GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

LENNARD RIVER

WESTERN AUSTRALIA

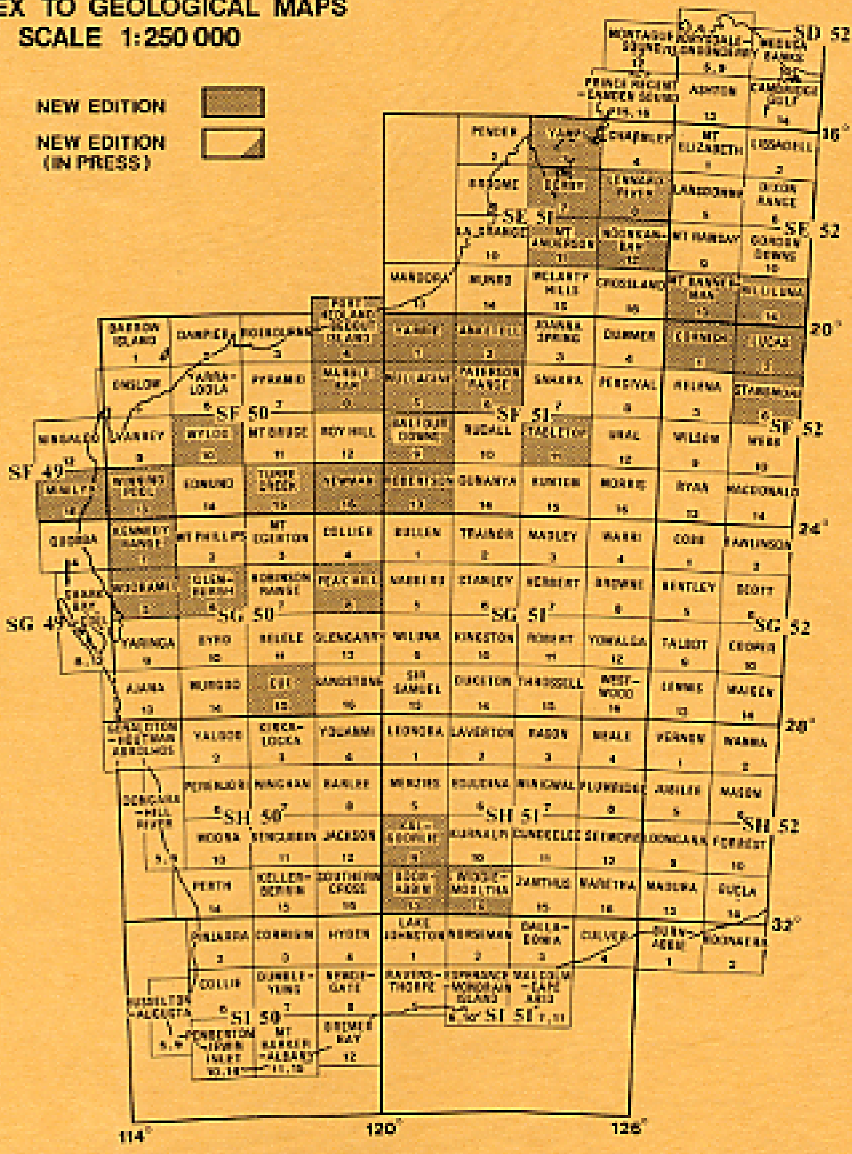
THIRD EDITION

SHEET SE51-8 INTERNATIONAL INDEX

WESTERN AUSTRALIA
INDEX TO GEOLOGICAL MAPS
SCALE 1:250 000

NEW EDITION

NEW EDITION (IN PRESS)



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by

T. J. GRIFFIN, I. M. TYLER, AND P. E. PLAYFORD
(WITH A CONTRIBUTION FROM J. D. LEWIS)

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by T. J. Griffin, I. M. Tyler, and P. E. Playford
(with a contribution from J. D. Lewis)

INTRODUCTION

The LENNARD RIVER* 1:250 000 geological sheet (SE51-8) is bounded by latitudes 17°00' and 18°00' S, and longitudes 124°30' and 126°00' E and lies within the Kimberley Region of northern Western Australia. The sheet takes its name from the Lennard River which drains the northern half of the sheet area.

Beef-cattle grazing is the major commercial activity and is supported by a network of gravel roads between homesteads and the towns of Derby and Fitzroy Crossing, respectively 90 km west and 20 km south of the sheet boundary. Major tourist routes through LENNARD RIVER are the Gibb River Road and the Windjana Gorge–Tunnel Creek Road.

Oil is extracted from the Blina field, and facing-stone is quarried intermittently at several localities.

Water is available in the major drainage channels which are reduced to scattered waterholes in the dry season. Bores provide a more permanent water supply for homesteads and stock.

PHYSIOGRAPHY

Four physiographic provinces recognized by Wright (1964) on LENNARD RIVER are:

1. The *Kimberley plateau province* in the northeast which consists of high, rugged plateaus up to 550 m (Mount House) above sea level, and up to 300 m above the almost flat valley floor at Mount Clifton;

2. The *Kimberley foreland province* which forms the southwestern margin to the Kimberley plateau province and comprises high (Mount Ord, 937 m) quartzite strike ridges and narrow valleys of low bouldery hills 300 m above sea level;

3. The *Fitzroy upland province* which forms a wide zone (40 to 60 km) of rugged hills and ranges, and valley plains developed on mainly granitoid and metamorphic rocks. The relief ranges between 100 and 300 m above sea level. The exhumed limestone reef complex of the Napier Range, which stands 100 m above the plains, marks the southwestern limit of the province;

4. The *Fitzroy plains province* is in the southwest and includes the Lennard River and Fitzroy River floodplains. It is underlain by sedimentary rocks of the Canning Basin.

* Sheet names are printed in capitals to avoid confusion with identical place names

The relief changes gradually from the highest (200 m) plains adjacent to the Fitzroy uplands province, to 60 m above sea level in the west. A few small, isolated hills such as Mount Percy rise up to 60 m above the plain.

CLIMATE AND VEGETATION

The climate is semi-arid monsoonal, characterized by warm, dry winters and hot, wet summers. Maximum temperatures in November average nearly 38°C, and in July almost 25°C. Annual rainfall ranges from 500 mm in the south to 800 mm in the northwest and is mostly cyclonic, with January being the wettest month.

LENNARD RIVER covers parts of the Fitzgerald and Dampier phytogeographic districts of Beard (1979, 1981). The following summary is based on vegetation studies in the Kimberley by Beard (1979, 1981) and Petheram and Kok (1983).

The Fitzgerald district encompasses the Kimberley plateau and Kimberley foreland provinces and consists mainly of open woodland of *Eucalyptus brevifolia* (snappy gum), *E. dichromopholia* (bloodwood), *E. phoenicea* (scarlet gum) and *E. ferruginea* (rusty bloodwood). Two small trees with bright flowers commonly found on rocky slopes and hillsides are the yellow-flowered *Cochlospermum fraseri* (kapok tree) and the red-flowered *Sterulia viscidula* (kurrajong). *Eucalyptus tectifica* (Darwin box) and *E. grandifolia* (large-leaf cabbage gum) occur in the wetter parts of the valleys. Grasses are dominated by *Plectrachne pungens* (curly spinifex), *sorghum* (cane grass), *Aristida latifolia* (feathertop wiregrass) and several ephemeral species. Valleys contain *Sehima nervosum* (white grass), *Chrysopogon* (ribbongrass) and *Heteropogon contortus* (speargrass).

The granitoid hills of the Fitzroy uplands province are characterized by mixtures of mainly *Trodia* sp. (spinifex) and *Plectrachne pungens* (curly spinifex) in a low savanna of *E. brevifolia* and *E. perfoliata* (twin-leaf bloodwood).

Vegetation of the Dampier district covers the Fitzroy plains province. The low plains are covered by grasses and scattered trees: *E. papuana* (ghost gum), *E. microtheca* (flooded box or coolibah), *Dicanthium* sp. (bluegrass) and *Chrysopogon* sp. (ribbongrass). Where the trees are very sparse *Astrebla* sp. (Mitchell grass) joins other grasses.

A characteristic tree in the Lennard River area is *Adansonia gregorii* (boab). It ranges from the Fitzroy plains province where it is common on loamy plains, through to the Kimberley plateau where it lines intermittent water courses and is scattered on rocky hill slopes.

HISTORY OF INVESTIGATIONS

Derrick and Playford (1973) and Gellatly et al. (1974) discuss the history of geological investigations on LENNARD RIVER up to the early 1970's, beginning with a report by Hardman in 1884. Recently several of Hardman's notebooks have been located in England and donated to the Alexander Library, Perth. Hancock and Rutland (1984) refer to some aspects of the Proterozoic geology in their review of the tectonics of the Kimberley, but this is based mainly on work in the Halls Creek Orogen. Griffin and Myers (1988a, b), Stewart (1988), Griffin (1989), and Tyler and Griffin (1990) have commented on various aspects of the tectonic evolution of the King Leopold Orogen as a result of the fieldwork associated with the production of this third edition of LENNARD RIVER.

