Report 251

Notes to accompany the Hay River–Mount Whelan Special 1:250 000 Geological Sheet, southern Georgina Basin

J. H. Shergold

Bureau of Mineral Resources, Geology and Geophysics

Department of Resources and Energy

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

REPORT 251

NOTES TO ACCOMPANY THE HAY RIVER-MOUNT WHELAN SPECIAL 1:250 000 GEOLOGICAL SHEET, SOUTHERN GEORGINA BASIN

by

J.H. Shergold

AUSTRALIAN GOVERNMENT PUBLISHING SERVICE
CANBERRA 1985

DEPARTMENT OF RESOURCES AND ENERGY
Minister: Senator The Hon. Gareth Evans, QC
Secretary: A.J. Woods

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS
Director: R.W.R. Rutland

Published for the Bureau of Mineral Resources, Geology and Geophysics
by the Australian Government Publishing Service

ISSN 0084-7100
ISBN 0 644 03797 0

Printed by Graphic Services Pty Ltd Northfield SA 5085

CONTENTS

FIGURE

MAP

ABSTRACT

This Report is a commentary on the geology of the Hay River-Mount Whelan Special 1:250 000 Sheet area. Though it is essentially a review of the Late Proterozoic to Cainozoic stratigraphy placed in a biochronological framework, it also includes comments on the structural interpretation of the area, and on the economic potential as suggested from geochemical observations. Stratigraphic emphasis is placed on the time interval Late Proterozoic to Middle Ordovician, and includes new or unpublished data for the Middle Cambrian and Early Ordovician.

The lithostratigraphy of the Middle Cambrian is completely revised: the previously introduced Hay River Formation is expanded in concept; and the 'Marqua Beds' are formalised and restricted. Significant biochronological breaks occur at the beginning and end of both Ordian and Templetonian time; indeed, no sediments were deposited between the late Templetonian and late Floran stages, a fact requiring revision to existing palaeogeographic interpretations.

In the Ordovician, the Nora Formation is now assigned an Early Ordovician late Arenig age, rather than Middle Ordovician, as a result of trilobite studies.

A major hydrothermal event is documented from Middle Cambrian sequences in the north of the Sheet area; this has adversely affected the petroleum prospects of potential source rocks in that area. In the southern part of the Sheet area, however, source rocks are not overmature and some potential may still exist. The combination of hydrothermal activity, structural complexity, stratigraphic breaks, and original organic-rich sediments may indicate a potential gold occurrence. Previously unpublished elemental geochemical data are appended.

1. INTRODUCTION

This Report attempts to explain, justify, and provide documentary background for stratigraphic revisions in the southern Georgina Basin, essentially in the country between the Hay River and Mount Whelan. These revisions result from BMR and Geological Survey of Queensland (GSQ) mapping and interpretation between 1975 and 1981. The accompanying map sheet presents new information on the Early Proterozoic, Late Proterozoic, Middle Cambrian, and Devonian geology of the area in particular. Since it represents a synthesis of observations made by the Georgina Basin Project, which was mainly concerned with Late Proterozoic and early Palaeozoic geology, this Report largely focuses on the rocks of this interval. New information presented here on the Middle Cambrian stratigraphy is based on stratigraphic coreholes drilled since the relevant 1:100 000-scale preliminary maps were compiled.

Interpretation of the subsurface geology depicted on the schematic cross-sections is based on information obtained from three commercially drilled petroleum exploration wells; two stratigraphic coreholes drilled by GSQ; and fourteen stratigraphic coreholes drilled by BMR. Additionally, seismic stratigraphy developed from a major seismic survey in the Toko Syncline (Mathur & Bauer, 1977; Harrison, 1979, 1980; Harrison & Schmidt, 1978) conducted in 1977 has proved essential in the southern part of the Sheet area; and gravity and magnetic modelling undertaken by Tucker & others (1979) has also proved useful.

2. PRECAMBRIAN

The Precambrian geology of the Hay River-Mount Whelan Special Sheet area is represented by sequences no older than the Proterozoic, which is divided on the stratigraphic key into early and late portions.

(i) Early Proterozoic

Two metasedimentary sequences, Mount Smith Metamorphics and Your Dam Metamorphics, and two granitic bodies occur on the Field River Block (Warren, 1981), which is considered to be an extension of the eastern Arunta Complex in the western part of the Sheet area. The metasediments, referred to Arunta Complex Divisions II (at Mount Smith) and III (at Your Dam, south of the Marqua Monocline), predate the granites and are considered to be older than 1800 m.y. The Teikens Granite Complex, also in the western part of the Sheet area, is a big-feldspar leucogranite, dated (K/Ar) by a comagmatic pegmatite at 1725 m.y.

The Mount Dobbie Granite, a muscovite-rich leucogranite south of the Desert Syncline, has yielded a K/Ar age of 1662 m.y., while a pegmatite vein south of Mount Dobbie has indicated 1545 m.y.; but these ages may be partly reset. At Christmas Creek Dam, north of the axis of the Field River Anticline, a pegmatite vein has yielded a K/Ar age of 1719 m.y. (Warren, 1981) for undivided granite.

Granite has also been encountered in two petroleum exploration wells: PAP Netting Fence No. 1, located at the northern end of the Toomba Range, at a depth of 2010 m (PAP, 1965); and AOD Mirrica No. 1, beyond the southern end of the Toomba Range, at 3318 m (Jackson, 1982). GSQ drilled granite at 606 m in GSQ Mount Whelan No. 1 stratigraphic corehole (Green & Balfe, 1980). These subsurface granites have not been dated.

(ii) Late Proterozoic

Before the recent activities of the Georgina Basin Project, all the Upper Proterozoic rocks in the Sheet area were referred to the 'Field River Beds' (Smith, 1963, 1972). The stratigraphy of these beds has been investigated in detail by Walter & others (see Walter, 1980), and the relationships of the resultant new stratigraphic units are shown on the key of the accompanying geological sheet (see also the Adam 1:100 000 Geological Sheet 6451); the numbers 1-4 in the key refer to specific tectosomes recognised by Walter (1980).

The oldest datable Upper Proterozoic sedimentary rocks, the Yackah beds (about 250 m thick), crop out in the Desert Syncline and in the Field River Anticline. Lithographic similarities, similarity of position, and the common presence of the stromatolite *Acaciella australica* permit correlation with the Bitter Springs Formation of the Amadeus Basin (Walter & others, 1979a).

A distinct hiatus, resulting from the Areyonga Movement (Walter, 1980), separates the Yackah beds from a glacigene sequence, Yardida Tillite, which in the Field River area has a thickness variation of 650-2900 m. To the east, an unnamed tillitic sequence has also been identified in GSQ Mount Whelan No. 1, where a thickness of 103 m is recorded by Green & Balfe (1980). Locally in the Hay River Sheet area, a thin grey dolomite interval (Put_d) less than 100 m thick indicated to Preiss & others (1978) that the Yardida Tillite correlates with the lower tillite (Sturt Tillite) of the Adelaide Geosyncline.

The Yardida Tillite is overlain disconformably by the Black Stump Arkose, up to 700 m thick at the surface. The intervening hiatus represents the Rinkabeena Movement (Walter, 1980). To the west of the Toomba Range, the Black Stump Arkose grades upwards into the Wonnadinna Dolomite (380-700 m thick). To the east of the Toko Range, it correlates with the Sun Hill Arkose (>65 m thick).

The type area of the Sun Hill Arkose is in the Mount Whelan area in a northwest-southeast belt which extends discontinuously from Sun Hill on the Georgina River to Watchie Hut on Sylvester Creek, 65 km to the southeast. In spite of the assertions of Henderson (1977, see below), the Sun Hill Arkose is lithologically most similar to the Black Stump Arkose to the west of the Toomba Fault Zone (Walter, 1980). Near Watchie Hut (not in the Sheet area), the Sun Hill Arkose is overlain by dolomitic 'grits', dolostone, and sandy dolostone which may be equivalent to the Proterozoic Wonnadinna Dolomite of the western region of the Sheet area. In its type area the Sun Hill Arkose is overlain, apparently conformably, by the Sylvester Sandstone, but no contact has been seen. The relationship of this unit to the overlying dated Thorntonia Limestone is not known.

Öpik (1960) ascribed an Early Cambrian age to the Sun Hill Arkose on the basis of ichnofossils found near Dingo Hill and near Mount Caley Tank, 18 km southeast and 14 km northeast of Mount Whelan respectively. This age is rejected by Shergold & Walter (1979), who regard the ichnofossils as sedimentary structures which commonly occur in the finer-grained rocks of the formation. A post-Cambrian age, also proposed for the Sun Hill Arkose (Henderson, 1977), implies that the formation is underlain by Cambrian and Ordovician carbonate sequences, but these do not crop out and have not been proved by stratigraphic drilling.

Green & Balfe (1980) have identified a 'Sun Hill Arkose correlative' in GSQ Mount Whelan No. 1 corehole, where a mere 12 m of arkose and sandstone directly overlies an unnamed tillite and is overlain by 17 m of shale, siltstone, and sandstone regarded as a correlative of the Sylvester Sandstone. These 'correlatives' are shown in Figure 1 as Cambrian stratigraphic units because the 'Sylvester Sandstone correlative' grades upwards into the Thorntonia Limestone, and the general relationship of the lithofacies is strongly reminiscent of those at the base of the Red Heart Dolomite in the Desert Syncline 130 km to the west. Since the Thorntonia Limestone in GSQ Mount Whelan No. 1 contains the trilobite Redlichia and a hyolith, it is assumed to have an early Middle Cambrian (Ordian)

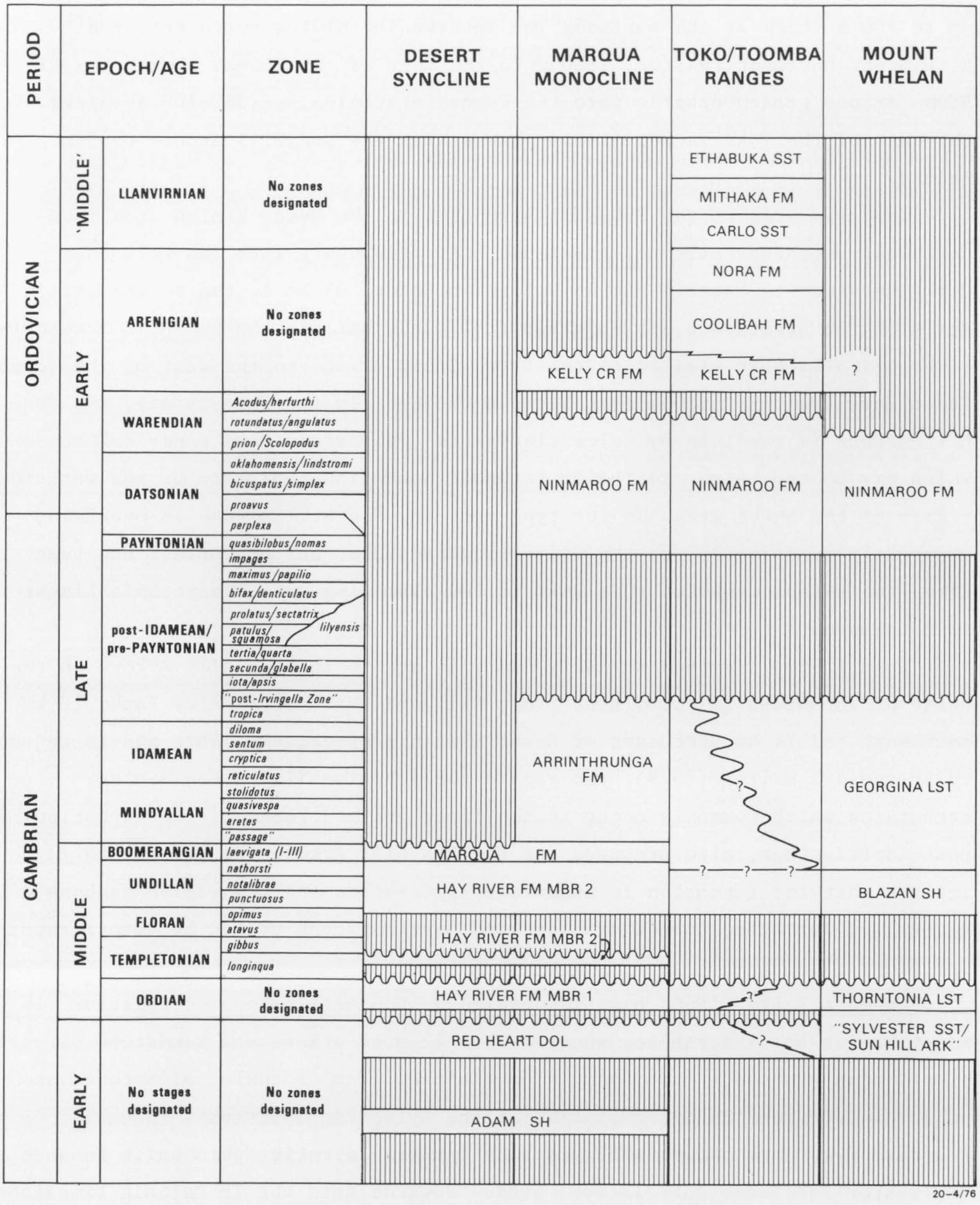


Fig. 1. Cambrian and Ordovician time-rock correlations in the southern Georgina Basin.

age, so that on superpositional evidence the 'Sun Hill Arkose/Sylvester Sandstone' sequence in the corehole may be interpreted as representing terminal Early Cambrian or even initial Middle Cambrian transgressive deposits which are considerably younger than the typical Sun Hill Arkose/Sylvester Sandstone in their type area.

There is no evidence for the Wonnadinna Dolomite east of the Toomba Range, and the unit is very thin west of the Tarlton Range. Accordingly, it is interpreted as a carbonate lens localised in the Hay River area. Palaeomagnetic work (Burek & others, 1979) indicates that the Wonnadinna Dolomite was deposited largely during periods of normal polarity; there were, however, two brief intervals of magnetic reversal.

A further hiatus, resulting from the Toomba Movement (Walter, 1980), separates the Wonnadinna Dolomite from an overlying siliciclastic sequence, Gnallan-a-gea Arkose, up to 1450 m thick west of the Toko Syncline; here the arkose conformably underlies sandstone and shale referred to the Grant Bluff Formation (Smith, 1964), up to 1170 m thick. Neither of these formations crops out to the east of the Toomba Range at the surface, but correlatives are known to the west (Walter, 1980) in the Huckitta region, southwestern Georgina Basin. The basal Gnallan-a-gea Arkose was deposited during normal magnetic polarity, but the upper half of the formation has reversed polarity. These and other facts led Burek & others (1979) to postulate revised Late Proterozoic correlations throughout central Australia.

Aspects of Late Proterozoic stratigraphy have been explored in the following coreholes: BMR Hay River Nos. 5, 6, 7, 8, 10, and 11B; BMR Mount Whelan No. 2; GSQ Mount Whelan No. 1; and in the petroleum exploration well, AOD Mirrica No. 1. No Upper Proterozoic sedimentary rocks were found in PAP Netting Fence No. 1, in which Cambrian sedimentary rocks directly overlie granite.

3. CAMBRIAN

In the Hay River-Mount Whelan Sheet area, Cambrian strata overlie Proterozoic formations with marked unconformity. This is best demonstrated near Boat Hill, at the eastern end of the Marqua Monocline, where Cambrian sedimentary rocks overstep flexed Gnallan-a-gea Arkose and Wonnadinna Dolomite, and in PAP Netting Fence No. 1 exploration well, where Cambrian strata rest directly on granite.

