upper Ordovician and the Lower Cretaceous formed a "geocratic interval" during which the foundations were laid for the present landscape. Erosion, deep weathering and leaching characterize this period. The landscape thus formed coincides with the top of the O'Hara Shale mesas and plateaux.

A regional subsidence during the Lower Cretaceous was followed by the deposition of a regionally widespread cover of fresh water conglomerate and sandstone followed by marine siltstone and shale.

The Cretaceous cover was eroded during the next uplift in the Tertiary, and was reduced to a few scattered mesa cappings. Lateritic alteration produced ferruginous cappings and "grey-billy" surfaces. In the Upper Tertiary, a lake was formed in the Burke River Outlier in which siliceous limestone and chalcedony deposits were laid down.

Finally, at the beginning of the Quaternary(?), the Burke River Outlier was tilted to the south by the Selwyn Range Uplift, the old drainage system became rejuvenated in its headwater region, and alluvial sediments were deposited in the Burke River Plain.

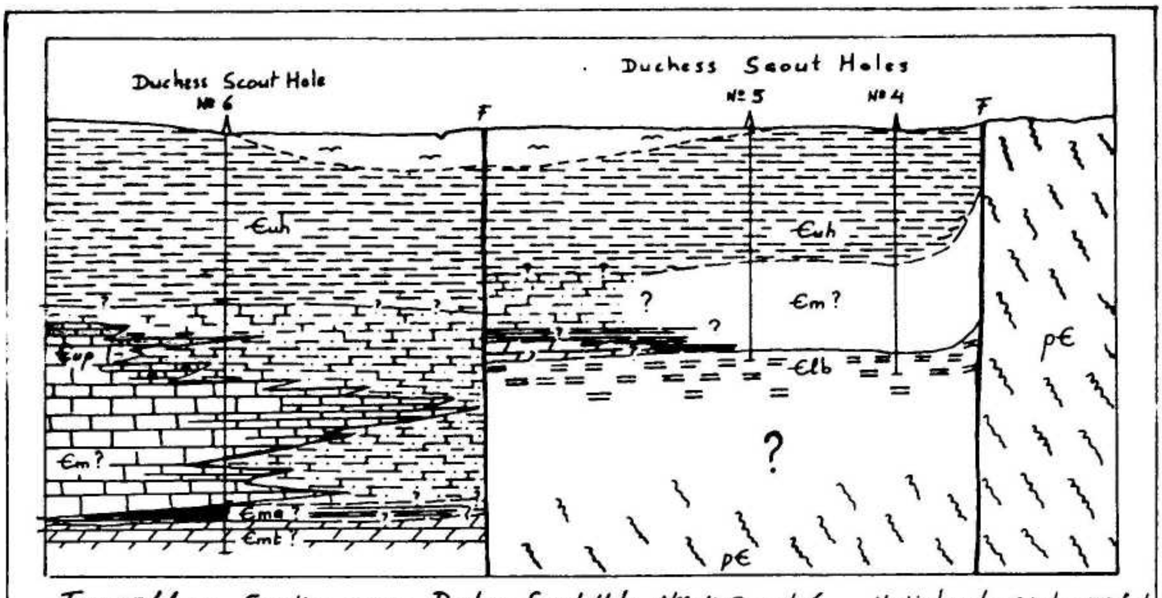

FIGURE 66 - Section across Duchess Scout Holes Nos 4, 5, and 6. Vertical scale: 1 inch = 100 feet.

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DRILLING PROGRAMME

Twelve stratigraphic scoutholes, with a total footage of 1962 feet and with a depth range from 30 feet to 300 feet, were drilled during the period from 24th July to 30th August. The drill rig used was a BMR Mayhew 1000. Lack of casing and diamond drill bits, combined with hard rock intervals and total water loss in some of the limestone formations, severely restricted the scope of the drilling, so that the original intention of continuous coring to a depth of 400 feet in three selected holes had to be abandoned. Nevertheless, the information obtained in some of the shallow drill holes was of reasonable assistance in appraising the stratigraphy of the area.

Table 2 summarises the results of the holes, and sections are shown in Figures 65 and 66.

ACKNOWLEDGMENTS

The co-operation and hospitality of the company geologists and staff is gratefully acknowledged, and I especially wish to thank Messrs R. Bluck, R. Keevers, and J. Teluch, who spontaneously gave up some of their hard-won spare time to show party members over areas of geological interest.