Detailed descriptions of the Eocene lamproite pipes and ejecta, together with their diamond-bearing potential are provided by Jaques et al. (1986). Base-metal mineralization on the Lennard Shelf associated with the Devonian limestone is discussed by Ringrose (1989) and Buchhorn (1986). Unpublished information on various exploration projects is held in the M-series files of the Geological Survey of Western Australia (GSWA).

Recent work on the Devonian Reef complexes is described by Playford (1980, 1984) and Playford et al. (1989), and aspects of the geology of the northern margin of the Canning Basin are outlined in a special volume edited by Purcell (1984a).

This third edition of LENNARD RIVER makes extensive use of data from the second edition, particularly in areas where little or no recent work has been undertaken, such as in the southwest. Boundaries and large-scale deformation structures in the rugged ranges in the northeast were checked with the aid of a helicopter.

REGIONAL GEOLOGICAL SETTING

The main structural units on LENNARD RIVER are shown in Figure 1. Proterozoic rocks are exposed in the northeast and their nomenclature follows the recommendations of the IUGS and Plumb and James (1986). LENNARD RIVER occupies the central part of the King Leopold Orogen in the West Kimberley Region of Western Australia (Myers and Hocking, 1988). The sheet straddles the Early Proterozoic Hooper Complex (Griffin, 1989; Tyler and Griffin, 1990; Griffin and Grey, 1990b) which consists of highly deformed metasedimentary rocks, gabbro sills, felsic volcanic rocks, and granitoid rocks. Overlying the Hooper Complex in the northeast is the Early Proterozoic Kimberley Basin succession which is in turn unconformably overlain by Late Proterozoic glacigene rocks. This extensive, thick sequence of mainly sedimentary rocks appears to have accumulated on stable continental crust which probably included rocks of Archaean age in the area of the Kimberley plateau province. Both the Kimberley Basin succession and the glacigene rocks are deformed by the late Proterozoic to early Palaeozoic Precipice Fold Belt.

The southwestern third of the sheet is dominated by shallow-dipping rocks of the Phanerozoic Canning Basin succession, most of which are poorly exposed. The narrow Napier Range, which is made up of an exhumed Devonian limestone reef complex, forms a conspicuous ridge beyond the southwestern margin of the Hooper Complex.

The previous accounts of the geology by the Bureau of Mineral Resources, Geology and Geophysics, Canberra (BMR) and GSWA (Derrick and Playford, 1973; Gellatly et al., 1974), provided the framework on which this study was based.

PROTEROZOIC GEOLOGY

There are four groups of Proterozoic rocks on LENNARD RIVER: Early Proterozoic Hooper Complex, Early Proterozoic Kimberley Basin succession, ?Middle to Late Proterozoic sedimentary sequences, and Late Proterozoic glacigene rocks.

HOOPER COMPLEX — EARLY PROTEROZOIC

The Hooper Complex includes the Marboo Formation (metasedimentary rocks), Ruins Dolerite (metamorphosed dolerite sills), Whitewater Volcanics (partly recrystallized felsic volcanic and volcaniclastic rocks), a wide range of granitoid rocks ranging from gabbro to

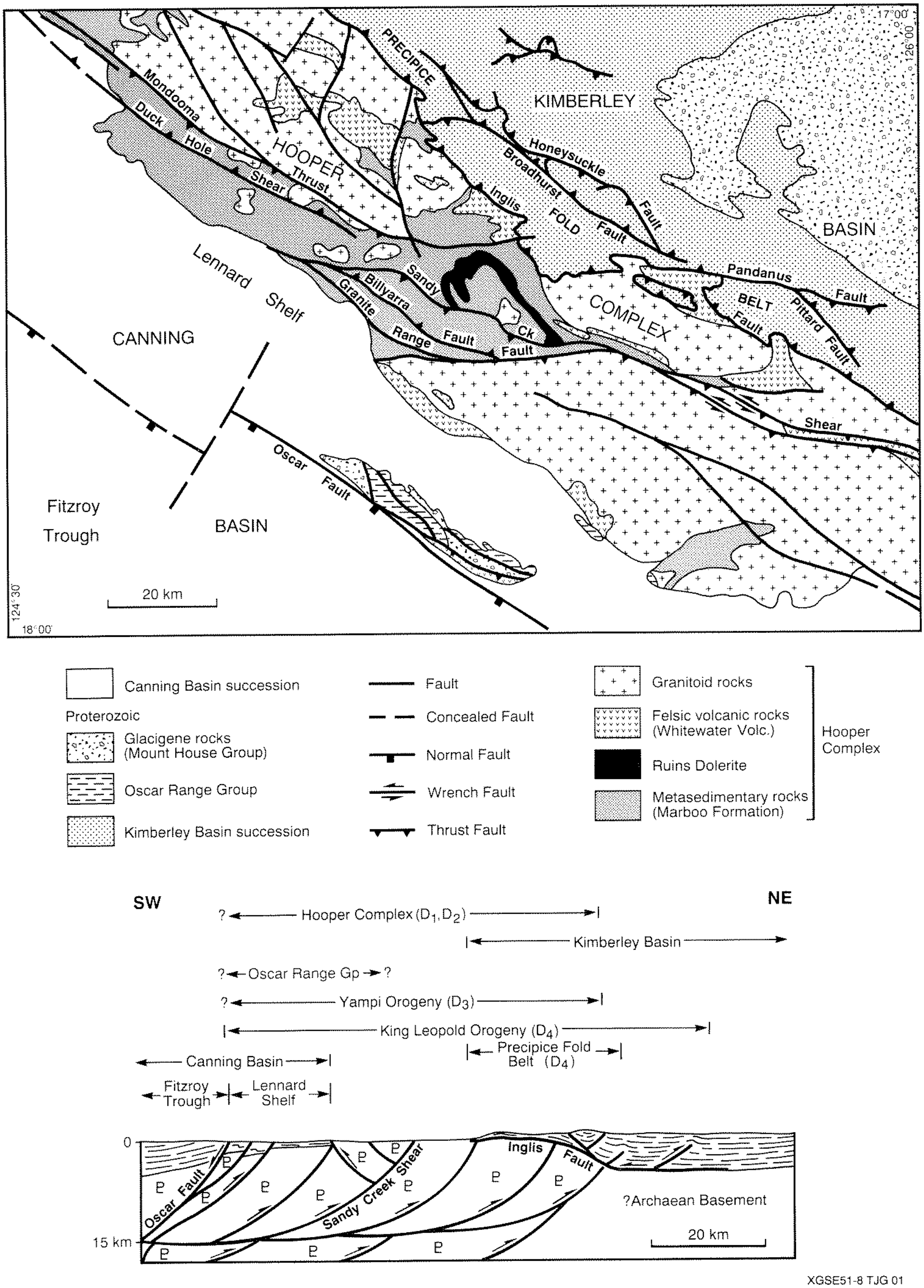

Figure 1. (a) Structural sketch map of LENNARD RIVER showing the major tectonic elements
(b) A schematic cross section which illustrates the limits and structural styles of the major orogenic events (after Tyler and Griffin, 1990)

syenogranite and intrusive porphyry. These are intruded by porphyry, pegmatite, aplite and dolerite dykes.

Components of the Hooper Complex have previously been included in the Lamboo Complex (established in the East Kimberley by Dow and Gemuts, 1969, and Gemuts, 1971) because of their apparent similarity in lithology, age and structural evolution (Sofoulis et al., 1971; Derrick and Playford, 1973; Gellatly et al., 1974; Plumb and Gemuts, 1976; Gellatly et al., 1975; Plumb et al., 1981). However, the exact nature of the correlation is unclear, and the reason for the 90° difference in orientation of these two complexes is not understood. Work by Hancock and Rutland (1984) and Plumb et al. (1985) indicates a very complex tectonic evolution for the Halls Creek Orogen which differs from that of the King Leopold Orogen presented by Tyler and Griffin (1990). Consequently Griffin and Grey (1990a), in a review of the geology, proposed that the Early Proterozoic crystalline rocks of the two orogens be given different names pending a more rigorous investigation of the geology of both areas and, in particular, further evaluation of the stratigraphic and structural correlations.