(i) Early Cambrian

Lower Cambrian sedimentary rocks are represented by basal arkose, sandstone, shale, and dolomite. The oldest datable rocks, Adam Shale (up to 16 m), were originally described from BMR Hay River No. 11B in the Desert Syncline (Walter in Walter & others, 1979b), and their Tommotian age was suggested on the basis of acritarchs (Muir in Walter & others, 1979b). They were subsequently recognised in surface outcrop to the west of the Desert Syncline, and are also interpreted to occur in BMR Tobermory No. 14 in the Marqua Monocline.

The Red Heart Dolomite, up to 20 m thick where cored, is arkosic at the base, and interpreted to rest disconformably on the Adam Shale. It is generally a highly compacted unit, but parts are vuggy, and mineralised. Its upper surface is irregular and weathered, suggesting a microkarst surface. Walter (in Walter & others, 1979b) has recognised U-shaped burrows (Diplocraterion sp.) in the basal sandy layers. Inarticulate brachiopod fragments, hyoliths, Chancelloria, and camenid shells (aff. Bercutia Missarzhevsky and Ramenta Jiang) occur in the upper part along with a poorly preserved archaeocyathan fauna described by Kruse & West (1980). The camenid shells and archaeocyathans indicate a pre-Ordian age (Atdabanian to early Lenian).

Vuggy intervals in the Red Heart Dolomite contain crystalline quartz linings, and some of these crystals contain hydrocarbon-bearing fluid inclusions. The presence of mesophase (a pyrobitumen believed to form at temperatures in the range 400-470°C) in the same interval that contains the quartz crystals suggests that the host rocks were considerably heated. These vuggy intervals mark the path of a short-lived hydrothermal event whose timing is not known (see p. 25).

First identified in the Desert Syncline, and investigated in BMR Hay River Nos. 11A and 11B coreholes, the Red Heart Dolomite was also penetrated in BMR Tobermory No. 14 in the Marqua Monocline. Correlatives of the formation also occur in the western Georgina Basin (Errarra Formation of Freeman & others, in press) and eastern Amadeus Basin (Todd River Dolomite), but it is not known for certain east of the Toko Syncline even though it is shown on the geological cross-section. The Red Heart Dolomite is the source of the archaeocyathan dolostone surface rubble occupying a broad belt extending from the southern Tarlton Range to the Marqua Monocline and Desert Syncline.

In the east of the Sheet area, the Sylvester Sandstone crops out south-southeast of Glenormiston, and has also been interpreted in GSQ Mount Whelan No. 1 (Green & Balfe, 1980), where it is only 17 m thick. It disconformably overlies the Upper Proterozoic sequence north of Watchie Hut (south-southeast of Mount Whelan, just outside the Sheet area). It is considered here as an Early Cambrian sand sheet, like the Mount Baldwin Formation in the western Georgina Basin and the Mount Birnie beds in the Burke River area, although it lacks the trace fossils which occur in these formations. It is correlated with the Adam Shale and Red Heart Dolomite west of Mount Whelan.

(ii) Middle Cambrian

Contrasting Middle Cambrian lithofacies are mainly clastic to the west and mainly carbonate to the east of the axis of the Toko Syncline. These facies interdigitate in PAP Netting Fence No. 1. Major stratigraphic breaks in both sequences are correlatable.

Eastern lithofacies. Middle Cambrian rocks are poorly known along the northern periphery of the carbonate pediment south of Glenormiston; in the vicinity of Sun Hill; and to the east of Mount Whelan. Surface exposures have been referred to the basal Georgina Limestone, which is mainly an Upper Cambrian stratigraphic unit. The complete eastern sequence was penetrated in GSQ Mount Whelan No. 1 (Green & Balfe, 1980), in which a basal Middle Cambrian carbonate unit (39 m thick) overlies a Sylvester Sandstone correlative. This carbonate contains *Redlichia* sp., and is accorded an early Middle Cambrian (Ordian) age; it is correlated with the Thorntonia Limestone as known along the eastern margin of the Georgina Basin, and is regarded as the peritidal carbonate equivalent of the lower Hay River Formation west of the axis of the Toko Syncline.

A thin calcareous black shale interval (8 m thick) overlying the carbonate unit is correlated by Green & Balfe (1980) with the Inca Formation of the Burke River Structural Belt. More likely it represents the most southerly extent of the Blazan Shale (not shown on the map) originally described from the eastern Georgina Basin south of Ardmore. This shale interval contains agnostid trilobites indicative of an age between late in the *Ptychagnostus atavus* Zone (Fig. 1) and early in that of *Pt. punctuosus* (Shergold *in* Green & Balfe, 1980), which is consistent with the age of the Blazan Shale and indicates direct correlation with the upper Hay River Formation of the Marqua Monocline. This age determination signifies an hiatus equivalent to the complete Templetonian Stage, and probably most of the zone of *Pt. atavus* as well, between the Thorntonia and Blazan/Inca correlatives.

The remainder of core from GSQ Mount Whelan No. 1 is referred to the Georgina Limestone, at least 409 m thick. That the basal part of this formation is of late Middle Cambrian age is indicated by the record of Oidalagnostus personatus (Fleming in Green & Balfe, 1980) and fossils obtained from outcrop (Öpik, 1967). The upper part of the core contains Late Cambrian trilobites (see below). Öpik (1967, table 1) suggested an hiatus at the base of the Georgina Limestone, between the Pt. punctuosus and Leiopyge laevigata Zones.

Western lithofacies. Before 1979, all strata between the Upper Proterozoic Grant Bluff Formation and the Upper Cambrian Arrinthrunga Formation were referred to the 'Marqua Beds' (Smith & Vine, 1960; Smith, 1963, 1965, 1972), and assigned a Middle Cambrian age. The name was applied to sequences of blue chert, silicified shale and siltstone, limestone, and calcareous sandstone which occupy this stratigraphic position between Hay River and the Toko Syncline. The 'Marqua Beds' have been reassessed following the recognition of Lower Cambrian formations - Adam Shale and Red Heart Dolomite - initially in the Desert Syncline (Walter & others, 1979b; Shergold & Walter, 1979) and subsequently in the Marqua Monocline.

Throughout the western part of the Sheet area, the lower part of the 'Marqua Beds' is represented by a mainly siltstone sequence which forms recessive topography and accordingly crops out poorly. This part of the unit, fully cored in BMR Hay River No. 11 and Tobermory No. 14, is now renamed the Hay River Formation (Shergold in Walter & others, 1979). The upper part of the 'Marqua Beds' consists mainly of carbonates which form mappable features, and is shown as Marqua Formation on the accompanying map.

The Hay River Formation is best developed in the Marqua Monocline, where it is 110 m thick, as estimated from core section (BMR Tobermory No. 14) and surface observations. In BMR Hay River No. 11, the formation is 68 m thick. The two coreholes show that the formation comprises essentially two black shale or dark silty carbonate members separated by a prominent, laterally persistent, often dolomitised grainstone layer which can be recognised over a wide area. The stratigraphy of the Hay River Formation is described in some detail here, since the information is largely new and may not be published elsewhere.

The lower member of the formation is equivalent to the Hay River Formation as originally described in the Desert Syncline coreholes (Shergold in Walter & others, 1979b), where a minimum thickness of 56 m was observed. The earlier presented lithological description applies to the Desert Syncline area, and is not repeated here. Nevertheless, some comment must be made on lithological changes occurring at this level between the Desert Syncline and Marqua Monocline, some 30 km to the north. Essentially, the basal intraclastic dolostone interval found in BMR Hay River No. 11 (Desert Syncline) also occurs in BMR Tobermory No. 14 (Marqua Monocline). Above this, however, the lower member in the Marqua Monocline is, in general, more calcareous: its dark fetid carbonate siltstone intercalated with pale fetid carbonate contrasts with the grey and black shale of the Desert Syncline.

Being more calcareous, the Tobermory core is considerably more fossiliferous than the Hay River one. In the latter, fossils, particularly inarticulate brachiopods, occur most frequently in coquinitic laminae and layers in the basal 7 m of the member. Oboloid and acrotretid brachiopods are the most common forms, but sandy dolostone and grainstone layers also contain hyolith fragments. Small smooth lenticular phosphatised molluscs also occur in this interval, and black rounded phosphatic pellets, derived from mollusc or echinodermal shell debris, give the rock a spotted appearance. In the Desert Syncline no fossils have been obtained from the essentially black shale sequence which forms the bulk of the member, with the exception of the topmost beds, from which the following have been identified: three genera of Bradoriida (a possible *Aristaluta* sp., a beyrichoniid aff. *Beyrichona rotundata* Matthew, and a reticulate form with ornament too fine for *Tuzoia* but too coarse for *Reticulocambria*), and species of the trilobites *Redlichia* and *Pagetia*.

In contrast, the lower member in the Marqua Monocline is highly fossiliferous throughout. Enormous numbers of inarticulate brachiopods are associated with a species of *Pagetia*, a punctate bradoriid crustacean, and an indeterminate species of *Xystridura* in the basal part of the member. In the upper part, a profusion of inarticulate brachiopods is associated with a finely granulose species of *Redlichia*, a species of *Pagetia* resembling *P. pollosta* Jell or *P. leptoskolos* Jell, the helcionellid mollusc *Latouchella penecyrano* Runnegar & Jell, and an undetermined bradoriid crustacean. Surface outcrops at the eastern end of the Marqua Monocline (close to locality T87 of Öpik, 1961, p.48) have yielded in addition species of *Mellopegma* and *Peronopsis*.

The lower member of the Hay River Formation, by virtue of its contained association of *Xystridura* with *Redlichia*, assumes an Ordian age. Since no Metadoxididae are recorded, these faunas may not represent the whole of Ordian time; they may indicate only a late Ordian age.

Lower and upper members of the Hay River Formation are separated by a dolomitised phosphatic pelletal skeletal intraclastic grainstone, 0.5 m thick in BMR Hay River No. 11, and 1.4 m thick in BMR Tobermory No. 14. It has an irregular erosional contact with the uppermost layer of the lower member in BMR Hay River No. 11, and its upper surface is a black manganiferous lamina. Internally it is a phosphatic intraclastic grainstone, comprising wackestone clasts set in a matrix of black comminuted inarticulate brachiopod shell sand, which also contains a hyolith and fragments of trilobites referable to Xystridura, Pagetia, and Peronopsis. In BMR Tobermory No. 14, this bed is represented by a pale grey glauconitic skeletal dolostone, 1.4 m thick, almost entirely composed of comminuted inarticulate brachiopod debris. Available faunal evidence suggests that this grainstone has a Templetonian age, and that it is bounded top and bottom by disconformity surfaces. Although a distinct stratigraphic entity, this grainstone is included with the upper member of the Hay River Formation on the map.

The remainder of the upper member is a mainly shaly interval comprising medium grey to black siltstone interlaminated with pale grey coarser sediment, pale grey fine-grained non-laminated fetid carbonate, and random thin crystalline dolostone layers. This lithofacies is very poorly exposed at the surface and is incomplete in both the Hay River and Tobermory coreholes. Nevertheless, 62 m were penetrated in the former, and 85 m in the latter.

The upper shaly member of the Hay River Formation is not fossiliferous throughout; a sparse fauna of agnostid trilobites, sponge spicules, and inarticulate brachiopods is confined to the silty carbonate layers. In the Hay River corehole, two agnostid assemblages can be recognised. The older of them contains species which are difficult to determine by virtue of their scarcity. However, one species is similar to Ptychagnostus idmon Öpik; a second closely resembles members of the Pt. atavus group; and a third seems to be comparable with Onymagnostus hybridus (Brögger). Collectively, these forms may suggest an age for the initial assemblage late in the Euagnostus opimus Zone (Fig. 1). The younger assemblage contains Pt. punctuosus punctuosus (Angelin), Pt. punctuosus affinis (Brögger), Aotagnostus cf. ponebrevis Öpik, and Diplagnostus floralis Öpik, which indicate the succeeding Pt. punctuosus Zone.

In BMR Tobermory No. 14, the initial 11 m of the upper member has not yielded fauna. Subsequent core has yielded Ptychagnostus punctuosus affinis, an undetermined species of Hypagnostus, and a species of Triplagnostus which resembles T. disremptus Öpik but is smooth; these forms are associated with tetrad sponge spicules and acrotretid brachiopods. This assemblage can also be referred to the Pt. punctuosus Zone.

A slightly younger assemblage has been collected from surface outcrops at the site of BMR Tobermory No. 14. It contains Pt. punctuosus punctuosus, Pt. punctuosus affinis, Pt. punctuosus fermexilis Öpik, Pt. cassis Öpik, Hypagnostus melicus Öpik, Diplagnostus cf. planicaudata vestgothica (Wallerius), Leiopyge praecox Öpik, and Pseudophalacroma dubium (Whitehouse). This fauna seems to indicate an age late in the Pt. punctuosus Zone (Fig. 1), and it dates the uppermost beds of the Hay River Formation.

A significant time break is therefore postulated between the grainstone and the upper silty carbonate unit of the upper Hay River Formation. The zones of Triplagnostus gibbus and Ptychagnostus atavus appear not to be represented in either the Hay River or Marqua areas, and the succeeding Euagnostus opimus Zone may also not be represented at Marqua. This break is of similar magnitude to that at Mount Whelan and is significant for the palaeogeography of the basin at this time. Thus, the palaeogeographical figures published earlier (Shergold & Druce, 1980; figs. 13-14) require emendation.

In the Hay River-Mount Whelan Special Sheet area, the carbonates which Smith (1972) regarded as the upper part of his 'Marqua Beds' form the basis of the Marqua Formation. The type area for the Marqua Formation is the Marqua Monocline, and the reference section for the 'Marqua Beds' (Smith, 1972; p.88; fig. 24) is retained as the type section for the formation.

The Marqua Formation overlies the Hay River Formation conformably. Its base is mapped at the incoming of persistent carbonate layers above the generally poorly outcropping siltstones of the Hay River Formation. These carbonate layers form the first continuous features above the recessive topography of the Hay River Formation, and are well defined in the western portion of the Marqua Monocline, to the west of Marqua Creek.

In this area, the Marqua Formation comprises two recognisable divisions ($€mm_1$ and $€mm_2$ on the inset map). A lower unit, 430 m thick, comprises relatively thin layers and groups of layers, up to about 1 m thick, of laminated sandy and bioturbated micrite and wackestone, peloidal and intraclastic grainstone, and non-outcropping intercalations of siltstone. These rocks contain a fauna dominated by agnostid and mapaniid trilobites including: Leiopyge laevigata (Dalman), Grandagnostus cf. velaevis Öpik, Hypagnostus melicus Öpik, Diplagnostus sp., Quitacetra sp., and other mapaniids. These are associated with small inarticulate acrotretid brachiopods and Chancelloria sp. A somewhat similar faunal association has been recorded by Öpik (1961, p.48; 1979, p.181) at locality T87, at the eastern end of the Marqua Monocline, where the formation overlies faulted Hay River Formation. Öpik assigned a latest Middle Cambrian age to these beds (Leiopyge laevigata II and III Zones).

The highest beds of the Marqua Formation in the western part of the Marqua Monocline consist of some 60 m of pale laminated silty micrite, sandy wackestone, and mottled two-tone carbonate. No fauna has been recorded from these. They lie conformably below the basal peloid carbonate sand shoals of the overlying Arrinthrunga Formation, which at one locality north of Old Marqua Bore contains the trilobite Blackwelderia - probably indicative of an age close to the Middle/Late Cambrian boundary.

To the east of Marqua Creek, the Marqua Formation is disturbed by faulting and folding associated with the Marqua Monocline: the attitude of the beds varies from subhorizontal to vertical, and strike faults are inferred. At Smith's type section, the diagrammatic sequence shown (1972, p.89; fig.24) is only partly faithful to the actual stratigraphy. Certainly the siltstones, calcareous sandstones, and carbonates shown occur, but their relationships are not satisfactorily documented; beds lying subhorizontally appear to be mainly leached ferruginised sandstones.