TABLE 2

SUMMARY OF BMR DUCHESS SCOUT DRILL HOLES

Duchess (BMR) Scout Hole No.	Location	Total Depth	Generalized lithological log		Formations	Cored interval
1.	Lat. 21°29'10" Long. 139°57'55"	300'	0'-257'10":	quartz siltstone, silty clay-shale, fine sandstone, little chert	O'Hara Shale	225'-259'
			257'10"-300':	calcareous siltstone with calcite-lined vugs	Selwyn Ra. Lst.?	295'-300'
2.	Lat. 21°29'10" Long. 139°57'25"	293'9"	0'-293'9":	calcareous siltstone and shale with thin tongues (¼"-1") of grey limestone (N.B. Beds almost vertical, hence section does not represent thickness)	Inca Formation	60'-78'6" 120'-130' 190'-193'5" 265'-269' 292'-293'
3.	Lat. 21°27'25" Long. 139°57'00"	63'	0'-15':	siltstone, fine arkosic sandstone)		15'-16'2"
			15'-16'2":	sandy fine conglomerate gritty sandstone, kaolinic sandstone)	Roaring Siltstone	17'-21'4" 32'9"-35'
			16'-32'9":	mudstone and siltstone with chert fragments	Beetle Creek Formation?	56'-63'
			32'9"-35':	chert-siltstone-limestone-siltstone breccia with sandy or silty matrix	"Unnamed chert rubble horizon?"	
			35'-56':	probably chert	Thorntonia "quartzite"?	
			56'-63':	purple micaceous siltstone	Mount Birnie Beds	
4. (see also Fig. 65)	Lat. 21°34'10" Long. 140°15'05"	127'6"	0'-abt 75':	micaceous siltstone	O'Hara Shale	40'-43'6"
			75'-abt 120':	clay with chert fragments	"Unnamed chert rubble horizon?"	125'-127'6"
			120'-127'6":	chocolate brown micaceous siltstone	Mount Birnie Beds	
5.	Lat. 21°35'00" Long. 140°14'55"	118'	0'-abt 75':	silicified siltstone, micaceous siltstone	O'Hara Shale	-
			75'-abt 115':	clay with chert fragments	"Unnamed chert rubble horizon?"	
			115'-118':	chocolate brown micaceous siltstone	Mount Birnie Beds	
6.	Lat. 21°35'10" Long. 140°13'55"	218'	0'-15":	overburden, ferruginous laterite	-	88'-98'
			15'-25':	pallid zone, laterite profile	-	118'-123'
			25'-88':	siltstone and clay shale	O'Hara Shale	205'-214'
			88'-121':	fissile silty limestone, calcareous siltstone)	Middle Cambrian, undifferentiated	
			121'-190':	pyritic fissile limestone)		
			190'-195':	siliceous siltstone)		
			195'-218':	bedded dolomite, somewhat phosphatic	Thorntonia Limestone	
7.	Lat. 21°55'50" Long. 140°17'10"	165'	0'-165':	limestone and micaceous calcareous siltstone	Chatsworth Limestone	-
8.	Lat. 21°03'25" Long. 140°09'10"	192'	0'-165':	sandy limestone, calcareous siltstone, calcilutite	Devoncourt Limestone and Roaring Siltstone	
			165'-175':	sandstone (with limestone fragments?)	Thorntonia Limestone	
			175'-192':	dolomite, limestone, chert, siltstone		
9.	Lat. 21°03'15" Long. 140°09'20"	157'	0'-135':	siltstone, calcilutite calcareous siltstone	Devoncourt Limestone and Roaring Siltstone	
			135'-157':	dolomite, chert, limestone, siltstone	Thorntonia Limestone	
10.	Lat. 21°03'25" Long. 140°09'20"	58'	0'-abt 30':	calcareous siltstone		30'-58'
			30'-48':	sandy limestone with siltstone interbeds	Devoncourt Limestone	
			48'-58':	friable clayey calcareous siltstone	Roaring Siltstone?	
11.	Lat. 21°02'10" Long. 140°13'00"	30'	0'-11':	limestone	Devoncourt Limestone	11'-17'
			11'-30':	impure dolomite, dolomitic siltstone	Thorntonia Limestone	20'-21'
12.	Lat. 21°02'02" Long. 140°09'27"	240'	0'-240':	quartz siltstone and fine sandstone, slightly calcareous at bottom of hole. Some ferruginized fragments at 225' and 240' some chert fragments at 240'.	Roaring Siltstone?	-

We remember with pleasure our visits to "Dead Horse Motel".

We also appreciated very much the cordial relationships we had with the various families and station owners in the area, in particular the Kelly family of Duchess, and Mr and Mrs Salmar of Devoncourt Station.

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APPENDIX

CAMBRIAN PALAEONTOLOGY

By J.H. Shergold

A total of 89 palaeontological samples were collected during the course of the 1967 field season in the Duchess area. The location of these samples is shown on Figure 67. All formations examined, with the exception of the Mount Birnie Beds, yielded fossils, although not all were equally productive.

Palaeontological investigations in the Duchess area were instgated by Whitehouse (1936, 1939). Later, more extensive and detailed work was undertaken by Opik who, in a series of papers (1956, 1961, 1964, 1967), has laid the framework for faunal zonation of the Middle and basal Upper Cambrian. The faunas dated herein were determined with respect to Opik's findings. Most important in matters of correlation and dating are the agnostid trilobites, especially in the higher Middle Cambrian. A number of new forms are present in the collections whose stratigraphical value is best exploited by referring them to the nearest related group of species. For other agnostids free use is made of affinitive and comparative identifications.