Detailed descriptions of the Proterozoic rock units on LENNARD RIVER are given by Gellatly et al. (1974), therefore these notes will concentrate on the relationships between the lithologies, and understanding their structural evolution

Marboo Formation (*Em, Ema, Ems*)

The oldest rocks on LENNARD RIVER are a sequence of low- to high-grade turbiditic metasedimentary rocks and felsic volcanic rocks. Derrick and Playford (1973) correlated these rocks with the Halls Creek Group in the Halls Creek Orogen (cf. Dow and Gemuts, 1969). Gellatly et al. (1974) tentatively suggested a correlation with the Olympio Formation described by Dow and Gemuts (1969) as part of the Halls Creek Group. Tyler and Griffin (1993) decided that although rocks on YAMPI were similar to the Olympio Formation, the lack of continuous outcrop, and the absence of other formations of the Halls Creek Group, made this direct correlation inappropriate. The name Marboo Formation was preferred, and this is extended to the rocks on LENNARD RIVER.

The Marboo Formation is unconformably overlain by the Whitewater Volcanics dated at c. 1850 Ma (Page and Hancock, 1988), and is intruded by granitoids that gave a Rb–Sr date of c. 1840 Ma (Bennett and Gellatly, 1970; Page, 1976; Page et al., 1984). An Archaean age was suggested for the metasedimentary rocks (Gellatly, 1971) based on a Rb–Sr model age of c. 2700 Ma from a pegmatite intruding the Halls Creek Group on GORDON DOWNS (Bofinger, 1967). Page (1976) reassessed the data and concluded that the available geochronological evidence pointed to a Lower Proterozoic, rather than an Archaean, age for the Halls Creek Group. This is consistent with c. 1880 Ma U–Pb dates on zircons from the Halls Creek Group in the Halls Creek Orogen (Page, 1988).

Three main outcrops of Marboo Formation occur on LENNARD RIVER: in the headwaters of Hawkstone Creek in the northwest corner of the sheet; around the Lennard and Richenda Rivers in the central part of the sheet; and in the Hooper Hills in the southeast corner of the sheet. The estimated thickness of the unit on the northeastern limb of the Richenda Anticline is in excess of 7000 m, but may be tectonically thickened by layer-parallel shearing and isoclinal folding. The top of the unit is not seen, and no base or basement has been recognized.

The rocks that make up the Marboo Formation have been described by Gellatly et al. (1974), and by Hancock and Rutland (1984). They consist of variously deformed and metamorphosed mudstone, siltstone, greywacke, and quartz wacke, with dacitic and rhyolitic tuff in the upper part. Thin calcareous layers are present throughout.

In the central part of the sheet, rocks forming the lower part of the Marboo Formation outcrop in the core of the Richenda Anticline. These consist of turbiditic quartz wacke, siltstone, and mudstone. Individual sandstone units are up to 10 m thick, and examples of graded bedding have been noted. The contact between the upper and lower parts of the formation is intruded by thick metadolerite sills making up the Ruins Dolerite.

The upper part of the formation consists of interlayered thin (less than 1 m) mudstone, siltstone, and fine-grained greywacke and quartz wacke. Similar rocks outcrop in the Hooper Hills and in the northwest corner of the sheet. Sandstone beds typically have sharply defined bases and grade upwards into siltstone and mudstone. Towards the top of the unit an increasing number of dacitic and rhyolitic lithic–crystal tuff beds were noted by Hancock and Rutland (1984).

Hancock and Rutland (1984, p. 405) described the upper part of the Marboo Formation on LENNARD RIVER as lacking turbidite deposition, however, the sedimentary rocks are parallel laminated and are interpreted here as turbidites displaying part (BDE) of a Bouma sequence (Walker, 1984). They probably represent deposition on the lower, more distal part of a submarine fan, with the thicker bedded and coarser grained sandstones in the lower part of the unit representing more proximal, mid-fan deposition.

The influx of felsic volcanic material towards the top of the unit was interpreted by Hancock and Rutland (1984) as a precursor to the extensive volcanism that produced the unconformably overlying Whitewater Volcanics.

Ruins Dolerite (*Ᵽdr*)

The Ruins Dolerite on LENNARD RIVER was previously called the Woodward Dolerite (Derrick and Playford, 1973; Gellatly et al., 1974). It has been renamed to distinguish it from the Woodward Dolerite, as defined by Gemuts (1971), which occurs as mafic and ultramafic intrusives in the Halls Creek Group on the southeastern part of MOUNT RAMSAY. Although outcrop between the two units is not continuous, the Ruins Dolerite is possibly equivalent in age to the Woodward Dolerite as it intrudes the Marboo Formation which could be equivalent to the Halls Creek Group.

The Ruins Dolerite consists of steeply dipping, layered mafic sills which intrude the Marboo Formation principally in the central part of LENNARD RIVER between the Richenda and Lennard Rivers. The dolerite is amphibolitized and forms prominent, dark bouldery ridges that define large-scale folds. This unit was described in detail by Derrick and Playford (1973) and Gellatly et al. (1974) as consisting of up to seven separate sills averaging about 270 m thick, and separated from each other by 30 to 100 m of metasedimentary rock. Although large-scale layering of porphyritic and non-porphyritic amphibolite occurs in most sills, ultramafic components are rarely seen. Pods of possible metaperidotite containing hypersthene, chlorite and some chromite are described from the Sandy Creek area by Derrick and Playford (1973).

Contacts with the Marboo Formation metamorphic rocks are sharp and hornfelsing was described by Gellatly et al. (1974) who also commented that the occurrence of corundum may be related to contact metamorphic effects of the Ruins Dolerite.

Zircons extracted from the differentiated upper part of a sill give a U–Pb ion-microprobe age of 1880 to 1890 Ma (Page et al., in prep.).

Whitewater Volcanics (*Ꝑw*)

The Whitewater Volcanics is an acid volcanic rock unit that lies unconformably on the Marboo Formation west of Mount Broome. Elsewhere the contact with the metamorphic rocks is faulted. The Whitewater Volcanics are intruded by, and faulted against, granitoid rocks, and grade texturally and chemically into intrusive porphyry and granitoid.

The Whitewater Volcanics consists mainly of rhyolite, rhyodacite and dacite lava, tuff, agglomerate and minor volcaniclastic sedimentary rocks. Most are crystal rich, containing angular quartz, K-feldspar and plagioclase phenocrysts (up to 5 mm across) which resist weathering to form a very rough outcrop surface.

A basal clastic unit (*Ꝑwc*), ranging in thickness from a few metres to 30 m, includes alternating beds of siltstone, sandstone, conglomerate and tuff. The conglomerate west of Mount Broome consists of a fine- to medium-grained silty matrix supporting subrounded to subangular pebble- to boulder-sized clasts of felsic volcanic material, vein quartz, dolerite, and phyllite from the Marboo Formation. East of Colemans Yard, a sequence of interbedded coarse sandstone and pebble conglomerate up to 100 m thick has been thrust onto granitoid. To the south, the basal conglomerate is overlain by strongly foliated felsic volcanics. The conglomerate layers are clast supported and consist predominantly of subrounded vein quartz, with lesser amounts of subrounded to subangular Marboo Formation and felsic volcanic clasts. Some layers contain a significant proportion of opaque grains (10–15%).

Hancock and Rutland (1984) noted the occurrence of felsic volcanic material in this basal conglomeratic unit throughout the Kimberley region and interpreted it as a subaerial braided alluvial fan deposit, derived from nearly contemporaneous early Whitewater Volcanics eruptive centres.

Welded tuff and flow-banded dacite and rhyodacite lava (*Ꝑwp*) form rugged boulder-covered hills which are difficult to distinguish on aerial photographs from fine-grained porphyritic intrusions such as the Mondooma Granite. Derrick and Playford (1973) and Gellatly et al. (1974) recognized four subdivisions within the Whitewater Volcanics. These four subdivisions are not easy to recognize either on the ground or on aerial photographs because of the strong, steeply dipping foliation in both the granitoids and volcanic rocks. Consequently the subdivision has been simplified into a mixed unit of acid volcanic rocks (*Ꝑw*); a generally massive unit of tuff and lava (*Ꝑwp*); and a volcaniclastic sedimentary unit (*Ꝑwc*).

Most rocks are foliated. Greenish brown to black biotite and chlorite form ragged lenticular aggregates and, together with recrystallized quartz, form an anastomosing foliation. A mineral-stretching elongation, involving biotite and quartz, accompanies the foliation and leads to the distinctive 'tombstone' style of outcrop. In some outcrops the stretching lineation is prominent and the foliation is barely detectable.

Granitoid rocks

Two new granitoid rock units are introduced and minor changes have been made to the previous unit boundaries shown on the second edition LENNARD RIVER (Derrick and Playford, 1973; Gellatly et al.,1974).

Field relationships, textural variations, geochemistry and isotopic dating indicate a close association between the Whitewater Volcanics and the granitoids. Together, they represent an Early Proterozoic volcano-plutonic suite similar to those, described by Wyborn (1988), from other parts of northern Australia.