(iii) Late Cambrian

As with the Middle Cambrian, the Toko Syncline divides the Sheet area into two quite distinct Upper Cambrian lithofacies, but by this time both now represent areas of carbonate sedimentation.

Eastern lithofacies. Upper Cambrian rocks have a wide distribution in the eastern part of the Sheet area, where they form extensive pediment topography to the west and south of Glenormiston. Two formations contain fossils of Late Cambrian age: the upper Georgina Limestone and the basal Ninmaroo Formation. Unlike the Late Cambrian stratigraphy of the Burke River Structural Belt, the easternmost appendage of the Georgina Basin (Shergold, 1975, 1980, 1982), a significant hiatus has to be postulated between the Georgina Limestone and Ninmaroo Formation in the Glenormiston area. Ten trilobite assemblage zones are unaccounted for in this gap, which is of widespread distribution throughout the central Australian Cambrian sedimentary basins. Even where the sequence is apparently complete, as in the Burke River area, extreme shallowing is evident (Shergold in Druce & others, 1982).

Green & Balfe (1980) have described in detail the Georgina Limestone from GSQ Mount Whelan No. 1 core section, and have given an historical account of the terminology of the formation. This core contains a complete section from the late Middle Cambrian up to the Late Cambrian Irvingella tropica Zone (Fig. 1), which occurs some 23 m below the top of the core. The biostratigraphy of this formation has been published in detail elsewhere (Öpik, 1963, 1967; Henderson, 1976, 1977). The faunas of the Mindyallan, Idamean (sensu Shergold, 1982), and immediate post-Idamean (Irvingella tropica Zone) are represented.

There is some dispute about the environment of deposition of the Georgina Limestone. Henderson (1976) has argued for the deposition of the sandy limestone in shallow subtidal conditions, but considered the laminated silty limestone and associated intraclastic lithologies to represent restricted supratidal and upper intertidal environments. He recorded the presence of a hypersaline horizon at one locality, and illustrated (fig. 4) possible pseudomorphs after gypsum which were interpreted as having a 'pan-evaporite origin'. Green & Balfe (1980, p.169), on the other hand, considered that the Georgina Limestone in GSQ Mount Whelan No. 1 was deposited in a relatively deep subtidal, oxygen-deficient environment. The nature of the fauna, and its diversity and relationships, point to the presence of cool-water subtidal environments, at least for the fossiliferous intervals.

The Georgina Limestone is disconformably overlain by stromatolitic dolostone, sandy dolomitic limestone, and sandstone, assigned to the basal member of the Ninmaroo Formation (Pritchard, 1960; Reynolds, 1965; Smith, 1972). The latest Cambrian (Payntonian) age of the basal Ninmaroo Formation is documented by Öpik (1963, p.16; 1967, p.31), who listed a trilobite association comprising Tsinania cf. ceres (Walcott) and species of Saukia, 'Eosaukia', 'Coreanocephalus', and Parakoldinioidia associated with the articulate brachiopods Billingsella and Eoorthis. The Ninmaroo Formation is considered further as an Ordovician stratigraphic unit (see below).

Western lithofacies. Equivalents of the upper Georgina Limestone crop out in the Toomba Range, where they are caught up in the Toomba Fault Zone, and to the north of the Marqua Monocline. They are referred to the Arrinthrunga Formation, which has its maximum development in the Huckitta region in the western Georgina Basin. The formation has been studied in considerable detail by Kennard (1980, 1981), who has shown its distribution and has analysed the petrology of its various lithofacies. In the Hay River-Mount Whelan Sheet area, Kennard (1981) estimated a thickness of 601 m in PAP Netting Fence No. 1, increasing to 777 m in the Marqua area.

The Arrinthrunga Formation contains a wide variety of petrographic types, including peloid and ooid grainstone, sandy dolostone, lime mudstone, intraclastic limestone and flat-pebble conglomerate, and algal boundstone. In the confines of the Sheet area the basal Arrinthrunga Formation is composed of a distinctive cross-stratified ooid and peloid grainstone (Cua_1 on the inset). This is followed by a mainly algal boundstone lithofacies. The depositional environments are described in great detail by Kennard (1981).

The Arrinthrunga Formation has yielded little biostratigraphic information: one trilobite pygidium obtained from the basal beds at Black Tank in the Marqua Monocline indicates an age close to the Middle/Late Cambrian boundary. However, correlation can be effected by seismic stratigraphy: the top of the Arrinthrunga Formation in PAP Netting Fence No. 1 can be traced on seismic profiles to AOD Ethabuka No. 1 (Harrison & Schmidt, 1978), and from there to the interpreted top of the Georgina Limestone near Mount Whelan (Harrison, 1979).

The Arrinthrunga Formation is overlain by the basal Ninmaroo Formation, one of the few units which is distributed throughout the southern Georgina Basin. In the western part of the basin there is an unconformity at the top of the Arrinthrunga Formation (see Kennard, 1981, p.5). However, it is not easy to define the contact in the Marqua area since the lithologies of the upper Arrinthrunga and basal Ninmaroo Formations are so similar. Nevertheless, by analogy with the Georgina Limestone of the eastern lithofacies, a hiatus between the formations is to be expected.

Though the basal Ninmaroo carbonates in the western part of the Sheet area have not yielded a macrofauna, latest Cambrian trilobites and molluscs have been collected from a small outcrop of decalcified siltstone originally mapped as a remnant of Tarlton Formation (*sensu* Smith, 1972) due south of Burnt Well, Gaphole Creek. This collection includes species of *Quadraticephalus*?, *Tsinania?*, *Haniwa*, and a saukiid associated with the rostroconch molluscs *Cymatopegma semiplicatum*, *Kimopegma pinnatum*, and *Ribeiria huckitta* (see Pojeta & others, 1977). This occurrence is presently regarded as either a clastic interbed within the basal Ninmaroo Formation, or a distal intercalation of Tomahawk beds extending from the western part of the Georgina Basin. It is distinguished on the map as Cuu (undivided Late Cambrian).

4. ORDOVICIAN

There is no definable break at the Cambrian-Ordovician boundary in the Hay River-Mount Whelan Special Sheet area: deposition of the Ninmaroo Formation continued across the boundary throughout the area.

(i) Early Ordovician

Radke (1980, 1981, 1982) has presented a very detailed analysis of the Ninmaroo Formation throughout the Georgina Basin. Aided by measured sections at outcrop (Radke, 1981), by information from coreholes, PAP Netting Fence No. 1, AOD Ethabuka No. 1, AOD Mirrica No. 1, and GSQ Mount Whelan No. 2, and by seismic stratigraphy in the Toko Syncline, Radke has been able to plot the distribution of lithofacies and sedimentary cycles across the Sheet area. Composite sections imply that the formation ranges in thickness from 225 m near Glenormiston in the east of the Sheet area to 725 m in the Toomba Range.

Unlike the Burke River area of the Georgina Basin, it is not possible to subdivide the Ninmaroo Formation into members in the Hay River-Mount Whelan Sheet area, although Pritchard (1960), Reynolds (1965), and Smith (1972) have attempted to do so in the Glenormiston area (see Shergold & others, 1976, p.40). Radke (1980, 1981) has instead recognised six lithofacies, documented their distribution, and correlated them with the lithological members recognised in the Burke River area (Druce & others in Radke, 1981, appendix IV; Druce & others, 1982). These lithofacies recur in time (Radke, 1980; fig. 8), and not all are present in any given section. Radke (1980, 1981) also recognised three carbonate sedimentary cycles throughout the formation: a cryptalgal carbonate cycle, a peloid carbonate cycle, and a skeletal ooid carbonate cycle, which may be repeated within a particular lithofacies. They are 'bounded by basal and upper erosional surfaces which separate repeated lithological patterns' (Radke, 1981, p.30).

In the context of the Hay River-Mount Whelan Sheet area, the Ninmaroo Formation of the Glenormiston district comprises mainly peloid carbonate and flat-pebble conglomerate/carbonate lithofacies, whereas in the Toomba Range a greater variety is present: ooid carbonate at the base of the formation, followed by repetitions of the peloid carbonate, ooid carbonate, skeletal carbonate, and terrigenous lithofacies, and the formation is capped by a mixed carbonate lithofacies.

Biostratigraphy of the Ninmaroo Formation in the Sheet area is sparse, and correlations with the type section in the Burke River area are tenuous, although they were attempted by Radke (1980, 1981). Reynolds (1965) reported nautiloids from the Ninmaroo Formation of the Glenormiston area; the rostroconch molluscs Euchasma caseyi and Eopteria struszi occur in the same area (Pojeta & others, 1977); and Pauropegma jelli occurs with Oneotodus variabilis and nautiloids between Burnt Well and Halfway Dam in the western part of the Sheet area.

Nevertheless, by extrapolation, the Ninmaroo Formation has an age range from terminal Cambrian to initial Arenig (Jones & others, 1971; Shergold & others, 1976).

The Kelly Creek Formation extends from the Toko Range, across the Hay River-Mount Whelan Sheet area, to the Dulcie Range in the western Georgina Basin. According to Radke (1981, p.11) it overlies a karsted and dolomitised upper Ninmaroo surface with apparent disconformity. In the Toko-Toomba Ranges, Shergold & Druce (1980, p.162) had earlier suggested a tripartite division of the formation, based mainly on the 110 m sequence in PAP Netting Fence No. 1. Thus, they recognised a basal dolostone unit, which is exposed in the Mulligan River area; a dolomitic sandstone and coquinitic interval; and an upper dolomitic limestone. However, the basal dolostone is apparently equivalent to the top of the Ninmaroo Formation according to Radke (1981), and is considered to mark a depositional hiatus (the Kelly Creek Movement of Webby, 1978) predating the deposition of the Kelly Creek Formation.

To the south of the Toko-Toomba area, the Kelly Creek Formation thickens: to 241 m in GSQ Mount Whelan No. 2 (Green & Balfe, 1980) and about 250 m in AOD Mirrica No. 1 (abstracted from Jackson, 1982, fig.6). The formation also appears to become less dolomitic, at least in the southern Toko Range, where Green & Balfe (1980) recorded a basal sandy limestone and calcareous sandstone (conformable on the Ninmaroo Formation), followed by dolostone, and an upper arenitic unit.

From the available lithological data, the Kelly Creek Formation apparently comprises a complex, mainly dolomitic facies mosaic which exhibits rapid lateral variation. As such, the proposed Withillindarma Dolostone Member of the Kelly Creek Formation, shown as representing the upper part of the formation on the Toko 1:100 000 Sheet preliminary map (though Radke & Duff, 1980, inferred that it is represented by the middle, dolostone unit in GSQ Mount Whelan No. 2), may lead to confusion, especially in the southern part of the Toko Syncline; consequently it has not been included as a distinct stratigraphic unit on the 1:250 000 Special Sheet.

Available information on the fauna of the Kelly Creek Formation has been previously published (Shergold & Druce, 1980); to date, none has been described. Druce (1978; in Shergold, 1978) suggested that four conodont assemblages occur in the Kelly Creek Formation (in the sense of Shergold & Druce 1980). The earliest represents the late Tremadoc, Warendian, Cordylodus rotundatus-C. angulatus Zone (of Druce & Jones, 1971). A younger fauna is that of the initial Arenig Scolopodus sexplicatus Zone (of Jones, 1971), while two even younger zones are indicated but not detailed since they have not previously been recorded in Australia; they also indicate an early Arenig age.

The Kelly Creek Formation is overlain by the Coolibah Formation, whose distribution is limited to the Toko-Toomba area, and Tarlton Range on the western margin of the Sheet area. Casey (in Smith, 1965) and Smith (1972) regarded the Coolibah Formation as disconformably overlying the Kelly Creek Formation. More recent studies (Druce in Shergold, 1979a) have suggested an interdigitating relationship, and Draper (1980a; fig.3) inferred conformity. The maximum development of the Coolibah Formation, which is basically an algal and/or clastic peloidal carbonate, is in the south of the Toomba Range where 79 m was penetrated in AOD Ethabuka No. 1. In GSQ Mount Whelan No. 1 at the southern end of the Toko Range, it is 28 m thick (Green & Balfe, 1980); in PAP Netting Fence No. 1, 36 m; and in the Tarlton Range west of the Sheet area, only a 2 m section is recognised (Gilbert-Tomlinson, 1973; Shergold & Druce, 1980).

As with the Kelly Creek Formation the fauna, although varied, is largely undescribed. To date, a cyrtodontid? pelecypod has been recorded by Pojeta & Gilbert-Tomlinson (1977) from near Cravens Peak in the Mount Whelan area; the gastropod Teiichispira cornucopiae has been described by Gilbert-Tomlinson (1973) from several localities in both the Toko and Toomba Ranges; and the rostroconch molluscs Euchasma skwarkoi, Euchasma sp.A, and Eopteria sp.A have been described by Pojeta & others (1977), mainly from the northern part of the Toko Syncline. Undescribed fauna is listed by Shergold (1976), Shergold & others (1976), and Shergold & Druce (1980). Unpublished information (Druce in Shergold, 1979a, 1979b) suggests the presence of three distinct conodont faunal assemblages in the Coolibah Formation. The oldest corresponds to the youngest of those of the Kelly Creek Formation, reinforcing the idea of interdigitation between the two formations. This particular assemblage provisionally contains Acodus deltatus Lindström, Chosonodina cf. lunata Harris & Harris, Scandodus costatus Abaimova, and Triangulodus brevibasis (Sergeeva). The succeeding assemblage is characterised by the presence of protoprioniodids, together with Oistodus multicorrugatus Harris, Belodella jemtlandica Löfgren, and species of Juanagnathus and Paraoistodus. The youngest assemblage contains Multicornis anonymus Moskalenko and several new forms. These assemblages are considered to be typically Arenig.

The Nora Formation is distributed in the Toko and Toomba Ranges, and the Tarlton and Dulcie Ranges outside the Hay River-Mount Whelan Sheet area. It is considered to form the basal unit of a revised Toko Group (Draper, 1980a), and to overlie the Coolibah Formation conformably. As with other Lower Ordovician formations, the Nora Formation is lithologically variable. Essentially three lithological divisions can be recognised in the northern part of the Toko

Syncline: a basal clastic unit, usually calcareous; a ferruginised coquinitic interval; and an upper sandstone/siltstone unit. The formation thickens southwards in the Toko Syncline. It is 114 m thick in PAP Netting Fence No. 1, 119 m at outcrop in the northern Toko Range, but 235 m in GSQ Mount Whelan No. 2 and 250 m in AOD Ethabuka No. 1. Southern sequences are also generally less calcareous (see Shergold in Fortey & Shergold, 1984, for the most current synthesis of this formation).

The faunas of the Nora Formation are prolific: several groups of fossils have been described and many others listed (Shergold, 1976; Shergold & others, 1976; Shergold & Druce, 1980). Beard (in Hill & others, 1969) and Wade (1977a, 1977b) have described some of the nautiloids; Nieper (in Hill & others, 1969), some of the conodonts; Telford (same source), some brachiopods; Pojeta & Gilbert-Tomlinson (1977), ten pelecypod taxa; and Pojeta & others (1977), a single rostroconch mollusc. More recently, the trilobite faunas have been published by Fortey & Shergold (1984); two assemblages contain species of Annamitella, Fitzroyaspis, Presbynileus, Hungioides, Phorocephala, Carolinites, Nambeetella, Gogoella, Prosopiscus, and two new asaphid genera. While the molluscs in general seem to indicate a Middle Ordovician* age, the conodonts (according to Druce in Shergold & Druce, 1980, but not Nieper in Hill & others, 1969) and certainly the trilobites suggest a middle to late Arenig age for the Nora Formation. Accordingly, the formation is shown on the map and in the legend as an Early Ordovician stratigraphic unit.