(1) Mount Birnie Beds

No identifiable fossils were collected from the Mount Birnie Beds, the sum total of our knowledge of the fauna of these being trace fossils recorded by Opik (1960, 1961) from Mount Birnie and from Sylvester Creek.

(2) Thorntonia Limestone

Few fossils were collected from outcropping Thorntonia Limestone. However, at locality D336, in the extensive outcrop area to the north of the Malbon River, the trilobite Redlichia was collected from chert layers. The specimens obtained were badly weathered and insufficient characteristics were preserved for specific identification. Phosphatic brachiopods referrable to Acrothele and to a Lingulelloid genus were collected from a point 2 miles west of Prickly Bush Bore, and Biconulites was observed, but not collected, at several other localities.

The overlying 'quartzite' horizon yielded both Biconulites, from the escarpment opposite Roaring Bore, and an indeterminate redlichioid trilobite, from the extreme north of the area (D338).

Fossils were collected from a number of localities in the 'zone of chert rubble'. They included Biconulites sp. (D305, 347, 348, 349, 477, 484), Redlichia sp. (D305, 347, 348, 349, 454, 455, 481), Helcionella sp. (D349) and an indeterminate archaeocyathid (D348). None of the specimens recovered were suitably preserved for an attempted specific determination. Limestone samples, digested in monochloracetic acid by E.C. Druce for their conodont content, all proved barren.

The nature of the preservation of the materials collected from the Thorntonia Limestone of the Duchess area prevents comparison with that of the type area in the Camooweal district or with the fauna of the "Yelvertoft Bed" of that area. The presence of the association of redlichioid trilobites and Biconulites places the fauna in the Ordian Stage (Opik, in press), of Lower Middle Cambrian age.

(3) Beetle Creek Formation

New collections were made from the Beetle Creek Formation between Mount Murray and the southern margin of the Duchess 1:250,000 Sheet. One of Opik's original localities, D135, was recollected.

The following species were determined from localities D303, 304, 664, and 666: Xystridura spp., Lyriaspis sigillum Whitehouse, Lyriaspis sp., Pagetia cf. significans (Etheridge), Peronopsis normata (Whitehouse), Acrotreta sp. and Botsfordia sp. At the type locality, Beetle Creek, and in the Thorntonia area this fauna occurs near the base of the Beetle Creek Formation.

At D135 a fauna of somewhat differing composition: Xystridura spp., xystridurid (new genus), Peronopsis normata, Pagetia cf. significans, Oryctocephalites cf. gelasinus Shergold (in press), Botsfordia sp.,