The Kongorow Granite, the Richenda Microgranodiorite and the Wombarella Quartz Gabbro were considered by Derrick and Playford (1973) and Gellatly et al. (1974) to represent early granitoid phases that pre-dated the Whitewater Volcanics and the porphyritic granitoids. New field evidence indicates that the majority of granitoid rocks on LENNARD RIVER post-date the Whitewater Volcanics. However, careful examination of this evidence supports only one, possibly complex, intrusive episode closely following the extrusion of the acid volcanic rocks. The timing of the Wombarella Quartz Gabbro is still uncertain.

The boundaries between the different granitoid phases are based on a combination of aerial photograph patterns and ground observations. However, boundaries are poorly constrained due to the variations in recrystallization and deformation fabrics which make aerial photographic interpretation difficult.

The coarser grained granitoids are generally rich in phenocrysts of K-feldspar (10 to 60 mm across) and less abundant sericitized plagioclase. Most outcrops have a moderate to strong foliation defined by aligned phenocrysts, lens-shaped biotite aggregates and flattened biotite-rich mafic xenoliths. A tectonic lineation plunging to the south at 45° to 65° throughout most of the Hooper Complex is defined by biotite streaking and quartz rods formed by recrystallization of coarse quartz. Deformation and recrystallization took place during the Yampi Orogeny which is discussed below.

In two areas in the southeast — one adjacent to the Sandy Creek and the other a parallel zone 15 km further south — deformation of the granitoid rocks is severe and occupies a wide zone (up to 6 km). These sheared granitoid rocks (*Egsh*) have not been assigned to a specific granitoid unit.

The granitoid rocks form smooth exfoliated whalebacks, coarse blocky steep-sided hills and knobbly undulating hills, locally separated by sandy plains or alluvial valleys. Steep foliations and joints are responsible for a widespread rectangular drainage pattern on the granitoid rocks.

Kongorow Granite (Egk)

Kongorow Granite is used here in a more restricted sense than that suggested by Derrick and Playford (1973) and Gellatly et al. (1974).

The Kongorow Granite comprises mainly foliated porphyritic monzogranite and granodiorite. It includes coarsely banded gneissic granitoid restricted to narrow (less than 20 m) zones close to the southwestern limit of outcrop of the Hooper Complex (e.g. in Barkers Creek). The gneissic rocks indicate a complex history of multiple intrusion suggesting that the Kongorow Granite may be one of the earliest phases of intrusion.

Identification of the Kongorow Granite is based on its generally dark colour, high proportion of biotite-rich mafic xenoliths, heterogeneous nature and strong foliation. Some of the variations mapped and described by Derrick and Playford (1973) and Gellatly et al. (1974) have been reinterpreted to be part of other granitoid units.

The Kongorow Granite intrudes the Whitewater Volcanics west of the Gibb River road, and metasedimentary rocks of Marboo Formation east of the Van Emmerick Range. Most observed contacts with other granitoid phases, in particular the Lennard Granite, are shear zones. Other contacts occur in valleys where there is no outcrop but they may also be shear zones. An intrusive contact is exposed northwest of the Barker River where a monzogranite phase of the Lennard Granite intrudes granodiorite of the Kongorow Granite.

Lennard Granite (Ꝑgl)

The Lennard Granite is a foliated, coarse-grained, porphyritic, leucocratic biotite monzogranite with minor syenogranite and granodiorite. Non-porphyritic varieties occur locally. Feldspar phenocrysts, dominated by large (up to 60 mm) K-feldspar crystals constitute up to half of the rock in some areas. The coarse to medium groundmass is dominated by feldspar and partly recrystallized quartz and minor biotite. Mafic xenoliths, aligned with the foliation, are abundant locally. Thin aplite, pegmatite and quartz veins are widespread and are most abundant close to the contacts with granitoid.

The Lennard Granite is a large composite unit consisting of many stocks which have intruded along the length of the Hooper Complex. It has intruded Marboo Formation, Whitewater Volcanics, Mondooma Granite and Mount Disaster Porphyry. However, many contacts with adjacent rock units are sheared. The composite nature of the Lennard Granite suggests that it probably intruded over a period of time spanning the intrusion of some less extensive granitoid units.

Many areas of granitoid rocks previously included in the Lennard Granite (Derrick and Playford, 1973; Gellatly et al., 1974) are reassigned to other granitoid rock units or to new units.

Mount Amy Granite (Ꝑga)

The Mount Amy Granite (Gellatly et al., 1974) is a foliated, fine-grained to coarse-grained, leucocratic biotite–muscovite syenogranite. It is generally even grained although locally it is porphyritic. It outcrops as small stocks northwest of the Gibb River Road, and locally contains streaky xenoliths of darker granitoid parallel to the foliation. Felsic veins and dykes in the eastern part of LENNARD RIVER, previously mapped as part of the Mount Amy Granite (Derrick and Playford, 1973; Gellatly et al., 1974), are not now included because they appear to be younger, unrelated veins.

Mondooma Granite (Ꝑgm)

The Mondooma Granite (Sofoulis et al., 1971) comprises light-grey foliated quartz-phyric biotite micromonzogranite and a minor even-grained phase. In a few places it contains syenogranite and granodiorite phases. In the field, the Mondooma Granite resembles coarse-grained crystal-rich ash-flow tuff of the Whitewater Volcanics but is distinguishable because of its microgranitic-textured groundmass.

The Mondooma Granite forms steep, rugged, bouldery hills. It intrudes the Whitewater Volcanics and is associated with them in the vicinity of the Gibb River Road. The Mondooma Granite possibly represents subvolcanic intrusions genetically related to the Whitewater Volcanics.

Bickleys Porphyry (Ꝑgbp)

The Bickleys Porphyry (Gellatly et al., 1975) comprises grey, foliated, fine-grained quartz–feldspar porphyry and porphyritic micromonzogranite that resemble both the

Mondooma Granite and crystal-rich, ash-flow tuff of the Whitewater Volcanics. Quartz phenocrysts are characteristically bipyramidal and plagioclase is strongly zoned. These, together with recrystallized biotite, are set in a micrograniticgroundmass of quartz and feldspar.

The Bickleys Porphyry intrudes the Whitewater Volcanics and is intruded by the Mount Disaster Porphyry and Lerida Granite. It is apparently equivalent to the Mondooma Granite, which is restricted to the northwestern part of the Hooper Complex, and is similarly interpreted as a subvolcanic equivalent of the Whitewater Volcanics.

Mount Disaster Porphyry (Ꞓgdp)

The Mount Disaster Porphyry (Sofoulis et al., 1971) is a distinctive, foliated, coarsely porphyritic biotite micromonzogranite which outcrops discontinuously along the northeastern limit of the exposed Hooper Complex adjacent to the rocks of the Kimberley Basin. Phenocrysts (up to 4 mm across) of pink or white K-feldspar, green or cream plagioclase, and blue-grey quartz are set in a fine-grained groundmass of quartz, feldspar and streaky biotite.

The Mount Disaster Porphyry intrudes the Whitewater Volcanics. The contact relationships with the Mondooma Granite are unclear and may be gradational. Therefore, this porphyry may also be a subvolcanic equivalent of the Whitewater Volcanics.

Lerida Granite (Ꞓgd)

The Lerida Granite (Gellatly et al., 1974) consists of foliated porphyritic biotite–hornblende granodiorite and minor tonalite. It is characterized by pale-green plagioclase phenocrysts, ragged chloritized biotite, and a partially recrystallized texture. Small mafic biotite-rich xenoliths are abundant locally. Contact relationships are not conclusive although the Lerida Granite appears to have been intruded by the Lennard Granite, Chaneys Granite and Dyasons Granite in the southeast.

Barker Monzogranite (Ꞓgb)

Low-lying boulder-covered hills south of Mount Hart homestead on CHARNLEY and extending onto the northern margin of LENNARD RIVER, are dominated by the Barker Monzogranite. This unit intrudes the Mondooma Granite and consists of a weakly foliated fine-grained biotite monzogranite with small biotite-rich mafic xenoliths.

Richenda Microgranodiorite (Ꞓgr)

The Richenda Microgranodiorite consists of foliated medium- to fine-grained granodiorite and tonalite. It forms two small stocks: one, less than 4 km across within the Marboo Formation in the centre of LENNARD RIVER; and the other covering an area of 12 km^2 southeast of Stumpys Jumpup on the Gibb River Road. The stocks in the Marboo Formation are relatively young, discrete intrusions and are unrelated to similar rock types found associated with the Kongorow Granite further to the northwest that were mapped as Richenda Microgranodiorite by Derrick and Playford (1973) and Gellatly et al. (1974). Contacts are sharp and markedly transgressive.

The western stock is intruded by several narrow (< 10 m), almost vertical, north-trending dykes of aplite, fine-grained porphyry and microgranite. Some of the porphyry has a strong foliation which dips steeply to the west and east. The dykes are parallel to prominent steep joints close to the western contact of the Richenda Microgranodiorite and they have been interpreted as cone sheets (Gellatly et al., 1974).