(ii) Middle Ordovician

The Nora Formation passes gradually, but possibly diachronously upwards into the Carlo Sandstone. The latter has a distribution limited to the Toko, Toomba, and Tarlton Ranges, where it forms massively bedded escarpment cappings. The Carlo Sandstone has been thoroughly investigated by Draper (1977), who has given a detailed sedimentological account of the formation and its distribution. A more general account was given by Draper (in Shergold & others, 1976).

Essentially, the Carlo Sandstone can be divided into three facies, each distinguished by sedimentary features - such as types of ripple marks, cross-stratification, lineation, scouring, lamination, and diagenetic deformation - and by biogenic structures. The basal facies consists mainly of sandstone which contains mudstone and siltstone clasts. Parts of this facies, which is about

---

* The term 'Middle Ordovician' is used in the sense of Webby & others (1981).

10 m thick, are extremely bioturbated: horizontal and vertical burrows, tracks, trails, brushmarks, and U-tubes all occur, together with abundant Cruziana and more rarely Skolithos. The middle lithofacies is also dominated by quartz sandstone, but has fewer sedimentary features and biogenic structures, although tracks and trails are fairly common; the assemblage Arthrophycus (the dominant trace fossil) and rare Cruziana indicates the Skolithos facies, succeeding the earlier Cruziana facies. These facts suggest a postulated gradual change from shallow subtidal or intertidal to upper intertidal and supratidal environments (Draper, 1977). The upper facies, generally less than 10 m thick, is again an extremely bioturbated quartz sandstone unit. It contains 'Asaphus' thorntoni Etheridge and skeletal debris derived from trilobites, molluscs, and fish; in addition, three genera of pelecypods have been described by Pojeta & Gilbert-Tomlinson (1977). Draper (1977) suggested that this facies accumulated in a lagoon-bay environment.

The Carlo Sandstone retains its thickness throughout the Toko-Toomba Ranges. PAP Netting Fence No. 1, spudded in this formation, penetrated 125 m of it. The formation is 155 m thick in GSQ Mount Whelan No. 2 and 174 m in AOD Ethabuka No. 1. No real analysis of the fauna has been made, but from what is known the Carlo Sandstone appears to span the Early-Middle Ordovician boundary. Until greater resolution is available it has been referred on the present map to the Middle Ordovician.

The Carlo Sandstone grades conformably upwards into the Mithaka Formation, a mainly fine-grained sandstone, shale, and siltstone unit confined to the Toko Syncline. A recessive formation, the Mithaka Formation crops out poorly, and is best known from core section in AOD Ethabuka No. 1 (127 m) and BMR Mount Whelan No. 1 stratigraphic hole (94 m). Draper (1980b) has described this formation in detail, and considers it to have been deposited in littoral and sublittoral environments, progressively deepening with time.

The fauna is very rich and, as yet, almost completely undescribed. It is dominated by very large asaphid trilobites, large nautiloids and pelecypods, gastropods, inarticulate and articulate brachiopods, ostracodes, sponge spicules, fish debris, Receptaculites, and chitinozoa (Draper, 1980b). Additionally, ichnofossils are abundant, particularly in the lower part of the formation, where sandstone layers contain Arenicolites, Diplocraterion, Monocraterion, irregular burrows, surface tracks and trails, and large specimens of Rusophycus - in one instance associated with the asaphid trilobite which was presumably responsible for it. Bioturbation is evident throughout the upper part of the formation. Some of these ichnofossils have been described by Draper

(1980b), and Cruziana dilatata had been described previously by Seilacher (1970). A Middle Ordovician, Llanvirn, age is indicated by the fauna.

The youngest Ordovician stratigraphic unit in the Sheet area is the Ethabuka Sandstone ('unnamed sandstone unit' of Shergold & others, 1976), which is also limited in its distribution to the Toko Syncline. The Ethabuka Sandstone is conformable with the underlying Mithaka Formation. It is defined and fully described by Draper (1980a), who regarded it as the youngest unit of the Toko Group. The formation is best developed in AOD Ethabuka No. 1, its type section, where it is 1147 m thick and consists of a basal division of fine-grained sandstone and siltstone with some pebble clast intervals, and an upper division of fine and medium-grained sandstone. However, four units can be recognised on the basis of seismic stratigraphy in the southern part of the Toomba Range (Harrison, 1979).

No fauna has been described, although Draper (1980b) recorded the presence of trilobites, nautiloids, pelecypods, gastropods, and brachiopods, together with biogenic sedimentary structures, all of which indicate a marine origin. A late Llanvirn age is assumed.

5. DEVONIAN

In the Sheet area, Devonian sedimentary rocks are limited to the Toko Syncline, and more particularly the Toomba Range, where they have been referred to the Cravens Peak beds (Reynolds in Smith, 1965; Smith, 1972) based on Pritchard's (1960) informal stratigraphic unit Om-11. These beds were originally assigned a Silurian-Devonian age. Recent field mapping by Draper (1976, 1980a; in Turner & others, 1981) has demonstrated that the Cravens Peak beds as originally mapped comprise three distinct lithological units: the lower part of Pritchard's (1960) Om-11 is now regarded as Ethabuka Sandstone (see above); the middle part is now regarded as the Cravens Peak beds in the strict sense; and the upper part is considered to be a post-Devonian valley-fill conglomerate (see Radke & others, 1983).

The revised Cravens Peak beds, at least 280 m thick, consist of a basal calcareous facies overlain by a conglomerate and sandstone facies. The basal facies - comprising calcareous siltstone, calcareous sandstone, limestone, and some conglomerate - unconformably overlies Lower and Middle Ordovician sedimentary rocks, and is confined to the northwestern and southwestern parts of the Toomba Range. It grades upwards (according to Draper in Turner & others, 1981) into the conglomerate and sandstone facies, which has a much wider distribution. The two divisions correspond to the lower and upper Cravens Peak beds of Gilbert-Tomlinson (1968), who considered them to have an unconformable relationship.

The basal calcareous part of the Cravens Peak beds contains stromatolites and oncolites; the ostracodes Healdianella inconstans?, Baschkirina? sp., and kloedenellaceans (Jones in Turner & others, 1981); the eridostracan species Cryptophyllus (Jones, loc. cit.); and fish which include the thelodonts Turinia australiensis, T. cf. pagei, and Grampsolepis?, the acanthodian species of Gomphonchus? and Nostolepis?, and placoderm and crossopterygian remains. The upper facies of sandstone and conglomerate contains a species of Wuttagoonaspis (see Ritchie, 1973, for discussion of the fish described by Gilbert-Tomlinson, 1968 from the Toko Syncline), and remains of placoderms, crossopterygians, and acanthodians.

Draper (1976; in Turner & others, 1981) has pointed to the controversy regarding the depositional environments of the Cravens Peak beds. While the stromatolites, ostracodes, and the eridostracan suggest marginal marine conditions, the fish in general have previously been regarded as fresh-water inhabitants. Accordingly, Draper (in Turner & others, 1981) has suggested the possibility of deposition in an upward-shallowing marginal marine to non-marine environment of late Early Devonian (Emsian) to early Middle Devonian (?Eifelian) age. A possible Early Devonian palaeogeography has been suggested by Draper (1976).

6. MESOZOIC

All sedimentary sequences definitely not dated as Late Proterozoic, early Palaeozoic, or Cainozoic have been shown on the Hay River-Mount Whelan Sheet as undivided Mesozoic. They have been variously shown on earlier preliminary 1:100 000-scale maps as Hooray Sandstone, of Late Jurassic to Early Cretaceous age, or undivided Cretaceous. Earlier maps still (e.g., Smith, 1972, 1:500 000 sheet) referred these sequences either to the Tarlton Formation, originally considered to be Triassic but now known on the basis of its flora to be of Jurassic to Early Cretaceous age (Gould in Senior & others, 1978), or to the Early Cretaceous Longsight Sandstone. Since these rocks were not studied in detail by Georgina Basin Project personnel, all presumed Mesozoic strata are mapped as a single unit. Essentially they belong to the Eromanga Basin sequence, and have been most recently discussed by Mond & Harrison (in Senior & others, 1978).

7. TERTIARY

Two Tertiary formations are mapped in the Hay River-Mount Whelan Sheet area: the Austral Downs Limestone and the Poodyea Formation, whose relationship to one another is not clear. Previously named siliceous sinters near Mount Whelan and Mount Caley and to the west and southwest of the Toomba Fault System (e.g., the Mount Caley Sinter of Casey, 1959) are not recognised as distinct sedimentary units, and are represented on the map by stippling indicating silcrete and ferricrete.

Scattered patches of varicoloured chert after carbonate, found throughout the Sheet area, and seemingly unrelated to the Late Proterozoic and early Palaeozoic sequences, have been arbitrarily mapped as Austral Downs Limestone. The sediments of the Austral Downs Basin (Paten, 1964), regarded by Grimes (1980) as an infilled and dammed ancestral Georgina River drainage system, are best developed outside the Sheet area. Of the three Cainozoic cycles proposed by Grimes (1980), the Austral Downs Limestone belongs to the second, which is a Miocene event. There is little direct evidence for the age of the Austral Downs Limestone in the Sheet area, although there is a previous record of charophytes in siliceous limestone near Aroota Bore on the western side of the Toomba Range (Paten, 1964, p.18).

The Poodyea Formation (Radke & others, 1983) is a probable fluvial unit which is confined to the Toko Syncline. It is represented by boulder conglomerate, cross-stratified conglomerate, and pebbly sandstone forming narrow linear and sinuous belts. The outliers are confined to existing valley systems cutting the Carlo Sandstone, or occur as low ridges on the flat topography over the Mithaka Formation in the Toko Syncline. The formation may be considered to represent a river channel deposit. There is some dispute about what outcrops should actually constitute the formation, and this problem is discussed in detail by Radke & others (1983).

The Poodyea Formation disconformably overlies the Ordovician Toko Group (Draper, 1980a) and the Devonian Cravens Peak beds, and is overlain by Quaternary alluvium, colluvium, and sand. Its relationships to the Austral Downs Limestone and to the Mesozoic sediments are not established. There is no unequivocal evidence for the age of the formation other than its stratigraphic relationships and outcrop pattern. The Poodyea Formation is formalised by Radke & others (1983): previously such sediments had been shown on the preliminary Toko 1:100 000 Sheet as Beattie Creek Conglomerate, but this name was not formalised.

8. STRUCTURE

As is evident from the Hay River-Mount Whelan map, the structure of the area is very complicated. That shown is the result of observations on fault-plane inclinations, sedimentary dips, attitude and occurrence of quartz dykes, and especially the interpretation of seismic records (Harrison & Schmidt, 1978; Harrison, 1979, 1980), and gravity and magnetic modelling (Tucker & others, 1979). A simplification is presented as the structural sketch.

The main structures of the area are four in number.

1. In the west, there is a broad, much faulted, compressional folded belt wrapped around the Mount Dobbie Granite. The disposition of the folds and nature of the faults indicate that a northerly compression has dominated. This fold belt includes the Wonnadinna Syncline, Desert Syncline, Field River Anticline, and Aroota Klippen. The folded sequence is much disturbed by the Adam Fault Zone, essentially a thrust system. The recognition of the Gnallan-a-gea Arkose outcrops at Aroota Bore as klippen was a critical factor in the development of the structural interpretations presented in the cross-section.
2. In the east of the Sheet area, there is a less complicated, mainly anticlinal, folded zone south of Glenormiston. This is bounded to the nortn by the Sun Hill Fault, and to the east by a suggested extension of the Pippagitta Fault, east of the map area. These faults bring granite and Proterozoic arkose to the surface locally.
3. Between these eastern and western areas are the Toko Syncline, and the Toomba Fault Zone and associated Marqua Monocline. The structure of the Toko Syncline is relatively simple: it is a southeasterly plunging asymmetrical feature, with relatively steep dips along its western limb and shallow dips along the eastern one, containing up to 10 000 m of sedimentary rock according to gravity modelling by Tucker & others (1979).
4. The Toomba Fault Zone has been the focus of seismic interpretation undertaken by Harrison (1979, 1980). Five seismic and gravity profiles across the Queensland segment of the Toomba Fault have established that it is a high-angle reverse fault with a fault plane dipping southwesterly between 40°-70°, and a vertical displacement of up to 6.5 km. It also has a strike-slip component estimated at about 4 km of right-lateral movement (Harrison, 1980). Though surface mapping suggests the Toomba Fault is a northerly overthrust, seismic sections show it also thrusts Upper Proterozoic and crystalline basement rocks 1-4.5 km to the east over

Palaeozoic rocks. The latter are overturned, folded, and faulted adjacent to the thrust zone. In places, these folds may be closed, as in the Mirrica-Ethabuka structure (approx. lat. 23°40'S, long. 138°17.5'E), and have been regarded as suitable petroleum exploration targets. Surface extrapolations of the Toomba Fault depicted on the map, and the sections, are directly based on the seismic interpretations of Harrison (1979, 1980) and shallow magnetic anomalies recognised by Tucker & others (1979). Northwards the Toomba Fault Zone passes into the Marqua Monocline, whose southern limb is vertical and northern limb is almost flat-lying.

9. GEOCHEMISTRY

A considerable amount of geochemical information was obtained during the research necessary to complete the interpretation of the geology of the Hay River-Mount Whelan Sheet area, but much of this data remains in unpublished form. Since geochemistry, mineralisation, and the economic potential of the Sheet area are intimately related, that information which is available is presented here.

(i) Inorganic geochemistry

Basic elemental distribution patterns have been analysed from cuttings of the Mithaka Formation in AOD Ethabuka No. 1 (Draper, 1976). This formation had previously yielded P_2O_5 values up to 13% (Reynolds, 1968), and crandallite had been identified from a locality southeast of The Gap (Tobermory outstation). Although the Mithaka Formation has reasonably high background P_2O_5 values, between 900-4200 ppm, surface exposures do not appear to contain significant amounts of phosphate (Draper, 1976).

Fairly high P_2O_5 values are also found throughout the BMR Hay River Nos. 11, 11A, and Tobermory No. 14 coreholes, particularly in the lower member of the Hay River Formation. In the basal layers of this member in BMR Hay River No. 11A, P_2O_5 values are as high as 2.6%, and in the same interval in BMR Tobermory No. 14 values range between 1 and 5% P_2O_5. These latter values seem to reflect the enormous quantity of phosphatic shelled inarticulate brachiopods in this part of the sequence.

The Georgina Limestone and the Arrinthrunga, Ninmaroo, Kelly Creek, Coolibah, and Nora Formations have all been analysed to establish regional background values for Cu, Pb, Zn, Ba, F, and P, and some analyses were also made on Fe and Mn-rich weathered profiles to examine their mineral potential (Draper, 1978). Geochemical analyses on samples from GSQ Mount Whelan No. 1 have given Ba values up to 2600 ppm, Zn to 780 ppm, and Pb to 1150 ppm (Draper in Shergold, 1979a) in equivalents of the Thorntonia Limestone; and Ba to 7150 ppm in the basal 150 m of the overlying Georgina Limestone.

The Hay River Formation has also been closely examined for a variety of elements, since it is largely a black shale/black calcareous siltstone/thin-bedded carbonate unit. In BMR Hay River Nos. 11, 11A, and 11B and BMR Tobermory No. 14 coreholes, samples were taken at intervals of 1 m (see Appendixes 1 to 3). In Hay River No. 11A the Ordian black shale interval of the lower Hay River Formation contains appreciable values of Ni, Zn, V, Mo, Th, and U, and is also enriched in Au (up to 0.3 ppm), Pd (to 0.8 ppm), and Pt (to 1.5 ppm). Such values are not evident in the equivalent interval in Tobermory No. 14, presumably because of the increased carbonate content, perhaps reflected in the Ba value which reaches 4000 ppm.