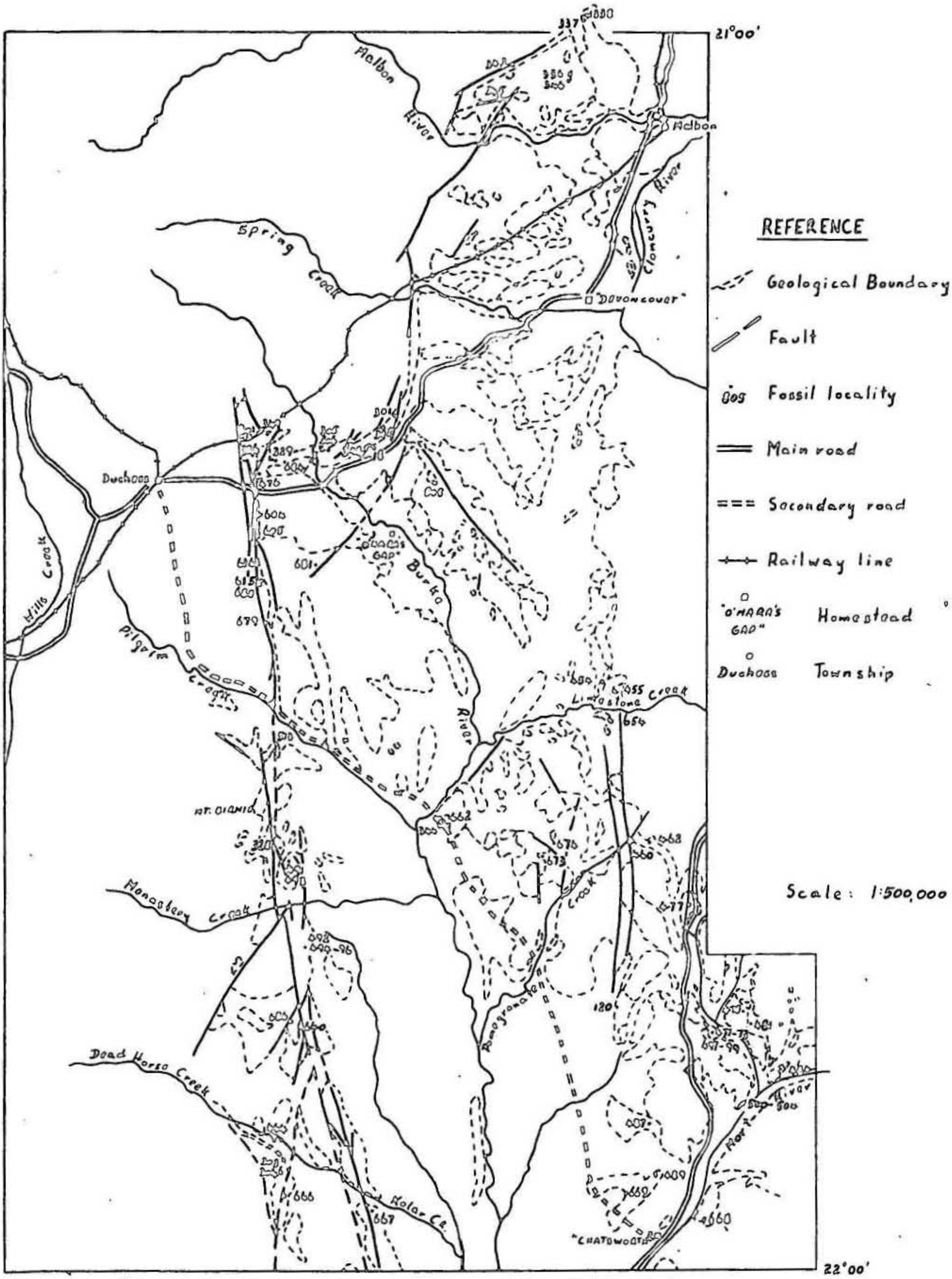

FIGURE 67 - Fossil localities as recorded in 1967 field note books.

Acrothele sp., and Hyolithes sp., lies higher in the succession. The presence of the oryctocephalid indicates that the higher Beetle Creek Formation lies here near the base of the Ptychagnostus gibbus Zone.

A very prolific fauna was obtained following acid treatment of a phosphorite sample from locality D640, 1½-2 miles north of Mount Murray (Table 1). Meraspid and holaspid morphogenetic growth stages of Pagetia cf. significans and Peronopsis spp. occur in profusion, together with Ptychagnostus sp. ex gr. praecurrens, lingulelloid brachiopods, Acrotreta sp., Acrothele sp., Stenotheca sp., Hyolithes sp., five genera of Bradoriida, a variety of straight, curved or plane coiled hollow tubes, and quantities of sponge spicules. The presence of the ptychagnostid again indicates a position high in the Beetle Creek Formation, at the base of the Ptychagnostus gibbus Zone.

(4) Inca Formation

Fossil evidence for the age of the Inca Formation is not entirely clear from the samples collected. Poorly preserved agnostids, obtained from siltstones referred to this formation between Monastery Creek and Bronzewing Bore, include Ptychagnostus ex gr. gibbus, P. cf. praecurrens, Cotalagnostus sp. and Peronopsis sp. and possibly indicate that the formation lies here at or near the overlap of the Ptychagnostus gibbus and P. atavus Zones (D328, 605, 615).

A limestone horizon (D686), a little to the north of Mount Murray, and mapped within the Inca Formation, yielded a species of Ptychagnostus which may be related to P. lundgreni (Tullberg). This would indicate a position within the late P. atavus to early P. punctuosus Zones, i.e. in a stratigraphical position intermediate between Inca Formation and Roaring Siltstone (see Opik in Opik and Carter 1963, Table 2).

(5) Roaring Siltstone

A basal Roaring Siltstone fauna was obtained from locality D476, north of the Duchess-Cloncurry road, where it crosses the Pilgrim Fault Belt. The recorded fauna includes: Hypagnostus brevifrons Opik, Ptychagnostus aff. cassis Opik, P. ex gr. punctuosus, Ptychagnostus spp., Peronopsis sp., Centropleura sp. indet., a conocoryphid trilobite aff. Meneviella, Stenotheca sp., undetermined phosphatic brachiopoda and possible phyllocarid fragments.

A position low in the Roaring Siltstone is indicated by the overlap of P. cassis and the variety of P. punctuosus, the presence of H. brevifrons and Centropleura, and the absence of Leiopyge and Pseudophalacroma.

Faunas collected from horizons in the basal part of this formation elsewhere to the north show little more variety. Localities D301, 302, 306, 326, 329 and 801 have yielded collectively: Ptychagnostus cassis, ?Doryagnostus sp., Diplagnostus sp., Ptychagnostus spiniger (Westergaard), Leiopyge laevigata (Dalman), Pseudophalacroma dubium (Whitehouse), Peronopsis sp., Centropleura phoenix Opik, poorly preserved phosphatic brachiopods and a variety of sponge spicules. The faunas of all these localities are referred to the Ptychagnostus cassis with Leiopyge laevigata Zone.