The outcrops of the Richenda Microgranodiorite to the northwest are strongly foliated. The microgranodiorite intrudes the Whitewater Volcanics and is intruded by the Lennard Granite. These outcrops were previously mapped as a tonalitic phase of the Wombarella Quartz Gabbro (Derrick and Playford, 1973; Gellatly et al., 1974).

Dyasons Granite (Ꝑgs)

Dyasons Granite (Gellatly et al., 1974) typically comprises weakly foliated, slightly porphyritic, medium- to fine-grained, leucocratic monzogranite. Syenogranite and granodiorite phases are locally present. Small biotite flakes are scattered throughout the rock rather than as aggregates. Secondary muscovite is a minor component. The Dyasons Granite appears to intrude the Lennard Granite and McSherrys Granodiorite although many contacts are sheared and intrusive relationships are destroyed.

Tarraji Microgranite (Ꝑgt)

The Tarraji Microgranite is primarily a foliated porphyritic biotite micromonzogranite which outcrops as a circular stock in northwest LENNARD RIVER. This stock was previously photo-interpreted as Lennard Granite (Derrick and Playford, 1973; Gellatly et al., 1974); however, it is very similar to rocks on YAMPI that were named Tarraji Microgranite by Sofoulis et al. (1971) and Tyler and Griffin (1993). K-feldspar, biotite and quartz are present as phenocrysts in a fine-grained, granitic-textured groundmass dominated by quartz, K-feldspar, plagioclase, and biotite.

The Tarraji Microgranite intrudes the Marboo Formation in which hornfels is developed in a contact metamorphic aureole.

Chaneys Granite (Ꝑgy)

The name Chaneys Granite is used here in the same sense as that described by Gellatly et al. (1975) on LANSDOWNE. It is a foliated biotite monzogranite which resembles the Lennard Granite. Although porphyritic in part, it lacks the coarse K-feldspar phenocrysts that are diagnostic of the Lennard Granite. Minor granodiorite is a component. Locally it contains small mafic biotite-rich xenoliths.

As with the Lennard Granite, the Chaneys Granite is a composite unit extending over the length of the Hooper Complex. It is probably closely related to the Lennard Granite and its components similarly span the intrusion of less extensive units. It intrudes the McSherrys Granodiorite but appears to be intruded by the Mondooma Granite and the Mount Amy Granite in the northwest of LENNARD RIVER.

McSherrys Granodiorite (Ꝑgms)

The McSherrys Granodiorite (Derrick and Playford, 1973; Gellatly et al., 1974) is a complex intrusion consisting of foliated, porphyritic to even-grained, biotite–hornblende granodiorite, and minor tonalite and monzogranite. Small mafic amphibole-rich xenoliths are abundant locally. The McSherrys Granodiorite generally forms low, rugged, boulder-covered hills

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in the south central part of the Hooper Complex. However, the central area of this extensive rock unit takes the form of a soil-covered plain. Much of the McSherrys Granodiorite is intruded by steeply dipping amphibolitized dolerite dykes which trend northwest.

The McSherrys Granodiorite has sheared contacts with most adjacent units, although a few observations indicate that it intrudes the Whitewater Volcanics and is intruded by the Mondooma Granite, Chaneys Granite, Dyasons Granite and Lennard Granite. It therefore appears to represent an early phase of intrusion, possibly associated with the Kongorow Granite which outcrops in the northwest of LENNARD RIVER.

Scrutons Monzogranite (Ꝑgsc)

A large area of very rugged granitoid rocks north of Scrutons Yard previously mapped as Lennard Granite (Derrick and Playford, 1973; Gellatly et al., 1974) is renamed Scrutons Monzogranite. The dominant rock type is a coarse, porphyritic biotite monzogranite that has suffered some recrystallization but it is not as pervasively affected as the Lennard Granite. Biotite is extensively altered to chlorite in the Scrutons Monzogranite whereas the biotite in the Lennard Granite is almost entirely recrystallized to fine-grained biotite mosaics.

Highly sheared granitoid (Ꝑgsh)

Many granitoids are cut by both small and large shear zones and have sheared contacts with adjacent rock units. Some of these zones are up to 7 km wide in southeastern LENNARD RIVER. These areas of rock are shown as highly sheared granitoid comprising strongly foliated to mylonitized porphyritic and non-porphyritic monzogranite and granodiorite.

Wombarella Quartz Gabbro (Ꝑggw)

The Wombarella Quartz Gabbro (Gellatly et al., 1974) is an unusual intrusive unit that outcrops close to the Gibb River Road where it forms a small layered lopolith 5 km across. Igneous layering defines an elliptical pattern opening to the north, and dips range from 30° to 80° with an average of 45°. Several smaller outcrops occur to the south.

The principal rock types are dark-grey medium- to fine-grained biotite, hornblende- and pyroxene-bearing quartz gabbro, gabbro and quartz norite. Compositional banding on both a large and small scale is widespread. The small southern outcrops are deformed and recrystallized, and are associated with garnet-bearing granitoid rocks. On aerial photographs, the Wombarella Quartz Gabbro forms a distinct dark mottled pattern with patches of black which represent vegetation-free hills covered by black, rounded boulders.

Contacts are deformed and therefore provide inconclusive evidence on the timing of intrusion of the Wombarella Quartz Gabbro. However, the close association and interfingering of a thin unit of deformed tonalite on the margin of the lopolithic structure indicates contemporaneous intrusion with the granitoids. The lack of a tectonic fabric within the Wombarella Quartz Gabbro, fine-grained material close to the margins, and the presence of granular green hornblende (?igneous) and pyroxene right up to the contact indicate that the quartz gabbro is a relatively late phase. Gellatly et al. (1974) observed granitoids which cut the gabbro south of the lopolith, thus indicating that some granitoid intrusions also post-date the Wombarella Quartz Gabbro.

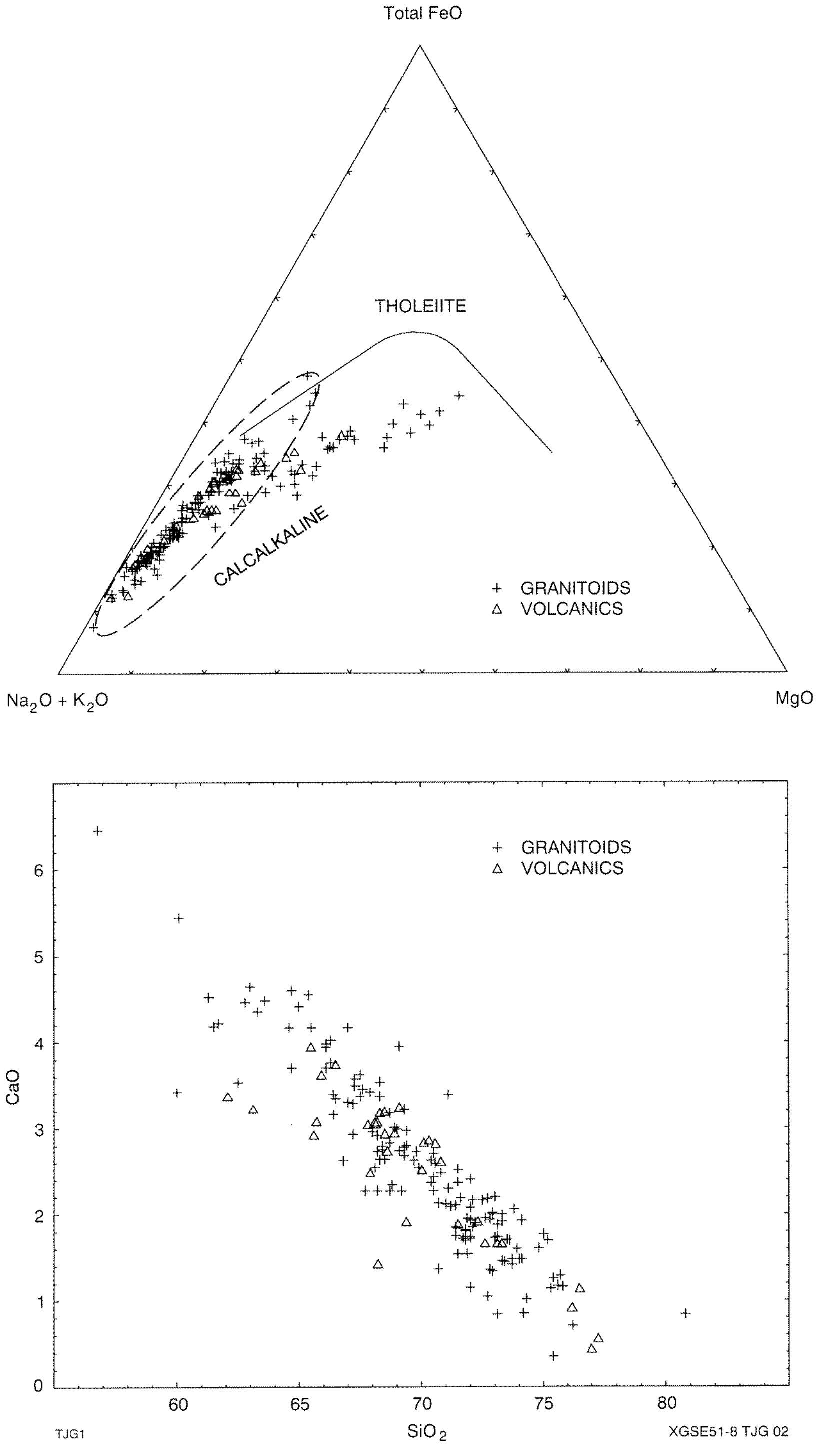


Figure 2. **AFM ($K_2O + Na_2O$, Total iron as FeO, MgO) diagram for the comagmatic Early Proterozoic Whitewater Volcanics and granitoids of the Hooper Complex. The field for the Australian Early Proterozoic granitoid suite is from Wyborn (1988). Detailed plot, CaO vs SiO_2, of granitoids and felsic volcanics of the Hooper Complex**