In BMR Hay River No. 11, relatively high Cr, Cu, Zn, Ni, V, U, and Mo also occur at the disconformity between the upper member of the Hay River Formation and the grainstone layer which separates it from the lower member. At this level in both the Marqua Monocline and Desert Syncline coreholes, Ba levels are consistently high, reaching 8100 ppm in one sample. Otherwise the geochemistry of the upper Hay River Formation is not remarkable.

As indicated above (under Early Cambrian), the Red Heart Dolomite, which underlies the Hay River Formation, is mineralised. Vugs in this formation contain crystalline quartz linings, and bipyramidal quartz crystals are commonly found where the Red Heart Dolomite has been weathered. Some of these crystals contain fluid hydrocarbon inclusions. Homogenisation temperatures between 174 and 225°C were estimated from the aqueous fluid apparently in an immiscible relationship with hydrocarbon gas in one of the crystals. According to Wilkins (in Shergold, 1979a), 250°C is a realistic minimum temperature for the growth of the crystal sampled. This temperature is too high for formation waters with no heat source other than the normal geothermal gradient, and the presence of mesophase also supports this concept. Salinity determinations on the aqueous fluids in the inclusions range between 7.8-9.2 wt% NaCl equivalent. Thus a hydrothermal event is postulated in which the mineralising fluid was mobilised by thrusting, presumably associated with the Alice Springs Orogeny (Late Devonian-Early Carboniferous). Relatively high Ag values (to 15 ppm) may also be a product of this hydrothermal event (Shergold & Walter, 1979). Anomalous mineralisation within the Red Heart Dolomite, and at stratigraphic hiati higher in the Middle Cambrian rocks in particular, also suggests the probability of such an event.

Economically the recognition of possible hydrothermal activity is significant. The Hay River-Mount Whelan Sheet area contains many of the conditions required to make it prospective for Carlin-style gold deposits. Among them are possible hydrothermal activity associated with thrusting, high-angle normal faults, porous stratigraphic formations, and stratigraphic breaks acting as potential or proven channelways for migrating fluids; the presence of organic sediments required for the production of gold-organic compounds; apparently appropriate temperatures; and a possible association with hydrocarbons (see below). Most of these factors occur in Nevada where the Carlin deposit was first described (Radtke, 1981).

(ii) Organic geochemistry

A geochemical synthesis of the petroleum exploration wells and stratigraphic holes drilled in the Toko Syncline, and evaluation of the petroleum potential of the area, have been published by Jackson (1982). To date, the occurrence of hydrocarbons in the Hay River-Mount Whelan Sheet area is not particularly encouraging in spite of the widespread distribution of potential organic-rich source rocks (Hay River Formation and correlatives in particular), suitable porous reservoir rocks in the Ordovician sequence, and cap rocks also in the Ordovician. Jackson (1982) has indicated the presence of bitumen, tar, a little oil, and gas in PAP Netting Fence No. 1; gas (7000+ m^3 per day open hole) in AOD Ethabuka No. 1; minor gas in AOD Mirrica No. 1; and bitumen in GSQ Mount Whelan No. 2. Additionally, mesophase (pyrobitumen) occurs in BMR Hay River No. 11A in association with hydrothermal quartz crystals containing fluid inclusions (Taylor in Shergold, 1978).

Details of total organic carbon, extractable organic matter, and proportions or aromatic hydrocarbons, saturated hydrocarbons, and polar organic compounds in the Toko Syncline wells, have been published by Jackson (1982). Additional information on total carbon values for the Hay River Formation (lower Marqua beds in Jackson's terminology) in the Desert Syncline is available (see Appendixes 1 to 3). In BMR Tobermory No. 14, organic carbon values reach 3.90% (mean 2.23%) in the lower and 3.65% (mean 2.35%) in the upper parts of this formation. No detailed systematic organic geochemical analyses have been undertaken, but what little information is available is from the Desert Syncline (see Shergold & Walter, 1979; fig. 7). Some information is also available for PAP Netting Fence No. 1 (McKirdy, 1977).

Kerogen reflectance studies have been carried out on two samples from the upper part of the Hay River Formation in BMR Hay River No. 11 (Russell _in_ Shergold, 1979b). Several kerogen types have been recognised, both in this hole and PAP Netting Fence No. 1. The Hay River kerogen partings have relatively high reflectivities and moderately strong anisotropy, exhibiting characteristics of an 'anthracitic' vitrinite or semifusinite (low-reflectivity inertinite); they have R_o values of about 2%, which indicate they have experienced a temperature of about 220°C. Porous kerogen values vary widely with R_o between 1 and 2.5%. Interstitial kerogen occurs in both the Netting Fence and Hay River coreholes, and this type of kerogen has R_o values in the 1.80-2.30% range, similar to the kerogen partings. The temperature range indicated by these studies largely agrees with the hydrothermal temperatures calculated for the quartz crystal growth in the Red Heart Dolomite of the Desert Syncline, and seems to indicate that, locally in the northern part of the Sheet area, the rocks have been too highly heated to preserve hydrocarbons.

Jackson (1982, figs. 3,4) has indicated that the potential source rock occurrences in the southern Toko Syncline are mostly in equivalents of the Hay River Formation and overlying Georgina Limestone. According to Jackson these source rocks are not overmature. His conviction is supported by conodont thermal colour alteration studies on material from AOD Ethabuka No. 1 (Nicoll, 1979); these indicate palaeotemperatures less than 200°C, mostly in the range 50-140°C, depending on depth in the well. According to Kantsler (_in_ Radke, 1982), kerogen R_o values of 0.7-0.97% are indicated by ultraviolet fluorescence of lamellar alginites and acritarchs. Similarly, kerogen reflectance data from GSQ Mount Whelan No. 2 indicate maturity (Radke, 1982).

Saddle dolomite, frequently associated with sulphate-rich carbonates and base-metal mineralisation, is also associated with hydrocarbon occurrences (Radke & Mathis, 1980). These authors have suggested that the mineral has a geothermal indicator potential, since it indicates diagenesis in the temperature range 60-150°C. Its presence in bitumen-stained carbonates on the eastern limb of the Toko Syncline is outlined by Radke (1982).

10. REFERENCES

AOD (Alliance Oil Development Australia NL), 1975 - Ethabuka No. 1 well completion report (unpublished).

BUREK, P.J., WALTER, M.R., & WELLS, A.T., 1979 - Magnetostratigraphic tests of lithostratigraphic correlations between latest Proterozoic sequences in the Ngalia, Georgina and Amadeus Basins, central Australia. BMR Journal of Australian Geology & Geophysics, 4, 47-55.

CASEY, J.N., 1959 - New names in Queensland stratigraphy (part 5) north-west Queensland. Australasian Oil and Gas Journal, 5(12), 31-36.

DRAPER, J.J., 1976 - The Devonian rocks of the Toko Syncline, western Queensland. Bureau of Mineral Resources, Australia, Record 1976/29.

DRAPER, J.J., 1977 - Environment of deposition of the Carlo Sandstone, Georgina Basin, Queensland and Northern Territory. BMR Journal of Australian Geology & Geophysics, 2, 97-110.

DRAPER, J.J., 1978 - Progress report on Georgina Basin geochemistry - results from 1975, 1976 field seasons. Bureau of Mineral Resources, Australia, Record 1978/23.

DRAPER, J.J., 1980a - Ethabuka Sandstone, a new Ordovician unit in the Georgina Basin, and a redefinition of the Toko Group. Queensland Government Mining Journal, 81(947), 469-475.

DRAPER, J.J., 1980b - Rusophycus (Early Ordovician ichnofossil) from the Mithaka Formation, Georgina Basin. BMR Journal of Australian Geology & Geophysics, 5, 57-61.

DRUCE, E.C., 1978 - Georgina research, September quarter, 1978. Bureau of Mineral Resources, Australia, file 1978/600 (unpublished).

DRUCE, E.C., & JONES, P.J., 1971 - Cambro-Ordovician conodonts from the Burke River Structural Belt, Queensland. Bureau of Mineral Resources, Australia, Bulletin 110.

DRUCE, E.C., SHERGOLD, J.H., & RADKE, B.M., 1982 - A reassessment of the Cambrian-Ordovician boundary section at Black Mountain, western Queensland, Australia. In BASSETT, M.G., & DEAN, W.T. (Editors) -- THE CAMBRIAN-ORDOVICIAN BOUNDARY; SECTIONS, FOSSIL DISTRIBUTIONS, AND CORRELATIONS. National Museum of Wales, Geological Series 3, Cardiff, 193-209.

FREEMAN, M.J., LAURIE, J.R., WALLEY, A., & DONNELLAN, N., in press - Huckitta, 1:250 000 geological map series. Northern Territory Geological Survey, Explanatory Notes SF/53-11.

FORTEY, R.A., & SHERGOLD, J.H., 1984 - Early Ordovician trilobites, Nora Formation, central Australia. Palaeontology, 27(2), 315-366.

GILBERT-TOMLINSON, J., 1968 - A new record of Bothriolepis in the Northern Territory of Australia. In Palaeontological papers 1965. Bureau of Mineral Resources, Australia, Bulletin 80, 191-226.

GILBERT-TOMLINSON, J., 1973 - The Lower Ordovician gastropod Teiichispira in northern Australia. In Palaeontological papers 1969. Ibid. 126, 65-88.

GREEN, P.M., & BALFE, P.E., 1980 - Stratigraphic drilling report - GSQ Mt Whelan 1 and 2. Queensland Government Mining Journal, 81(941), 162-178.

GRIMES, K.G., 1980 - The Tertiary geology of north Queensland. In HENDERSON, R.A., & STEPHENSON, P.J. (Editors) -- THE GEOLOGY AND GEOPHYSICS OF NORTHEASTERN AUSTRALIA. Geological Society of Australia, Queensland Division, 329-347.

HARRISON, P.L., 1979 - Recent seismic studies upgrade the petroleum prospects of the Toko Syncline, Georgina Basin. APEA Journal, 19(1), 30-42.

HARRISON, P.L., 1980 - The Toomba Fault and the western margin of the Toko Syncline, Georgina Basin, Queensland and Northern Territory. BMR Journal of Australian Geology & Geophysics, 5, 201-214.

HARRISON, P.L., & SCHMIDT, D.L., 1978 - Seismic and detailed gravity survey in the Toko Syncline, Georgina Basin, 1977 - operational report. Bureau of Mineral Resources, Australia, Record 1978/34.

HENDERSON, R.A., 1976 - Idamean (early Upper Cambrian) trilobites from northwestern Queensland, Australia. Palaeontology, 19, 325-364.

HENDERSON, R.A., 1977 - Stratigraphy of the Georgina Limestone, and a revised zonation of the Upper Cambrian Idamean Stage. Journal of the Geological Society of Australia, 23, 423-433.

HILL, D., PLAYFORD, G., & WOODS, J.T. (Editors), 1969 - ORDOVICIAN AND SILURIAN FOSSILS OF QUEENSLAND. Queensland Palaeontographical Society, Brisbane.

JACKSON, K.S., 1982 - Geochemical evaluation of the petroleum potential of the Toko Syncline, Georgina Basin, Queensland. BMR Journal of Australian Geology & Geophysics, 7, 1-10.

JONES, P.J., 1971 - Lower Ordovician conodonts from the Bonaparte Gulf and the Daly River Basin, northwestern Australia. Bureau of Mineral Resources, Australia, Bulletin 117.

JONES, P.J., SHERGOLD, J.H., & DRUCE, E.C., 1971 - Late Cambrian and Early Ordovician stages in western Queensland. Journal of the Geological Society of Australia, 18(1), 1-32.

KENNARD, J.M., 1980 - Stratigraphic field sections and drillhole logs of the Arrinthrunga Formation, Georgina Basin, central Australia. Bureau of Mineral Resources, Australia, Record 1980/75.

KENNARD, J.M., 1981 - The Arrinthrunga Formation: Upper Cambrian epeiric carbonates in the Georgina Basin, central Australia. Bureau of Mineral Resources, Australia, Bulletin 211.

KRUSE, P.D., & WEST, P.W., 1980 - Archaeocyatha of the Amadeus and Georgina Basins. BMR Journal of Australian Geology & Geophysics, 5, 165-181.

McKIRDY, D.M., 1977 - Diagenesis of microbial organic matter: a geochemical classification and its use in evaluating hydrocarbon generating potential of Proterozoic and Lower Palaeozoic sediments, Amadeus Basin, central Australia. Ph.D. Thesis, Australian National University (unpublished).

MATHUR, S.P., & BAUER, J.A., 1977 - Southeastern Georgina Basin seismic survey, Queensland and Northern Territory, 1977 - preview report. Bureau of Mineral Resources, Australia, Record 1977/25.

NICOLL, R.S., 1979 - Conodont colour alteration in petroleum exploration well, Ethabuka No. 1, Queensland. Bureau of Mineral Resources, Australia, Professional Opinion, Geol. 79.018 (unpublished).

ÖPIK, A.A., 1960 - Cambrian and Ordovician geology (of Queensland). Journal of the Geological Society of Australia, 7, 89-109.

ÖPIK, A.A., 1961 - The geology and palaeontology of the headwaters of the Burke River, Queensland. Bureau of Mineral Resources, Australia, Bulletin 53.

ÖPIK, A.A., 1963 - Early Upper Cambrian fossils from Queensland. Ibid. 64.

ÖPIK, A.A., 1967 - The Mindyallan fauna of northwestern Queensland. Ibid. 74.

ÖPIK, A.A., 1979 - Middle Cambrian agnostids: systematics and biostratigraphy. Ibid. 172.

PAP (Papuan Apinaipi Petroleum Co. Ltd), 1965 - Netting Fence No. 1 well completion report (by Minad; unpublished).

PATEN, R.J., 1964 - The Tertiary geology of the Boulia region, western Queensland. Geological Survey of Queensland, Publication 319.

POJETA, J., & GILBERT-TOMLINSON, J., 1977 - Australian Ordovician pelecypod molluscs. Bureau of Mineral Resources, Australia, Bulletin 174.

POJETA, J., GILBERT-TOMLINSON, J., & SHERGOLD, J.H., 1977 - Cambrian and Ordovician rostroconch molluscs from northern Australia. Ibid. 171.

PREISS, W.V., WALTER, M.R., COATS, R.P., & WELLS, A.T., 1978 - Lithological correlations of the Adelaidean glaciogenic rocks in parts of the Amadeus, Ngalia, and Georgina Basins. BMR Journal of Australian Geology & Geophysics, 3, 48-55.

PRITCHARD, P.W., 1960 - The Ordovician section in the Toko Range. Journal of the Geological Society of Australia, 7, 110-114.

RADKE, B.M., 1980 - Epeiric carbonate sedimentation of the Ninmaroo Formation (Upper Cambrian-Lower Ordovician), Georgina Basin. BMR Journal of Australian Geology & Geophysics, 5, 183-200.

RADKE, B.M., 1981 - Lithostratigraphy of the Ninmaroo Formation (Upper Cambrian-Lower Ordovician), Georgina Basin, Queensland and Northern Territory. Bureau of Mineral Resources, Australia, Report 181; BMR Microform MF 153.

RADKE, B.M., 1982 - Late diagenetic history of the Ninmaroo Formation (Cambro-Ordovician), Georgina Basin, Queensland and Northern Territory. BMR Journal of Australian Geology & Geophysics, 7, 231-254.

RADKE, B.M., & DUFF, P., 1980 - A potential dolostone reservoir in the Georgina Basin: the Lower Ordovician Kelly Creek Formation. Ibid. 5, 160-163.

RADKE, B.M., & MATHIS, R.L., 1980 - On the formation and occurrence of saddle dolomite. Journal of Sedimentary Petrology, 50(4), 1149-1168.