Contorted siltstones within the Camel Fault belt at locality D342 have yielded a fauna of uncertain age: Centropleura sp., Dorypyge sp., Tosotychia sp., Ptychagnostus sp., ?Hypagnostus sp., Grandagnostus cf. velaevis Opik and Hadragnostus las Opik. According to the fossil range chart of Opik (1961, p. 34, fig. 15) G. velaevis occurs in the higher, Holteria arepo, subzone of the Leiopyge laevigata Zone. Hadragnostus las was originally described from the Mungerebar Limestone of the Georgina Basin where its age is basal Upper Cambrian, from the Mindyallan Zones of Erediaspis eretes and Cyclagnostus quasivespa (Opik 1967, pp. 102-4). There is perhaps some evidence, therefore, that the Roaring Siltstone is slightly younger in the country to the northwest of Malbon than it is to the east of Duchess.

The same may also be true for the exposures of siltstone along the eastern margin of the Burke River Structure (e.g. D460) which are interposed between the 'zone of chert rubble' and the O'Hara Shale. Locality D460 has yielded Pseudophalacroma dubium, ?Leiopyge sp., ?Mapania sp., Amphoton sp., Helcionella sp., brachiopods and spicules.

(6) Devoncourt Limestone

It is difficult to distinguish the lithologies of limestones in the higher Inca Formation and those of the Devoncourt Limestone, and there is evidence from the vicinity of Prickly Bush Bore that the former passes directly upwards into the latter without the intervention of Roaring Siltstone.

Four horizons were sampled along a tract of easterly dipping limestone, approximately 2 miles south of Monastery Creek (D492, 494-496), originally mapped as limestone within the Inca Formation. In order of succession from the base the faunas identified were:

Locality D496 - Ptychagnostus cf. cassis, P. ex gr. punctuosus, Leiopyge laevigata, Leiopyge sp., sponge spicules.

Locality D495 - P. ex gr. punctuosus, P. ex gr. scarabeus Whitehouse, Ptychagnostus sp., L. laevigata, Hypagnostus cf. willsi Opik.

Locality D492 - P. ex gr. punctuosus, P. ex gr. scarabeus, L. laevigata, Leiopyge sp., Pseudophalacroma dubium, phosphatic brachiopods and sponge spicules.

Locality D494 - Ptychagnostus sp., L. laevigata.

The overlap of P. ex gr. punctuosus, P. cassis and L. laevigata places these limestones at a stratigraphical horizon similar to that at the base of the Roaring Siltstone, east of Duchess, i.e. within the P. cassis with L. laevigata Zone.

Exposures in this limestone belt are continued north of Monastery Creek, approximately 2 miles west of Prickly Bush Bore (D491A-J, 493). The lowest horizon collected here again contains P. cassis, L. laevigata and Pseudophalacroma dubium. Succeeding horizons (D491H-B) contain an assemblage of the Centropleura fauna, collectively: L. laevigata, P. dubium, Hypagnostus hippalus Opik, Ptychagnostus sp., Centropleura phoenix, Proampyx agra Opik, Amphoton bensoni Opik, Acontheus burkeanus Opik, Bradoriida, phosphatic brachiopods and spicules. The highest horizons (D491A, 493) contain L. laevigata, L. laevigata armata Opik, P. dubium, Diplagnostus humilis Opik, and Oidalagnostus cf. personatus Opik. These assemblages, compared against Opik's (1961, p. 34) chart, suggest that the Devoncourt Limestone, as exposed here, ranges from the highest part of the P. cassis Zone into the Proampyx agra with L. laevigata Zone.

Between Duchess and Devoncourt Station, where Devoncourt Limestone overlies Roaring Siltstone, Opik's localities D13, 16 and 18 were re-examined and a basal Devoncourt Limestone fauna found to fall within the Zone of Proampyx agra.

North of the Malbon River Devoncourt Limestone transgresses Roaring Siltstone and at locality D346 lies on Thorntonia Limestone. The mildly phosphatized basal bed and that succeeding it yielded L. laevigata, P. dubium, Ptychagnostus ex gr. nathorsti (= Ptychagnostus fumicola Opik 1961, p. 81, pl. 21, fig. 2) (a new species), Diplagnostus sp., mapaniid gen. et sp. nov., Acrothele sp., Acrotreta sp. and sponge spicules, this fauna being again referrable to the Zone of Proampyx agra.

(7) Selwyn Range Limestone

This formation is very sparsely fossiliferous and has yielded determinable material from a single locality (D805). A phosphatic brachiopod is identified as ?Acrothele sp., and an agnostid trilobite as Cyclagnostus aff. quasivespa Opik. No age can be deduced from these specimens.

(8) O'Hara Shale

A rich trilobite fauna was collected at locality D681 from a chert horizon at the base of the O'Hara Shale. This locality is close to Opik's D6. The fauna, composed solely of species described by Opik (1967), is as follows: Agnostardis amplinatis, Agnostogonus incognitus, Aulocodigma quasispinale, Auritama trilunata, Blountia (Mindycrusta) mindycrusta, Biaverta biaverta, Doremataspis ornata, Henadoparia integra, Idolagnostus agrestis, Liostracina volens, Polycertaspis flexuosa, Rhyssometopus princips and Acrotreta sp. This fauna belongs to the basal Upper Cambrian, Mindyallan Zone of Glyptagnostus stolidotus. It is not, however, the basal Mindyallan Zone, those of Erediaspis eretes and Cyclagnostus quasivespa lying below it in the Mungerebar-Mindyalla district. These intervals appear to be non-fossiliferous in the Selwyn Ranges (Opik 1967, p. 32).