The tonalitic to granodioritic rocks which outcrop 3 km east of the lopolith have been assigned to the Richenda Microgranodiorite rather than the Wombarella Quartz Gabbro (Derrick and Playford, 1973; Gellatly et al., 1974) because they are not gabbroic and lithologically correspond more to the rocks of the Richenda Microgranodiorite.

Geochemistry

Limited geochemical data from the granitoids and the Whitewater Volcanics indicate (Fig. 2) that these rocks are typical of modern I-type calc-alkaline igneous rocks (Griffin et al., 1978). Harker diagrams (Fig. 3) illustrate a linear relationship of most major elements for rocks ranging from granodiorite to rhyolite. The geochemistry of some of the more mafic rocks indicates a more complex history not directly related to partial melting and/or crystal fractionation from a source area in the lower crust. It possibly reflects more primitive histories of derivation; either partial melting in the mantle, or close to total melting of the lower crust (Griffin et al., 1978).

Dykes

Dolerite dykes

The oldest dyke suite (*d*) post-dated the intrusion of at least some of the granitoid rocks. It is best exposed in the southeast of LENNARD RIVER where it cuts McSherrys Granodiorite as a major swarm of subparallel to anastomosing, steeply dipping bodies of amphibolite

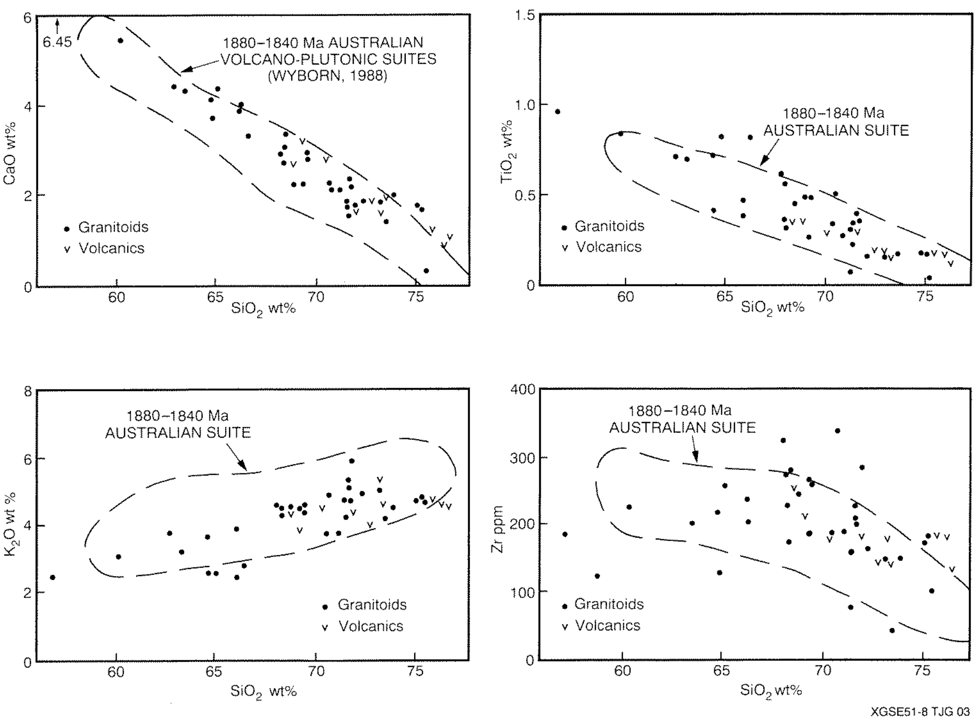


Figure 3. Harker variation diagrams of the comagmatic Early Proterozoic Whitewater Volcanics and granitoids of the Hooper Complex. The fields for the Australian Early Proterozoic granitoid suite are from Wyborn (1988)

from 3 m to 10 m wide. Their trends vary from northwest to almost north, and continuous outcrop rarely exceeds 10 km. They appear as dark lines on aerial photographs and can be traced across areas of soil and colluvium. On the ground they form positive features consisting of boulder-covered ridges, and negative features in the form of shallow depressions of dark soil and occasional weathered mafic schist.

This early dyke suite appears to have been completely amphibolitized during metamorphism. However, a subophitic texture between plagioclase and green to brown hornblende, replacing pyroxene, is preserved in the less-deformed dykes.

Felsic dykes

Aplite (*a*), pegmatite (*g*) and porphyry (*p*) dykes 1 m to 5 m wide are widespread, particularly in association with the larger granitoid intrusions. They appear to represent late-stage or marginal phases to granitoids. Large porphyry dykes occur within the small stock of Richenda Microgranodiorite in the centre of LENNARD RIVER, coarse muscovite-bearing pegmatite outcrops south of Kongorow Pool, and tourmaline-bearing pegmatites are abundant in the Lennard River southeast of Mount Joseph.

HOOPER OROGENY — EARLY PROTEROZOIC

The Hooper Orogeny affected the Marboo Formation, Ruins Dolerite and Whitewater Volcanics of the Hooper Complex and appears to have been synchronous in part with the intrusion of the granitoids. Two deformation events are recognized, together with two metamorphic events.

Deformation (D_1 and D_2)

The oldest deformation (D_1) is only recognized in Marboo Formation rocks, mainly as a layer-parallel foliation (S_1). The fabric is not pervasive, and no associated folds have been recognized on LENNARD RIVER. However, the sedimentary rocks were tilted prior to the deposition of the Whitewater Volcanics. An S_1 foliation is well developed northeast of Carpenter Gap.

The second deformation (D_2) produced upright open to tight folds at all scales. A pervasive axial planar cleavage (S_2) is well developed and occurs as a crenulation cleavage in areas where S_1 is present. A bedding/cleavage intersection lineation (L_1) is also prominent.

The folds show a variety of orientations. The principal structure is the Richenda Anticline in the central part of LENNARD RIVER (Fig. 1). This has a northwest-trending axial surface and plunges steeply to the west and southwest north of Black Hills Yard, and moderately to steeply to the southeast in the vicinity of Colemans Yard. Large-scale D_2 folds in Marboo Formation rocks west of Mount Eliza have northeasterly trending axial surfaces with moderate plunges to the southwest. Large-scale folds in the metamorphic rocks west of Mount Broome, which have easterly trending axial surfaces and plunge steeply to the east, also affect the Whitewater Volcanics.

Gellatly et al. (1974) reported folds in an area 11 km west of Mount Broome that plunged steeply to the south-southwest and were attributed to an older fold phase. However, there is only one phase of folding in this area that post-dates tilting during D_1. The axial surfaces of the D_2 folds maintain a west-northwest trend and dip steeply to the south-southwest, whereas bedding here is steep to vertical and trends north-northeast. The south-southwest plunges reflect the steep intersection of bedding with the S_2 cleavage. No folds have been observed that have south-southwest-trending axial surfaces.

Tyler and Griffin (1990) noted that this D_2 event appears to correspond to two events ('D_3' and 'D_4') described from the 'Lennard River Inlier' by Hancock and Rutland (1984) who separated easterly trending folds ('D_3') from northwest-trending folds ('D_4') north of Black Hills Yard. From our observations, described above, only one axial planar cleavage (S_2) is present in the area. The two orientations of folds are separated by a D_3 shear zone and the easterly orientation of the folds near Mount Broome is interpreted as the result of reorientation of D_2 folds during D_3. An 'S_4' fabric identified in the McSherrys Granodiorite by Hancock and Rutland (1984) is here attributed to D_3.

D_2 appears to have coincided with the volcano-plutonic event as it clearly folds the Whitewater Volcanics northwest of Mount Broome. D_2 pre-dated the main phase of granitoid intrusion although it appears to have had some control on the distribution of the granitoids which are extended in a northwesterly direction. The gneissic fabric in some of the phases of the early Kongorow Granite possibly reflect the effects of D_2.