RADKE, B.M., SIMPSON, C.J., & DRAPER, J.J., 1983 - The Poodyea Formation: a possible Tertiary fluvial unit in the Toko Syncline, Georgina Basin. BMR Journal of Australian Geology & Geophysics, 8, 157-160.

RADTKE, A.S., 1981 - Geology of the Carlin gold deposit, Nevada. United States Department of the Interior, Geological Survey, Open-File Report 81-97.

REYNOLDS, M.A., 1965 - Glenormiston, Qld - 1:250 000 Geological Series. Bureau of Mineral Resources, Australia, Explanatory Notes, SF/54-9.

REYNOLDS, M.A., 1968 - Mount Whelan, Qld - 1:250 000 Geological Series. Bureau of Mineral Resources, Australia, Explanatory Notes, SF/54-13.

RITCHIE, A., 1973 - Wuttagoonaspis gen. nov., an unusual arthrodire from the Devonian of western New South Wales, Australia. Palaeontographica, (A), 143, 58-72.

SEILACHER, A., 1970 - Cruziana stratigraphy of "non-fossiliferous" Palaeozoic sandstones. In CRIMES, T.P., & HARPER, J.C. (Editors) - TRACE FOSSILS. Seel House Press, Liverpool, 447-476.

SENIOR, B.R., MOND, A., & HARRISON, P.L., 1978 - Geology of the Eromanga Basin. Bureau of Mineral Resources, Australia, Bulletin 167.

SHERGOLD, J.H., 1975 - Late Cambrian and early Ordovician trilobites from the Burke River Structural Belt, western Queensland. Ibid. 153.

SHERGOLD, J.H., 1976 - Biostratigraphic synopsis: eastern Georgina Basin, Qld (Appendix to International Geological Congress Excursion Guidebook 4C). Bureau of Mineral Resources, Australia, Record 1975/69 (revised June 1976).

SHERGOLD, J.H. (Editor), 1978 - Georgina research, December quarter, 1978. Ibid. 1979/17.

SHERGOLD, J.H. (Editor), 1979a - Georgina research, March quarter, 1979. Ibid. 1979/39.

SHERGOLD, J.H. (Editor), 1979b - Georgina research, June quarter, 1979. Ibid. 1979/53.

SHERGOLD, J.H., 1980 - Late Cambrian trilobites from the Chatsworth Limestone, western Queensland. Bureau of Mineral Resources, Australia, Bulletin 186.

SHERGOLD, J.H., 1982 - Idamean (Late Cambrian) trilobites, Burke River Structural Belt, western Queensland. Ibid. 187.

SHERGOLD, J.H., & DRUCE, E.C., 1980 - Upper Proterozoic and Lower Palaeozoic rocks of the Georgina Basin. In HENDERSON, R.A., & STEPHENSON, P.J. (Editors) - THE GEOLOGY AND GEOPHYSICS OF NORTHEASTERN AUSTRALIA. Geological Society of Australia, Queensland Division, 149-174.

SHERGOLD, J.H., DRUCE, E.C., RADKE, B.M., & DRAPER, J.J., 1976 - Cambrian and Ordovician stratigraphy of the eastern portion of the Georgina Basin, Queensland and eastern Northern Territory. 25th Session of the International Geological Congress, Sydney, Excursion Guidebook 4C.

SHERGOLD, J.H., & WALTER, M.R., 1979 - BMR stratigraphic drilling in the Georgina Basin, 1977 and 1978. Bureau of Mineral Resources, Australia, Record 1979/36.

SMITH, K.G., 1963 - Hay River, N.T. - 1:250 000 Geological Series. Bureau of Mineral Resources, Australia, Explanatory Notes, SF/53-11.

SMITH, K.G., 1964 - Progress report on the geology of the Huckitta 1:250 000 Sheet, Northern Territory. Bureau of Mineral Resources, Australia, Report 67.

SMITH, K.G., 1965 - Tobermory, N.T. - 1:250 000 Geological Series. Bureau of Mineral Resources, Australia, Explanatory Notes SF/53-12.

SMITH, K.G., 1972 - Stratigraphy of the Georgina Basin. Bureau of Mineral Resources, Australia, Bulletin 111.

SMITH, K.G., & VINE, R.R., 1960 - Summary of the geology of the Tobermory 4-mile Sheet, N.T. Bureau of Mineral Resources, Australia, Record 1960/71.

TUCKER, D.H., WYATT, B.W., DRUCE, E.C., MATHUR, S.P., & HARRISON, P.L., 1979 - The upper crustal geology of the Georgina Basin region. BMR Journal of Australian Geology & Geophysics, 4, 209-226.

TURNER, S., JONES, P.J., & DRAPER, J.J., 1981 - Early Devonian thelodonts (Agnatha) from the Toko Syncline, western Queensland, and a review of other Australian discoveries. Ibid. 6, 51-59.

WADE, M., 1977a - Georginidae, a new family of actinoceratid cephalopods, middle Ordovician, Australia. Memoirs of the Queensland Museum, 18.

WADE, M., 1977b - The siphuncle of Georginidae, and other Ordovician actinoceroid cephalopods. Lethaia, 10, 303-315.

WALTER, M.R., 1980 - Adelaidean and early Cambrian stratigraphy of the southwestern Georgina Basin: correlation chart and explanatory notes. Bureau of Mineral Resources, Australia, Report 214; BMR Microform MF 92.

WALTER, M.R., KRYLOV, I.N., & PREISS, W.V., 1979a - Stromatolites from Adelaidean (Late Proterozoic) sequences in central and South Australia. Alcheringa, 3, 287-305.

WALTER, M.R., SHERGOLD, J.H., MUIR, M.D., & KRUSE, P.D., 1979b - Early Cambrian and latest Proterozoic stratigraphy, Desert Syncline, southern Georgina Basin. Journal of the Geological Society of Australia, 26, 305-312.

WARREN, R.G., 1981 - Tectonic setting of the easternmost Arunta Block. Bureau of Mineral Resources, Australia, Report 221; BMR Microform MF 154.

WEBBY, B.D., 1978 - History of the Ordovician continental platform shelf margin of Australia. Journal of the Geological Society of Australia, 25(1), 41-63.

WEBBY, B.D., & OTHERS, 1981 - The Ordovician System in Australia, New Zealand and Antarctica. International Union of Geological Sciences, Publication 6.

APPENDIX 1a. GEOCHEMISTRY OF SAMPLES FROM BMR TOBERMORY NO. 14

Ptychagnostus punctuosus Zone

Sample	74716497	74716498	74716499	74716500	74716501	74716502	74716503	74716504	74716505	74716506	74716507
Depth (m)	8.63	14.50	17.00	18.04	24.40	27.14	34.90	33.92	34.80	39.00	41.04
Total C%	8.10	6.70	4.80	10.2	4.90	4.80	9.15	4.55	5.15	5.50	5.25
Organic C%	0.20	0.55	1.10	0.85	2.70	2.95	2.05	3.00	3.40	3.55	3.65
Inorganic C% (by difference)	7.90	6.15	3.70	9.35	2.20	1.85	7.10	1.55	1.75	1.95	1.60
S%	0.36	0.60	0.96	0.22	1.53	1.83	0.88	1.49	0.78	2.19	2.23
P_2O_5%	0.073	0.069	0.092	0.034	0.105	0.128	0.069	0.041	0.128	0.197	0.220
Ba ppm	620	450	500	480	780	1200	700	840	860	1900	1300
Pb	<2	<2	8	<2	12	17	6	7	3	16	17
Th	6	14	16	4	18	24	8	14	20	20	16
U	4	6	6	4	16	26	16	10	18	16	14
La	30	20	20	20	20	<20	<20	30	30	<20	20
Ce	30	40	50	30	30	50	40	20	40	40	40
V	40	90	60	110	70	130	150	100	1000	200	580
Cr	10	10	10	<10	20	20	10	10	20	20	20
Ni	15	20	20	15	30	40	30	45	65	55	95
Cu	8	22	28	12	42	60	36	48	95	75	80
Zn	18	60	44	55	42	210	90	90	130	55	240
Mo	<4	<4	6	4	26	50	28	22	28	46	36
As	<2	6	4	<2	13	24	4	24	14	22	32
Cd	<1	<1	<1	<1	<1	1	<1	<1	1	<1	3
Ag	1	1	1	1	1	1	1	1	1	1	3
Sb	<4	6	<4	4	<4	6	8	8	<4	6	8
Au	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pd	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	<0.005	0.005
Pt	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.005

UPPER HAY RIVER FORMATION

Ptychagnostus punctuosus Zone (74716508–74716515) | Euagnostus opimus Zone (74716516–74716518)

Sample	74716508	74716509	74716510	74716511	74716512	74716513	74716514	74716515	74716516	74716517	74716518
Depth (m)	43.18	46.00	51.07	55.00	56.44	58.83	65.52	69.30	73.54	77.88	79.18
Total C%	5.10	5.20	8.55	6.80	4.75	5.75	6.50	10.2	6.25	4.15	5.60
Organic C%	2.70	3.00	0.85	2.70	1.40	2.40	1.20	0.85	2.70	2.25	3.30
Inorganic C% (by difference)	2.40	2.20	7.70	4.10	3.35	3.35	5.30	9.35	3.55	1.90	2.30
S%	2.15	2.21	0.63	1.75	1.12	1.45	0.93	0.42	2.09	3.00	1.12
P_2O_5%	0.110	0.142	0.055	0.092	0.096	0.105	0.064	0.034	0.092	0.128	0.119
Ba ppm	1000	1050	380	780	640	2600	540	200	600	2650	1800
Pb	18	14	5	8	<2	7	<2	<2	13	22	7
Th	18	16	8	16	14	14	12	<4	16	28	22
U	8	16	6	12	<4	14	8	8	20	22	18
La	<20	<20	<20	20	30	20	<20	30	20	30	30
Ce	30	50	40	50	60	50	40	70	60	70	60
V	100	60	30	60	50	70	150	50	160	840	1600
Cr	20	20	10	20	10	10	10	<10	20	20	20
Ni	40	25	15	35	20	30	30	15	60	120	100
Cu	55	55	16	60	30	50	30	14	40	75	100
Zn	50	46	28	40	40	46	65	28	120	280	1600
Mo	18	24	6	10	<4	36	8	4	100	110	55
As	20	20	3	12	5	8	6	4	30	50	14
Cd	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	14
Ag	1	1	1	2	1	1	1	1	2	1	1
Sb	4	4	<4	<4	<4	<4	<4	<4	14	20	10
Au	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pd	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.005	<0.005	0.005	0.01	0.02
Pt	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

UPPER HAY RIVER FORMATION

Euagnostus opimus Zone —— | —— Ordian section

Sample	74716519	74716520	74716521	74716522	74716523	74716524	74716525	74716526	74716527	74716528	74716529
Depth (m)	82.60	84.76	88.10	89.64	92.84	93.75	95.63	97.26	99.62	101.94	102.16
Total C%	4.75	4.95	11.6	10.1	8.40	7.65	7.90	7.80	10.0	10.4	10.4
Organic C%	1.85	3.00	1.70	3.05	3.90	2.35	0.85	2.60	2.70	2.00	0.30
Inorganic C% (by difference)	2.90	1.95	9.9	7.05	4.50	5.30	7.05	5.20	7.3	8.4	10.1
S%	1.20	2.83	0.41	0.95	1.84	1.81	0.92	1.73	1.19	0.55	0.13
P_2O_5%	0.137	0.229	0.188	3.40	5.00	1.00	1.90	2.00	3.20	4.10	3.60
Ba ppm	8100	820	180	520	720	340	190	280	180	140	40
Pb	10	65	<2	3	3	2	<2	6	<2	<2	<2
Th	18	20	6	6	14	12	12	14	10	<4	<4
U	16	18	4	10	4	8	6	8	4	8	4
La	50	40	<20	30	50	<20	20	40	30	20	<20
Ce	80	50	30	40	50	50	30	50	40	30	30
V	660	550	60	40	20	20	20	30	20	30	20
Cr	10	20	10	30	10	10	10	20	10	10	<10
Ni	55	100	45	85	25	20	15	50	25	40	10
Cu	65	150	12	24	14	18	12	16	12	6	2
Zn	75	150	90	150	36	110	20	36	12	18	10
Mo	28	110	<4	4	<4	<4	<4	<4	<4	<4	<4
As	16	48	<2	14	5	8	5	9	6	3	<2
Cd	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ag	2	3	2	3	1	1	1	1	2	2	2
Sb	<4	14	8	4	<4	<4	4	<4	<4	8	4
Au	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pd	0.005	0.015	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pt	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

—— UPPER HAY RIVER FM —— | —— LOWER HAY RIVER FORMATION ——

	Ordian section		
Sample	74716530	74716531	74716532
Depth (m)	104.43	106.18	107.16
Total C%	7.95	8.85	13.3
Organic C%	2.30	1.90	3.10
Inorganic C% (by difference)	5.65	6.95	10.2
S%	1.23	1.04	0.50
P_2O_5%	3.94	3.12	1.24
Ba ppm	900	4000	110
Pb	13	24	14
Th	10	10	6
U	34	20	<4
La	40	30	20
Ce	40	50	20
V	70	40	20
Cr	20	10	<10
Ni	95	65	10
Cu	18	12	8
Zn	48	44	160
Mo	4	4	<4
As	7	4	4
Cd	<1	<1	<1
Ag	2	2	2
Sb	4	<4	<4
Au	<0.005	<0.005	<0.005
Pd	<0.005	<0.005	<0.005
Pt	<0.005	<0.005	<0.005

LOWER HAY RIVER FORMATION

APPENDIX 1b. MEAN GEOCHEMICAL VALUES, BMR TOBERMORY NO. 14

	punctuosus Zone (74716497-6515) N = 19	*opimus* Zone (74716516-6520) N = 5	Ordian (74716521-6532) N = 12
As ppm	12	32	6
Pb	8	23	6
Ba	885	2794	633
Ce	42	64	38
La	19	34	26
Sb	4	12	4
Mo	19	81	<4
Th	14	21	9
U	11	19	9
Cr	14	18	13
Cu	43	86	13
Cd	<1	3	<1
Ag	1	2	1.75
Ni	34	87	40
Zn	72	445	61
V	163	762	32
Pt	<0.005	<0.005	<0.005
Pd	<0.005	0.01	<0.005
Au	<0.005	<0.005	<0.005
$C_{\varepsilon+org.}$ %	2.06	2.62	2.23
S_{total} %	1.25	2.05	1.03
P_2O_5	976 ppm	1410 ppm	2.72 %

APPENDIX 2a. GEOCHEMISTRY OF SAMPLES FROM BMR HAY RIVER NO. 11

	Ptychagnostus punctuosus Zone									
Sample	74715957	74715958	74715959	74715960	74715961	74715962	74715963	74715964	74715965	74715966
Depth (m)	32.16	33.13	34.00	35.76	36.69	37.90	38.50	39.74	40.32	41.31
Organic C%	1.10	2.52	2.88	0.77	0.95	0.75	0.86	1.23	0.95	1.29
S%	1.17	1.55	2.05	0.77	0.71	0.74	0.97	0.88	0.97	1.14
P_2O_5%	0.15	0.26	0.37	0.17	0.17	0.18	0.21	0.17	0.21	0.18
Ba ppm	260	470	740	310	320	300	330	300	320	280
Pb	11	15	26	<2	4	9	15	9	5	3
Th	10	16	16	10	10	12	16	10	12	12
U	10	14	10	6	6	4	8	4	6	4
La	40	50	50	50	60	30	30	40	40	30
Ce	20	70	80	60	80	70	50	80	70	70
V	140	550	120	75	60	110	75	75	70	200
Cr	70	65	70	50	55	45	55	40	40	50
Ni	15	40	30	10	15	15	20	5	45	30
Cu	35	70	60	25	25	20	25	25	25	30
Zn	60	50	30	30	25	35	35	40	35	55
Mo	4	28	26	<4	22	8	20	<4	4	14
As	24	24	18	8	7	4	4	8	8	12
Cd	1	2	<1	<1	<1	<1	<1	<1	<1	<1
Ag	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
Sb	<4	<4	<4	6	<4	8	<4	<4	<4	<4
Au	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pd	<0.005	0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pt	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	UPPER HAY RIVER FORMATION									