A comparable fauna was collected from a small patch of silicified limestone 4 miles south of Bronzewing Bore (D679). This includes: Agnostogonus incognitus, Auritama aurita, Aulocodigma quasispinale, Blackwelderia sp., Idolagnostus sp., Pseudagnostus sp., Rhyssometopus princeps and Acrotreta sp. All these elements have been recorded by Opik (1967) from the O'Hara chert layer at D6 and D29.

(9) Pomegranate Limestone

Faunas were collected from 22 horizons in the Pomegranate Limestone, covering all but the youngest Idamean Zone yet established, that of Irvingella tropica and Agnostotes inconstans.

The basal Idamena fauna, from the Zone of Glyptagnostus reticulatus with Olenus ogilvei, was obtained from locality D674, near the heads of Pomegranate Creek. The fauna of the lowest horizons (D674B, 674C) included: Glyptagnostus reticulatus (Angelin), Olenus ogilvei Opik and Innitagnostus inexpectans (Kobayashi). At slightly higher levels (D674A, 673) G. reticulatus was found associated with Proceratopyge cf. lata Whitehouse, phosphatic brachiopods and carbonaceous fragments. This fauna is probably representative of the Zone of G. reticulatus with Proceratopyge nectans.

That Zone was certainly collected at the eastern margin of the Burke River Structure on Mistake Creek, where six horizons were collected on a 42-foot vertical section (D471-473, 497-499). The fauna here includes G. reticulatus, I. inexpectans, Proceratopyge nectans Whitehouse, Eugonocare tesselatum Whitehouse and species of Pseudagnostus.

Similar faunas were found on the Mort River, near its confluence with Mistake Creek (D500, 501). Locality D502, at the same site, yielded additionally Corynexochus plumula Whitehouse, the index fossil of the succeeding Zone (Zone 6 of Opik 1963).

The youngest Zone collected, Zone 7, Erixanum sentum, was found some 2 miles south-east of Pilgrim Well. Here E. sentum was associated with Proceratopyge lata, Eugonocare tesselatum, species of Pseudagnostus, phosphatic brachiopods and sponge spicules.

(1) Chatsworth Limestone

Poorly preserved trilobite fragments were collected from localities D668 and 669, but better material was found at D487. At the last an olenid and an asaphid trilobite are associated with Pseudagnostus sp. and Acmarhachis sp. At D668 a Mansuyia-like pygidium was recovered. Insufficient material is at hand for the proper determination of these samples which have been set aside for future study.

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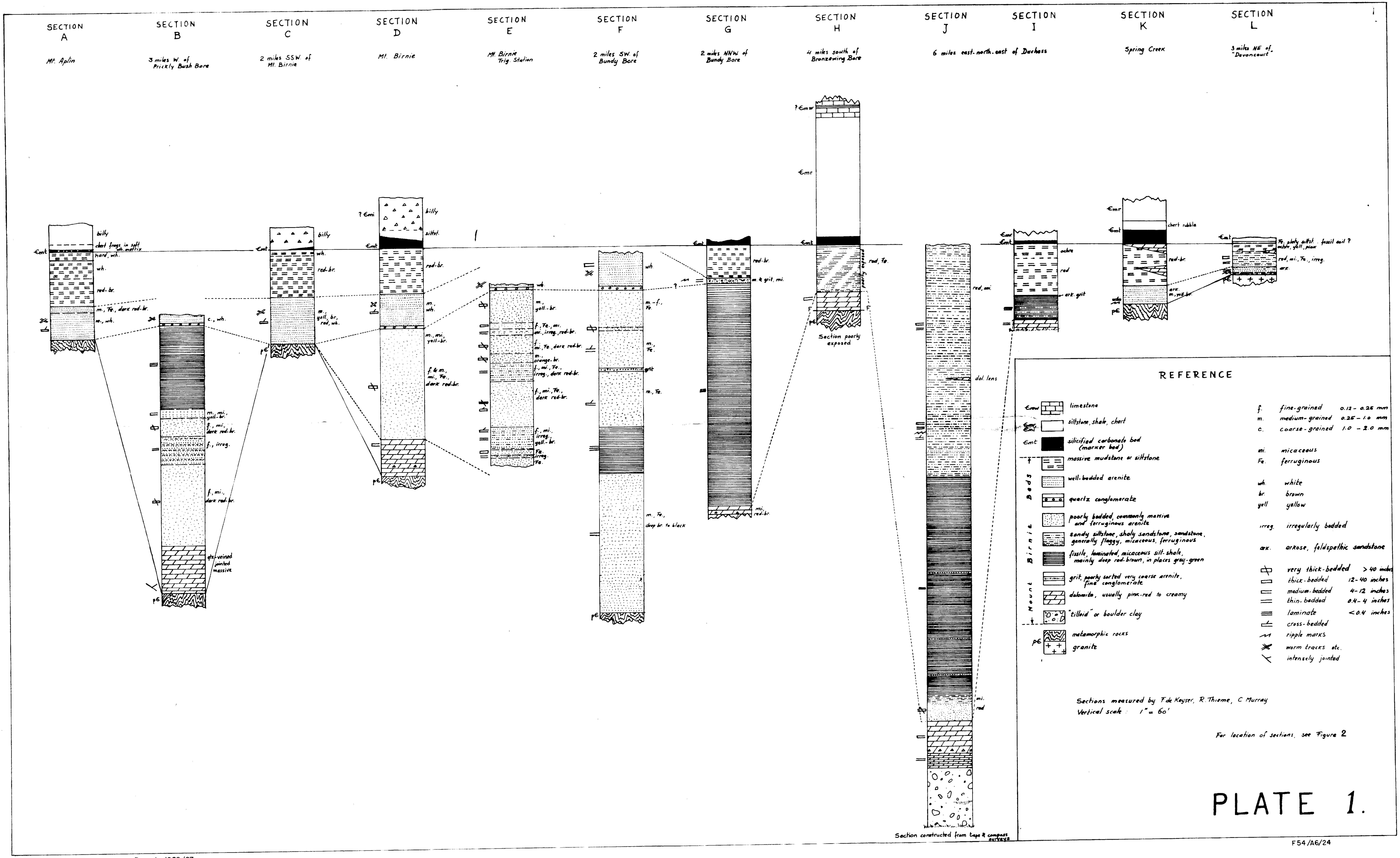