Metamorphism (M_1 and M_2)

The relationships between metamorphic mineral growth and deformation in Marboo Formation rocks are summarized in Figure 4. The first metamorphic event on LENNARD

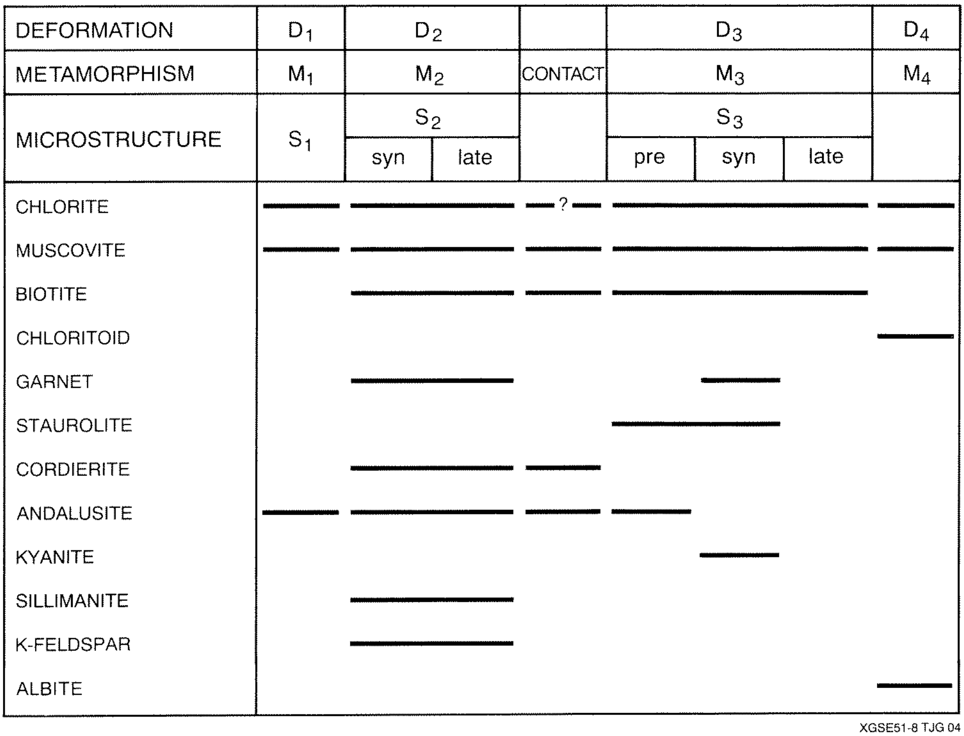


Figure 4. Relationship of metamorphic mineral growth to deformation events in Marboo Formation rocks

RIVER accompanied the first phase of deformation and appears to have been restricted to very low- and low-grade conditions. The S_1 fabric is typically fine grained, consistent with its formation within the greenschist facies, or lower.

The second metamorphic event (M_2) is recognized in medium- to high-grade (middle amphibolite facies to granulite facies) metamorphic rocks (*Ems*, *Emm*) which outcrop in an area to the north of Windjana Gorge. Other outcrops of the Marboo Formation on LENNARD RIVER do not show evidence of metamorphism at grades higher than the greenschist facies during M_2. The S_2 fabrics are typically fine grained. Muscovite–quartz(–chlorite–biotite) assemblages in metasedimentary rocks in areas unaffected by D_3 or M_3 (e.g. north of the Sandy Creek Shear), together with amphibole–epidote–plagioclase–biotite–quartz(–chlorite) assemblages in the Ruins Dolerite, are consistent with low-grade metamorphism.

Mount Joseph Migmatite (Emm)

Anatectic gneiss and migmatite, recognized by Gellatly et al. (1974), is referred to here as the Mount Joseph Migmatite. Tyler and Griffin (1990) interpreted the metamorphism producing the migmatite as syn-D_1, with leucosomes folded by D_2. Further work indicates that metamorphism is actually syn- to post-D_2 with anatectic melts intruding across folds and becoming aligned parallel to D_2 fold axial surfaces. The migmatite is intruded by the Lennard Granite.

Non-migmatitic, medium- to high-grade metasedimentary rocks are exposed around the margins of the migmatite. Four kilometres to the southeast of the Black Granite Quarry (a dolerite facing-stone quarry), medium-grade sillimanite–muscovite–biotite–quartz schist is exposed. This rock contains large crystals of tourmaline wrapped by the foliation. Sillimanite occurs as fine, randomly oriented needles within prograde muscovite plates. Similar rocks are exposed near Billyarra Billabong.

High-grade, well-bedded, medium-grained sillimanite–K-feldspar–garnet–biotite–quartz–cordierite metasedimentary rocks exposed 2 km to the southeast of the Black Granite Quarry indicate the presence of a sillimanite + K-feldspar isograd. Cordierite in this rock is restricted to the more psammitic layers.

Coarse-grained sillimanite–K-feldspar–biotite–muscovite–quartz assemblages are present in metasedimentary rocks to the southwest of Mount Joseph Yard. Muscovite growth was both prograde, intergrown with biotite, and retrograde, replacing K-feldspar.

On the west bank of the Lennard River, 6.5 km east of Mount Joseph, a medium-grained schistose pelite contains andalusite porphyroblasts that display inclusion-free cores within margins that overgrow a well-developed S_2 foliation. The core can be interpreted as static growth of an andalusite porphyroblast during M_1. During D_2 it continued to grow synchronously with the development of the S_2 fabric. Its occurrence suggests proximity to a prograde M_2 andalusite/sillimanite isograd, with metamorphic grade increasing from east to west.

The Mount Joseph Migmatite is dominated by a coarse-grained nebulitic migmatite containing the assemblage sillimanite–andalusite–biotite–plagioclase–K-feldspar–muscovite–quartz. Intergrowths of green biotite, andalusite, feldspar and quartz replace cordierite. Pelitic and psammitic restite fragments up to several metres across are present, together with smaller, rounded and corroded, quartz-vein fragments. Outcrops dominated by schollen, phlebitic, schlieren and stromatic migmatites occur and are interpreted as representing earlier stages of the migmatization process. Layering, which probably represents primary bedding, can be recognized locally. Fresh cordierite is preserved in some psammitic bands.

The pelitic restite material is typically rich in garnet that is highly irregular in shape, suggesting that resorption has taken place. Intergrowths replacing cordierite are also present, and fresh cordierite cores are infrequently preserved.

Coarse-grained stromatic migmatites outcrop 9.5 km west of the Black Granite Quarry. These contain a sillimanite–garnet–biotite–plagioclase–K-feldspar–quartz assemblage. A cummingtonite–biotite–plagioclase–quartz assemblage is also present and probably represents Al-poor layers.

The migmatite structures and prograde mineral assemblages noted above are all consistent with the interpretation of the migmatites as the product of melting in situ (Mehnert, 1968; Ashworth, 1985). The occurrence of non-migmatitic rocks containing the assemblage sillimanite–K-feldspar–quartz, implies that dehydration of muscovite took place before the onset of anatexis, requiring pressures below about 400 MPa (Kerrick, 1972; in the absence of graphite, a_{H_2O} is assumed to be 1).

Contact metamorphism

A contact-metamorphic aureole up to 1 km wide can be recognized in Marboo Formation around a circular stock of Tarraji Microgranite 14 km north of Kongorrow Pool. Medium-grained hornfelsic rocks at the granite contact consist of poikiloblastic andalusite intergrown with biotite, muscovite and quartz. In some rocks poikiloblastic cordierite is also present. The poikiloblastic andalusite may be wrapped by the later S_3 foliation.

Retrograde replacement of cordierite, resorption of garnet, and replacement of K-feldspar by muscovite in the Mount Joseph Migmatite may be the result of contact metamorphism by the Lennard Granite.

Discussion

Tyler and Griffin (1990) suggested that the restricted nature of D_1 is consistent with large-scale faulting and shearing which may have formed as part of an extensional fault system marginal to the basin in which the Marboo Formation was deposited. D_2 folding was attributed to large-scale, possibly sinistral, strike-slip movements on steep west-northwesterly trending shear zones. The suggested sense of movement was based on the orientation of the Richenda Anticline and of structures observed en echelon to the shear zones on YAMPI (Tyler and Griffin, 1993). The early Proterozoic movements on the shears have been extensively overprinted by later reactivation during D_3 (see below). The variation in the orientation of D_2 folds on LENNARD RIVER is here attributed to reorientation during D_3.

The Mount Joseph Migmatite and the associated medium- to high-grade Marboo Formation may represent sedimentary rocks metamorphosed at a deeper structural level than the rest of the Marboo Formation during M_2, and which were tectonically emplaced to a higher level during D_3.