	Ptychagnostus punctuosus Zone		Euagnostus opimus Zone							
Sample	74715967	74715968	74715969	74715970	74715971	74715972	74715973	74715974	74715975	74715976
Depth (m)	42.22	43.40	44.24	45.03	45.57	46.32	47.18	48.34	49.23	50.67
Organic C%	0.80	1.89	1.45	0.86	2.70	0.51	0.94	0.72	0.54	0.90
S%	1.03	1.61	2.20	0.86	2.72	0.90	1.73	0.60	0.70	1.13
P_2O_5%	0.19	0.21	0.22	0.25	0.21	0.19	0.21	0.15	0.17	0.22
Ba ppm	330	940	400	1650	540	270	540	500	250	320
Pb	4	22	16	6	22	11	20	2	3	12
Th	8	18	14	10	18	12	16	14	10	20
U	4	8	12	4	10	8	10	12	<4	6
La	60	60	40	30	20	60	50	60	70	60
Ce	60	70	70	90	80	70	110	50	90	110
V	70	150	120	130	180	95	85	320	150	160
Cr	35	40	45	35	55	40	45	30	40	45
Ni	10	35	30	10	45	25	20	25	15	20
Cu	25	50	40	25	60	50	30	30	25	35
Zn	20	55	50	35	40	30	30	220	55	40
Mo	4	32	22	6	36	<4	14	12	4	8
As	9	30	28	9	24	9	22	8	4	13
Cd	<1	<1	<1	<1	<1	<1	<1	2	<1	<1
Ag	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sb	6	<4	4	<4	12	<4	14	<4	<4	<4
Au	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pd	<0.005	0.01	0.005	<0.005	0.01	<0.005	0.01	<0.005	<0.005	<0.005
Pt	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

UPPER HAY RIVER FORMATION

	Euagnostus opimus Zone									
Sample	74715977	74715978	74715979	74715980	74715981	74715982	74715983	74715984	74715985	74715986
Depth (m)	51.89	53.05	54.15	55.05	56.00	57.23	58.35	59.37	60.08	61.82
Organic C%	0.71	2.06	0.77	0.76	2.20	1.18	2.02	1.66	0.99	0.97
S%	1.17	2.35	1.24	0.96	0.76	1.12	1.28	1.10	1.28	1.49
P_2O_5%	0.23	0.29	0.22	0.22	0.26	0.28	0.25	0.25	0.24	0.26
Ba ppm	2950	540	3000	3400	2100	2550	480	400	4100	4550
Pb	6	26	7	<2	4	16	13	10	15	8
Th	14	20	16	12	22	20	18	18	12	18
U	10	8	6	10	16	8	12	12	10	10
La	50	60	50	50	50	80	40	50	90	50
Ce	60	70	100	60	70	60	100	70	100	100
V	130	140	95	320	2000	490	1050	600	240	180
Cr	50	75	60	50	120	75	65	55	70	60
Ni	15	40	30	20	60	35	55	50	30	20
Cu	35	50	35	25	150	50	70	45	35	35
Zn	25	45	35	90	1100	150	260	100	55	40
Mo	10	18	10	8	24	12	36	34	18	16
As	15	22	14	22	11	15	20	18	18	24
Cd	<1	<1	<1	<1	15	<1	2	<1	<1	<1
Ag	<1	<1	1	1	1	1	1	1	<1	<1
Sb	<4	6	4	14	14	<4	12	<4	<4	<4
Au	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pd	<0.005	0.005	<0.005	<0.005	0.02	<0.005	0.01	<0.005	<0.005	<0.005
Pt	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

UPPER HAY RIVER FORMATION

	Euagnostus opimus Zone		
Sample	74715987	74715988	74715989
Depth (m)	63.73	65.22	66.62
Organic C%	2.20	3.14	2.64
S%	1.60	1.53	2.75
P_2O_5%	0.22	0.31	0.31
Ba ppm	4350	4200	2850
Pb	13	14	30
Th	14	22	18
U	16	26	16
La	80	60	100
Ce	50	130	140
V	490	2300	800
Cr	65	90	80
Ni	50	100	100
Cu	45	140	90
Zn	95	1350	10
Mo	50	120	95
As	20	32	38
Cd	<1	10	<1
Ag	<1	<1	<1
Sb	14	22	10
Au	<0.005	<0.005	0.015
Pd	0.015	0.02	0.01
Pt	<0.005	<0.005	<0.005
	UPPER HAY RIVER FORMATION		

APPENDIX 2b. MEAN GEOCHEMICAL VALUES, BMR HAY RIVER NOS. 11, 11A

	punctuosus Zone (74715957-5968) N = 12	*opimus?* Zone (74715969-5989) N = 21	Ordian (74715937-5956) N = 20
As ppm	13	18	50
Pb	10	20	39
Ba	408	1902	255
Ce	65	85	184
La	45	57	64
Sb	5	8	8
Mo	14	27	38
Th	12	16	22
U	7	10	18
Cr	51	59	110
Cu	34	52	56
Cd	<1	2	<2
Ag	<1	<1	<1
Ni	22	38	62
Zn	39	184	276
V	141	480	369
Pt	<0.005	<0.005	0.090
Pd	<0.005	<0.0075	0.302
Au	<0.005	<0.005	0.028
$C_{\varepsilon+org.}$ %	1.33	1.43	1.81
S_{total} %	1.13	1.36	1.97
P_2O_5 ppm	2079	2388	4155

APPENDIX 3. GEOCHEMISTRY OF SAMPLES FROM BMR HAY RIVER NO. 11A

	Ordian section									
Sample	74715956	74715937	74715938	74715939	74715940	74715941	74715942	74715943	74715944	74715945
Depth (m)	22.25	26.80	27.80	28.80	29.85	30.75	31.73	32.75	33.58	34.70
Organic C%	1.37	2.56	0.95	0.85	3.40	0.71	0.88	1.28	2.96	2.98
S%	0.07	2.14	1.72	2.55	2.80	2.60	2.14	1.94	3.65	2.05
P_2O_5%	0.07	0.04	0.04	0.06	0.45	0.55	0.05	0.06	0.19	0.07
Ba ppm	180	230	200	190	240	170	190	230	240	200
Pb	28	42	36	16	22	10	19	22	48	20
Th	24	30	24	24	26	26	22	24	22	26
U	18	22	14	12	18	10	6	18	16	14
La	60	30	60	40	70	60	60	80	50	40
Ce	100	140	130	80	80	90	100	110	140	130
V	470	270	290	180	470	240	200	300	340	190
Cr	110	110	100	100	100	100	110	120	120	110
Ni	15	75	15	20	35	40	30	30	45	25
Cu	50	70	55	50	70	40	45	60	65	45
Zn	35	35	30	25	30	30	35	40	60	40
Mo	12	18	6	10	36	4	6	12	40	10
As	55	32	26	110	34	60	80	50	70	32
Cd	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ag	1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sb	4	<4	6	<4	8	6	<4	<4	46	<4
Au	<0.005	<0.005	0.01	0.03	0.3	<0.005	<0.005	0.015	0.01	0.01
Pd	<0.005	0.015	<0.005	<0.005	0.15	0.01	0.02	0.8	0.08	<0.005
Pt	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.03	0.15	<0.005

LOWER MEMBER HAY RIVER FORMATION

Ordian section

Sample	74715946	74715947	74715948	74715949	74715950	74715951	74715952	74715953	74715954	74715955
Depth (m)	35.73	37.42	37.88	39.08	40.40	41.35	43.30	49.40	49.68	50.57
Organic C%	2.06	1.72	2.16	2.52	2.00	1.36	4.85	0.97	3.24	1.49
S%	2.60	3.15	1.83	1.43	4.50	2.55	0.002	0.16	0.13	1.43
P_2O_5%	0.09	0.23	0.15	0.23	0.32	0.28	0.34	1.20	2.15	2.60
Ba ppm	270	220	310	320	330	330	370	290	350	250
Pb	30	38	6	7	44	20	26	65	220	55
Th	26	20	24	28	22	22	22	14	12	14
U	32	24	26	34	24	30	18	12	12	4
La	80	100	80	70	80	70	110	30	80	40
Ce	130	100	110	160	110	110	160	80	50	100
V	490	340	1100	1700	170	230	160	65	85	85
Cr	140	120	140	120	110	120	110	85	110	75
Ni	55	100	120	160	130	95	180	20	40	20
Cu	65	55	90	95	60	50	55	30	40	25
Zn	90	280	300	520	420	240	1450	450	860	560
Mo	55	28	36	40	95	12	24	<4	12	4
As	40	60	46	34	110	34	90	12	15	13
Cd	<1	2	1	4	4	1	<1	1	2	2
Ag	<1	1	1	1	1	1	1	1	<1	1
Sb	10	10	<4	<4	12	6	4	4	<4	4
Au	0.03	<0.005	<0.005	0.01	0.1	0.01	<0.005	<0.005	<0.005	<0.005
Pd	<0.005	<0.005	<0.005	<0.005	0.15	<0.005	0.03	0.015	0.01	<0.005
Pt	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.08	<0.005	1.5	0.03

LOWER MEMBER HAY RIVER FORMATION

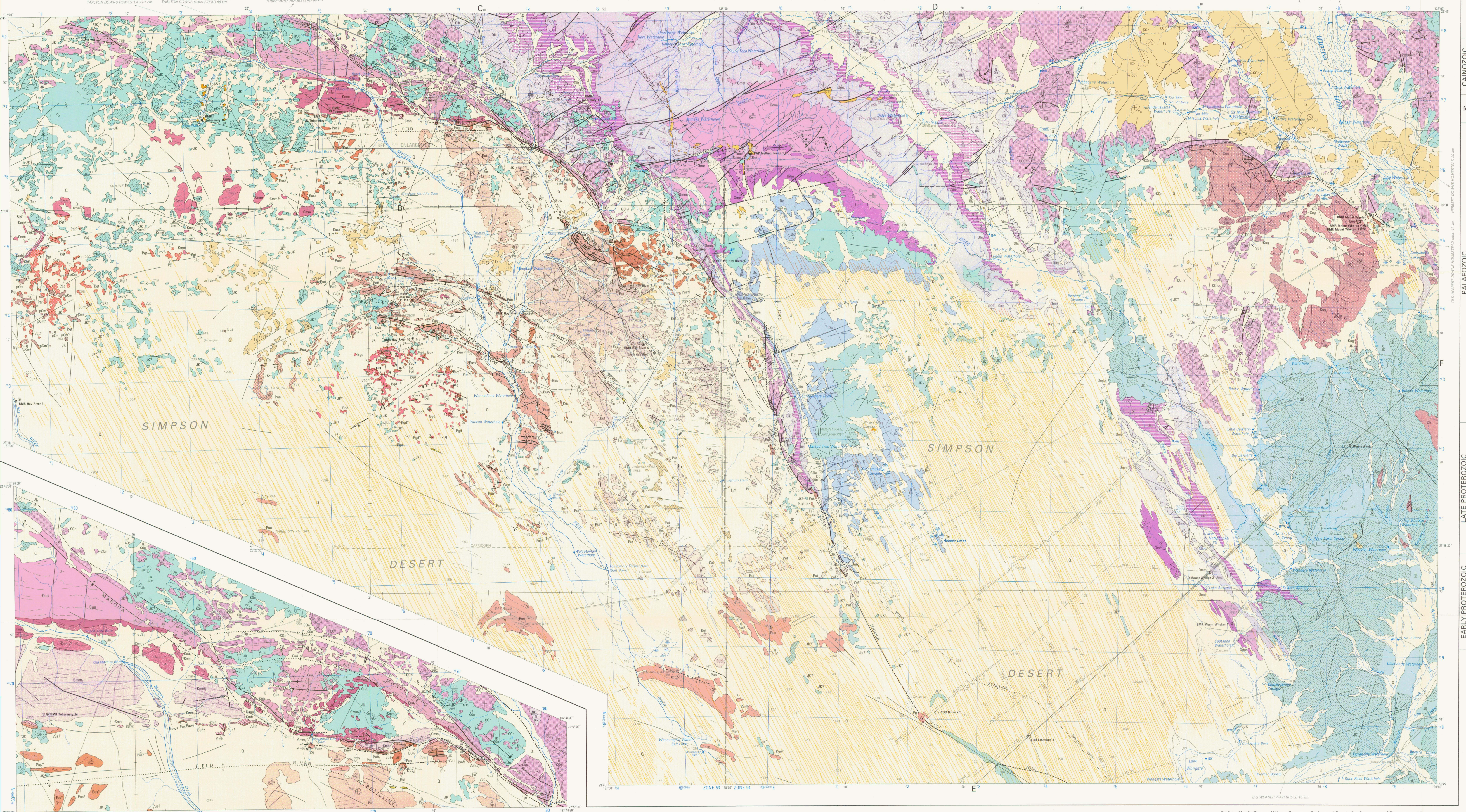
AUSTRALIA 1:250 000 GEOLOGICAL SPECIAL

GEOLOGY OF THE

HAY RIVER-MOUNT WHELAN AREA

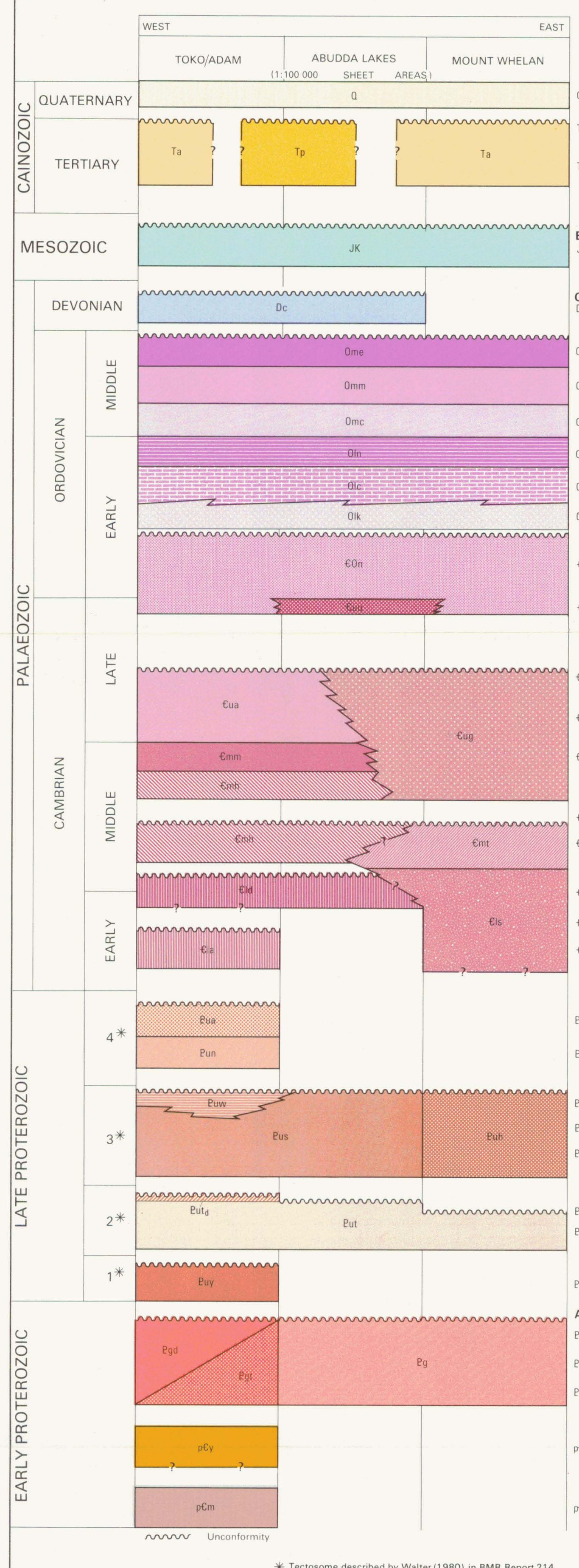
SOUTHERN GEORGINA BASIN

NORTHERN TERRITORY AND QUEENSLAND



ENLARGEMENT
SCALE 1:100 000

SCALE 1:250 000



MESOZOIC AND/OR TERTIARY (Developed on various units)