PLATE 1.

F54/A6/24

To Accompany Record 1968/67

CAMBRIAN GEOLOGY , DUCHESS AREA

NORTH–WESTERN QUEENSLAND.

SHEET 1

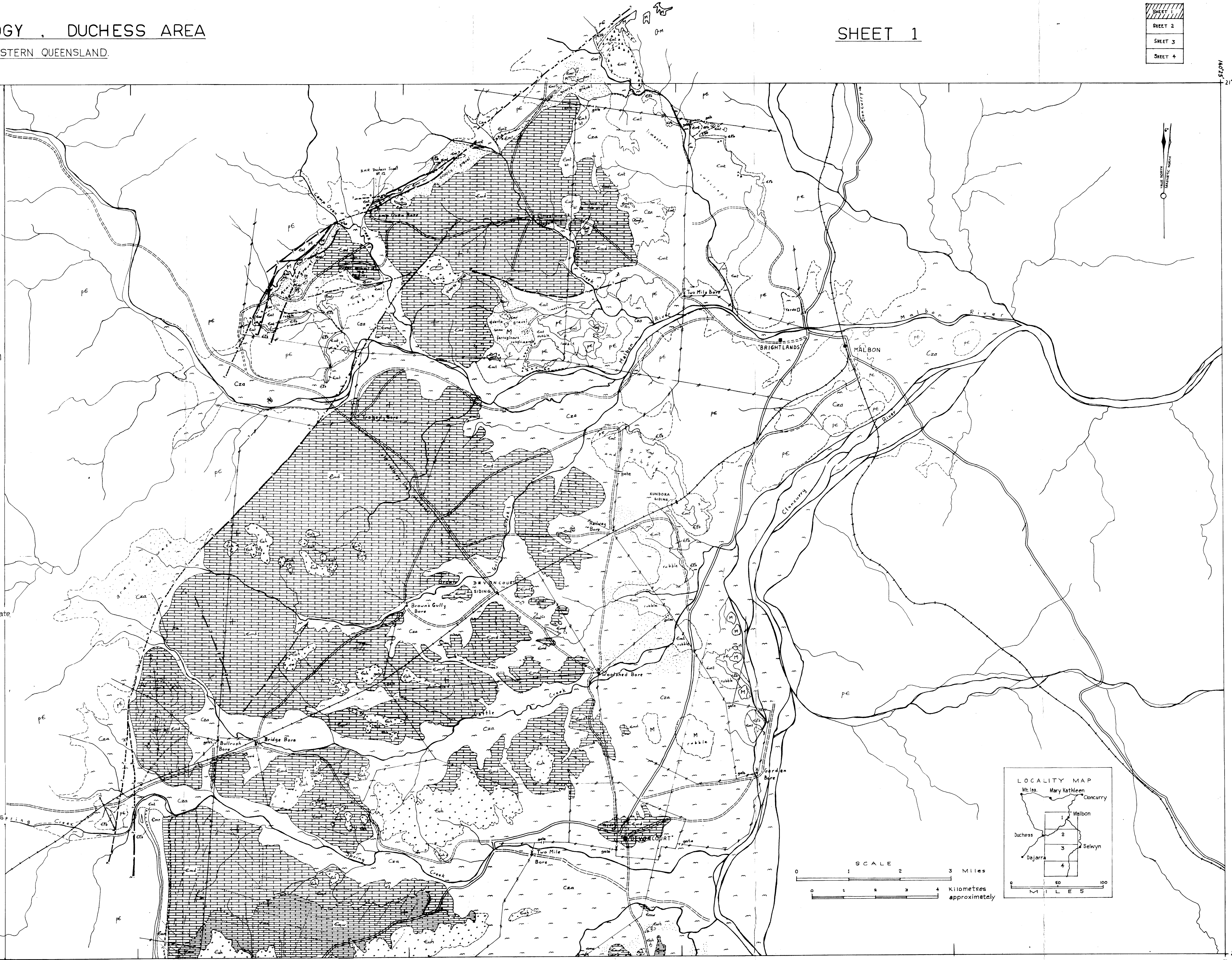
SHEET 1
SHEET 2
SHEET 3
SHEET 4

21°00' 139°55' 140°05' 21°00'

REFERENCE

CAINOZOIC	—	Cza	Alluvium , Soil.
	—		Gravel, including quartz gravel derived from Mesozoic conglomerate.
	—		Laterite, lateritic rubble.
	—	T	Chalcedony, limestone siliceous sinter, opal.
MESOZOIC	—	M	Undifferentiated: ferruginous quartz conglomerate, siltstone, mudstone, quartz grit, minor pebbly sandstone.
	Wilgunya Formation	Klw	Mudstone, siltstone, sandstone.
PALAEOZOIC – ORDOVICIAN	Swift Formation	Ols	Siltstone, sandstone, chert. Poor rubbly outcrops.
	Ninmaroo Formation	Oln	Dolomitic limestone, limestone, dolomite, intraformational breccias, oolitic limestone, marly interbeds.
PALAEOZOIC – CAMBRIAN (UPPER)	Chatsworth Limestone	Єuc	Limestone, sandy limestone, oolitic limestone, intraformational breccias, marly interbeds, rare coquinas.
	O'Hara Shale	Єuh	Bedded siltstone subordinate chert and fine sandstone.
	Pomegranate Limestone	Єup	Limestone, bituminous limestone, marly interbeds, intraformational breccias, subordinate chert.
	Selwyn Range Limestone	Єmw	Calcilutite, marly interbeds, subordinate chert.
PALAEOZOIC – CAMBRIAN (MIDDLE)	Devoncourt Limestone	Єmd	Bedded impure limestone, calcilutite, bituminous limestone sandy limestone, marly interbeds.
	Roaring Siltstone	Єmr	Bedded siltstone, fine sandstone, subordinate chert or siliceous shale
	Inca Formation	Єmi	Bedded siltstone, siliceous shale, fine sandstone, chert, limestone.
	Beetle Creek Formation	Єme	Bedded siltstone and chert, siliceous shale, phosphorite, phosphatic siltstone, fine sandstone.