Silcrete — Ferricrete

Q — *Undivided* QUATERNARY — *Sand sheets and dunes, alluvium, colluvium, soil*

Tp — Poodyea Formation — *Cobble and boulder conglomerate, cross-stratified sandy conglomerate, pebbly sandstone*

Ta — Austral Downs Limestone — *Chert, limestone*

EROMANGA BASIN

JK — *Undivided* MESOZOIC — *Sandstone, shale, conglomerate*

GEORGINA BASIN

Dc — Cravens Peak Beds — *Sandstone, conglomerate; calcareous at base*

Ome — Ethabuka Sandstone — *Sandstone*

Omm — Mithaka Formation — *Sandstone, siltstone, mudstone*

Omc — Carlo Sandstone — *Sandstone*

Oln — Nora Formation — *Limonitic coquina limestone; siltstone, sandstone*

Olc — Coolibah Formation — *Limestone (micrite, grainstone, cryptalgal boundstone), marl, chert*

Olk — Kelly Creek Formation — *Sandstone, siltstone, dolostone*

€On — Ninmaroo Formation — *Dolostone, limestone, (ooid, peloidal and echinoderm grainstone, cry… boundstone, flat pebble conglomerate), dolomitic sandstone*

€uu — *Undivided* LATE CAMBRIAN — *Siltstone, sandstone*

€ua — Arrinthrunga Formation — *Sandy dolostone, limestone (ooid clasts, grainstone, cryptalgal boundston… wackestone, mudstone, domed bioherms). Includes €ua* ***in enlargement o…***

€ug — Georgina Limestone — *Sandy laminated micrite, intraformational conglomerate, two-toned limes… algal boundstone, minor oolitic grainstone*

€mm — Marqua Formation — *Silty micritic limestone, sandy limestone (wackestone), mottled limesto… calcareous siltstone, sandstone. Includes* $€mm_1$, $€mm_2$ ***in enlargement only***

€mh — Hay River Formation — *Limestone and chert overlying black pyritic shale; shelly dolomite at bas…*

€mt — Thorntonia Limestone — *Micrite, silicified limestone, black shale, sandstone, siltstone, minor coq…* ***Section only***

€ld — Red Heart Dolomite — *Dolomite with archaeocyaths overlying bioturbated sandstone and arkose*

€ls — Sylvester Sandstone — *Silicified quartzose sandstone, green siltstone*

€la — Adam Shale — *Green and red shale and sandstone, bioturbated*

Pua — Grant Bluff Formation — *Sandstone (thin bedded), siltstone, shale*

Pun — Gnallan-A-Gea Arkose — *Pebbly arkose, sandstone, siltstone, shale*

Puw — Wonnadinna Dolomite — *Dolostone, arkose, siltstone, shale*

Pus — Black Stump Arkose — *Arkose, pebbly arkose, siltstone, shale*

Puh — Sun Hill Arkose — *Arkose, feldspathic sandstone, micaceous sandstone, siltstone, arkosic co…*

Put — Yardida Tillite — *Diamictite, shale, siltstone, sandstone*

Put_d — *Laminated black shale with dolostone.* ***enlargement only***

Puy — Yackah Beds — *Cherty dolomite, sandstone, siltstone*

ARUNTA BLOCK

Pgd — Mount Dobbie Granite K/Ar 1662 ± 25ma — *Coarse-grained leucocratic muscovite granite*

Pgt — *Leucocratic muscovite granite, leucocratic porphyritic granite*

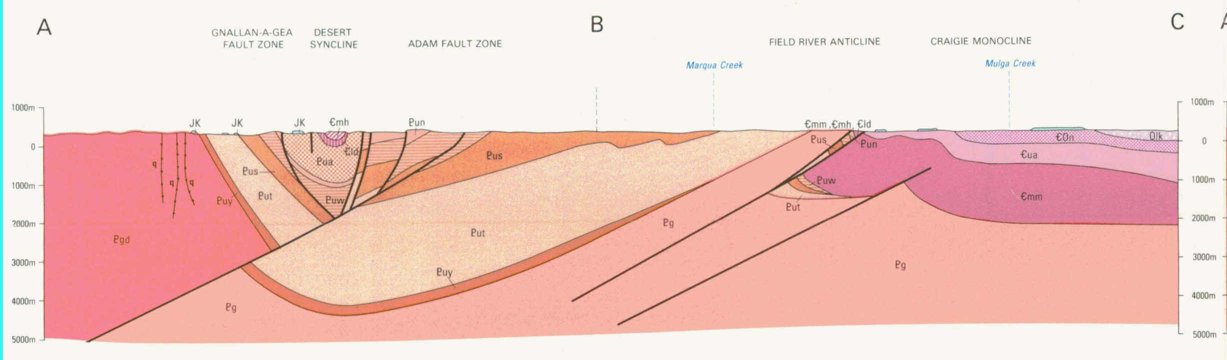
Pg — Teikens Granite Complex — *Undivided granite (muscovite-biotite granite, minor metamorphic rock and pegmatites)*

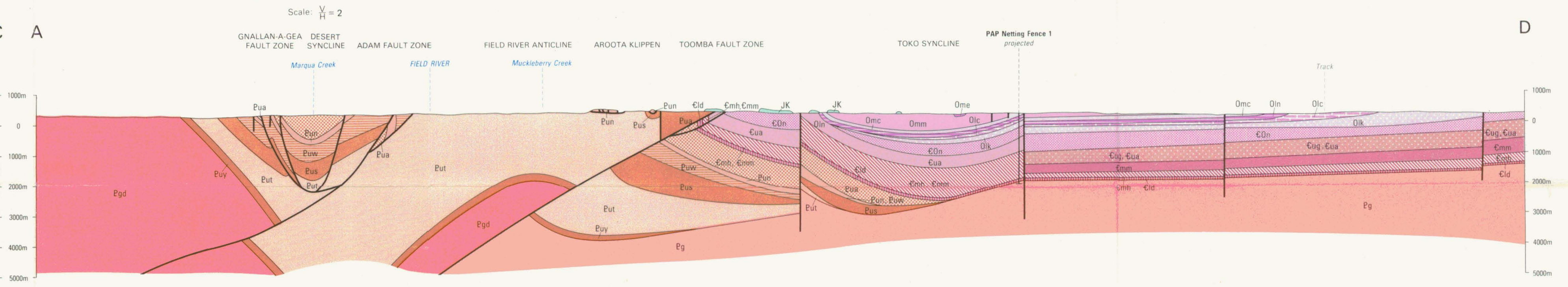
p€y — Your Dam Metamorphics — *Muscovite-biotite schists*

p€m — Mount Smith Metamorphics — *Schists, calc-silicate rocks*

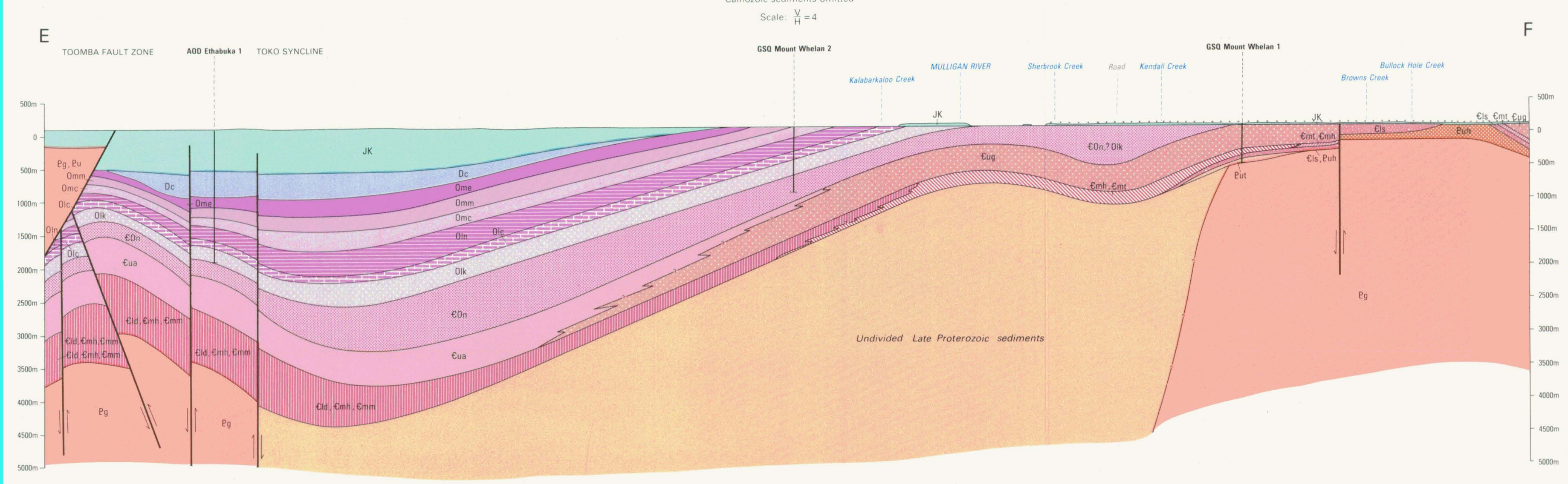
… in BMR Report 214

SCHEMATIC SECTIONS





SCHEMATIC SECTION



Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of Resources and Energy. Prepared in collaboration with the Geological Survey of Queensland. Issued under the authority of the Minister for Resources and Energy. Base map compiled by the Bureau of Mineral Resources from 1:100 000 scale orthophotomap line conversions, supplied by the Division of National Mapping

Geology 1959-1960 by J.N. Casey, D.J. Forman, W. Jauncey, A.R. Jensen, K.G. Lucas, F. Olgers, P.W. Pritchard, M.A. Reynolds, K.G. Smith, R.R. Vine, D.R. Woolley BMR; R.J. Paten GSQ

1975-1978 by E.C. Druce, P.L. Harrison, J. Kennard, P.J. Kennewell, B.M. Radke, J.H. Shergold, C.J. Simpson, M.R. Walter, R.G. Warren BMR; J.J. Draper, P.M. Green GSQ; P. West ANU

Photo-interpretation 1977-1981 by C.J. Simpson BMR

Compiled 1982 by C.J. Simpson, J.H. Shergold, B.M. Radke, M.R. Walter, G.E. Wilford, D. Green BMR; J.J. Draper GSQ

Geophysical data 1970-1981 by BMR and Alliance Oil Development Australia N.L.

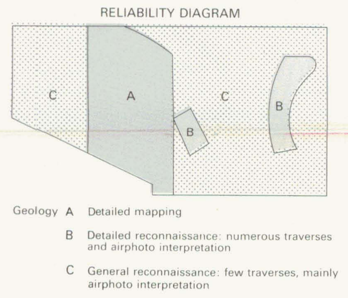
Edited 1983 by G.E. Wilford, I.C. O'Donnell

Cartography by J. Convine, J.N. Mason

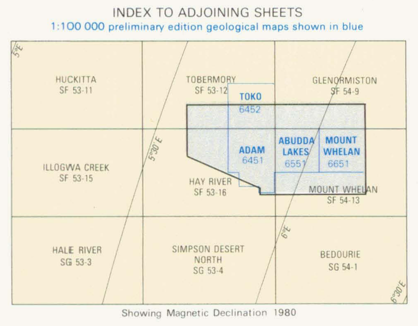
Drawn by Mercury-Walch

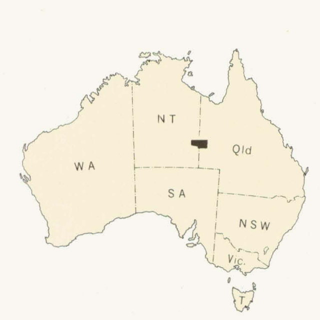
Printed by Valentine Graphics, Melbourne, Australia

RELIABILITY DIAGRAM

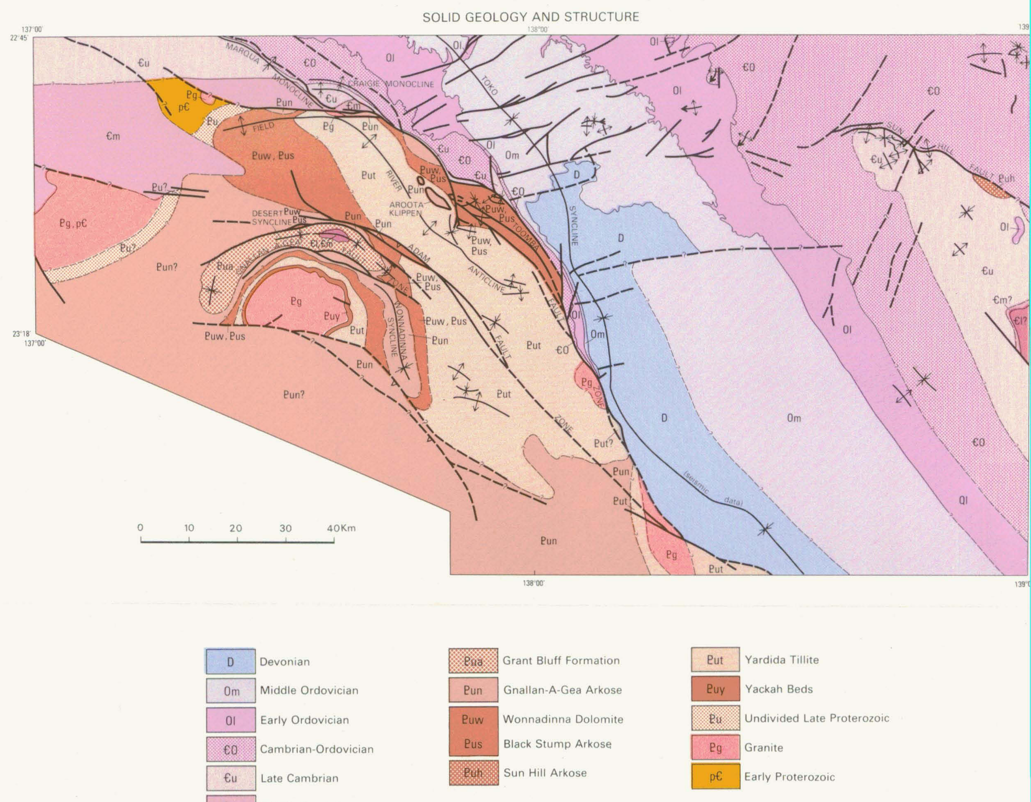


INDEX TO ADJOINING SHEETS

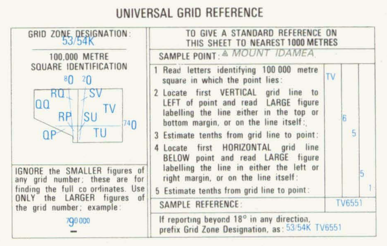




SOLID GEOLOGY AND STRUCTURE



UNIVERSAL GRID REFERENCE



GEOLOGY OF THE
HAY RIVER-MOUNT WHELAN AREA
SOUTHERN GEORGINA BASIN
FIRST EDITION 1985