	—	Єmt	Black and grey convoluted chert, chert nodules, silicified beds. = Yelvertoft Bed?
	Thorntonia Limestone	Єmt	Thick-bedded, yellowish dolomitic limestone and dolomite with chert nodules and silicified beds.
PALAEOZOIC – CAMBRIAN (LOWER)	Mount Birnie Beds	Єlb	Massive ferruginous sandstone, cross bedded sandstone, conglomerate, red and green shale, mudstone, dolomite, tilloid.
PRECAMBRIAN		pЄ	Metamorphic schists, quartzite, calc-silicate rock, slate, amphibolite, acid and basic altered volcanics , granite.

- Breccia
- Measured strike and dip of strata
- Vertical beds
- Horizontal beds
- Dips < 15° (Airphoto Interpretation)
- Dips (Airphoto Interpretation)
- Dips > (Airphoto Interpretation)
- Trend lines (Airphoto Interpretation)
- Joint pattern (Airphoto Interpretation)
- Geological boundary
- Anticline, with plunge shown
- Syncline, with plunge shown
- Fault (with down-thrown side shown) — Where location of boundaries and faults is approximate line is broken; where inferred queried; where concealed, faults are shown by short dashes.
- Fossil locality
- BMR Duchess Scout hole
- Homestead
- Settlement
- Yard
- Waterbore or well with wind pump
- Railway line with siding
- Telegraph line
- Fence
- Main road or track
- Vehicle track



21°15' 139°55' 140°05' 21°15'

To Accompany Record 1968/67

F54/A6/25

CAMBRIAN GEOLOGY, DUCHESS AREA   SHEET 2

NORTH-WESTERN QUEENSLAND

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CAMBRIAN GEOLOGY , DUCHESS AREA SHEET 3

NORTH-WESTERN QUEENSLAND

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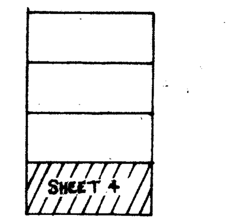
CAMBRIAN GEOLOGY , DUCHESS AREA

SHEET 4

NORTH-WESTERN QUEENSLAND



To Accompany Record 1968/67

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