The felsic-plutonic event post-dated the deposition and early deformation of the Marboo Formation. The granitoids which generally post-date the felsic volcanics also intrude the Mount Joseph Migmatite. The large volumes of felsic magma represented by the Whitewater Volcanics and Hooper Complex granitoids are similar to other Early Proterozoic felsic suites in northern Australia, which Wyborn (1988) has interpreted as having developed in an intercontinental environment. Alternatively the relatively high abundance of granodiorite and tonalite in the Hooper Complex (e.g. McSherrys Granodiorite) indicates possible development in a plate-margin collision environment.

The tectonic setting of the Hooper Orogeny is not clear but may reflect either a cycle of extension and oblique convergence, or a collision between two ancient cratonic crustal terranes that now presumably underlie the Kimberley Basin and the Canning Basin.

KIMBERLEY BASIN — EARLY PROTEROZOIC

The rugged King Leopold Ranges along the northeastern edge of the Hooper Complex are dominated by rocks of the Early Proterozoic Kimberley Basin succession. These rocks are tightly folded and faulted and all units are exposed. Further north the rocks are gently folded or flat-lying and they are unconformably overlain by Late Proterozoic glacigene rocks. Two groups of rocks are recognized in the Kimberley Basin succession: the Speewah Group, comprising mainly arenites and some siltstone; and the overlying Kimberley Group, comprising mainly quartz-rich arenite and minor siltstone and basic volcanic rocks. The following review draws on recent work by K. A. Plumb of the BMR, and earlier investigations by Dow et al. (1964), Derrick and Playford (1973), Gellatly et al. (1975) and Plumb and Gemuts (1976).

The boundary between the Speewah Group and Kimberley Group was defined at the conformable upper boundary of the Luman Siltstone by Gellatly et al. (1975). However, Williams (1969, unpublished report to Broken Hill Pty Co. Ltd), working on LANSDOWNE, showed that a conglomerate bed in the 'King Leopold Sandstone' marked a low-angle unconformity and represented a significant time break. This conglomerate bed was also noted throughout the East Kimberley by Dow et al. (1964) and Gellatly et al. (1970, 1975). The boundary between the Speewah and Kimberley Groups is now redefined at this unconformity. That part of the old 'King Leopold Sandstone' which lies beneath the unconformity is now named the Bedford Sandstone (Williams, 1969; informal usage) and is placed into the Speewah Group. King Leopold Sandstone is retained for the sandstone above the unconformity and remains the basal unit of the Kimberley Group. Thus the Luman Siltstone and King Leopold Sandstone are now separated by the Bedford Sandstone (Fig. 5).

Recent mapping has shown that the conglomerate at the base of the King Leopold Sandstone in the East Kimberley dies out to the west across LANSDOWNE. The lithological expression of the unconformity becomes more subtle and is complicated by extensive intrusion of Hart Dolerite sills on, above, and below the unconformity on LENNARD RIVER.

Throughout LENNARD RIVER and immediately to the east at the Diamond Gorge area on LANSDOWNE the Bedford Sandstone was previously mapped as part of the Lansdowne Arkose (Derrick and Playford, 1973; Gellatly and Derrick, 1967). A distinctive recessive sandstone and shale unit 150 m above the unconformity was interpreted as Luman Siltstone (Derrick and Playford, 1973). The redefined King Leopold Sandstone now also includes the recessive unit and, underlying it, more than 150 m of sandstone above the unconformity. Northwestwards from Bold Bluff, the unconformity cuts down the sequence through the Bedford Sandstone and Luman Siltstone so that the King Leopold Sandstone lies directly on the Lansdowne Arkose (Fig. 5).

All palaeocurrent direction indicators determined from cross-beds in the Speewah Group suggest sediment transport from the northeast and east, while the Kimberley Group has

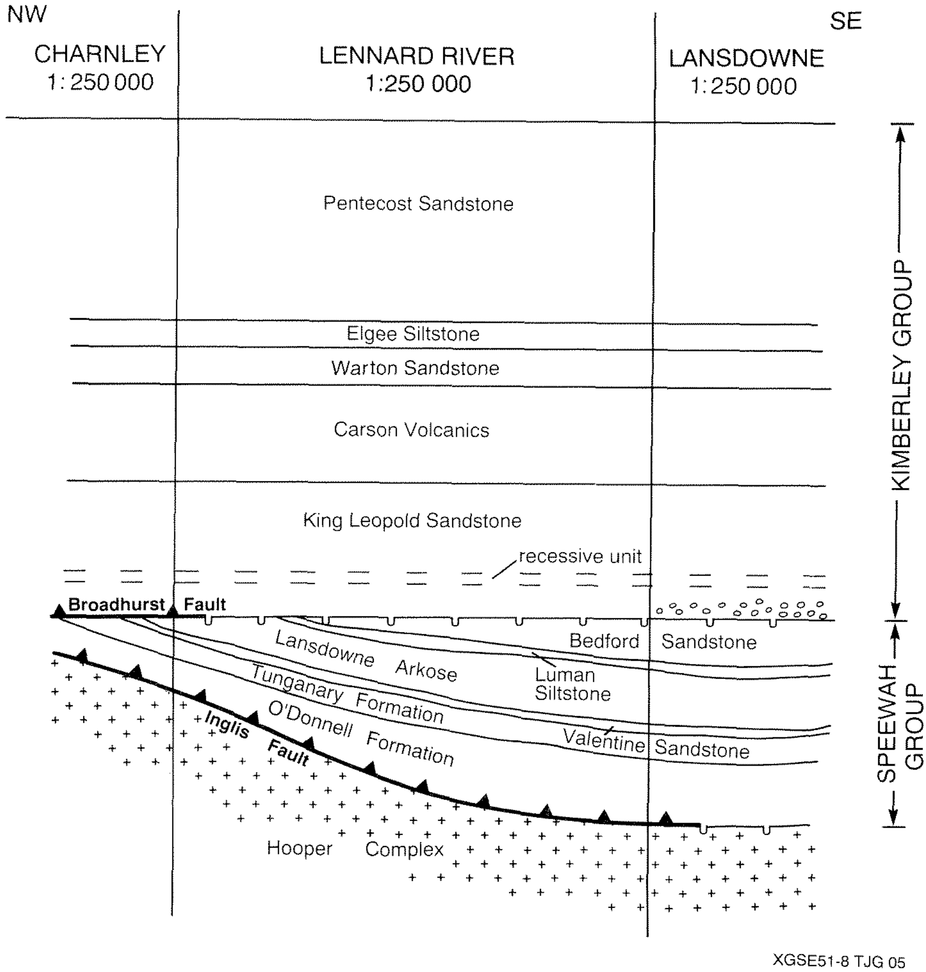


Figure 5. Sketch illustrating the stratigraphic and structural relationships of the Speewah and Kimberley Groups on LENNARD RIVER

remarkably consistent palaeocurrents which indicate sediment transport from the north and north-northwest (Gellatly et al., 1970; Plumb and Gemuts, 1976).

Speewah Group

O'Donnell Formation (ESn)

The O'Donnell Formation is a massive sandstone unit at the base of the Speewah Group. It has a maximum thickness of 523 m near 'The Rocks', thinning to about 20 m to the northwest, and about 300 m to the southeast. The contact with the underlying Hooper Complex on LENNARD RIVER is everywhere faulted (Inglis Fault) and varies in dip from shallow to steep towards the northeast (Griffin and Myers, 1988a,b; Griffin, 1989). The shearing on the contact dies out and an unconformity is preserved on LANSDOWNE

(Gellatly et al., 1975). The O'Donnell Formation is conformably overlain by the Tunganary Formation.

The sandstone is predominantly a poorly sorted, coarse-grained, granule quartz sandstone which is locally lithic, ferruginous or glauconitic. Planar and trough cross-beds up to 2–3 m are ubiquitous. Ripple marks and graded bedding are prominent. Conglomerate beds containing pebbles of quartzite, vein quartz and fine-grained felsic porphyry are widespread in the lower part of the formation. The prominent uppermost siltstone unit (Gellatly et al., 1975) grades northwestwards across LENNARD RIVER into 50 m and less of interbedded flaggy, fine-grained quartz and feldspathic sandstone, and poorly sorted siltstone. Another silty unit is conspicuous just above the base of this formation in the southeast.

Tunganary Formation (ⱣSt)

The Tunganary Formation is predominantly fine-grained feldspathic sandstone interbedded with micaceous or sericitic siltstone, phyllite and minor coarse quartz sandstone. The formation has a maximum thickness of about 170 m, compared with more than 200 m on LANSDOWNE, and is disrupted by the intrusion of extensive sills of Hart Dolerite.

Valentine Siltstone (ⱣSv)

The Valentine Siltstone is 45 m thick near 'The Rocks', poorly exposed and extensively intruded by the Hart Dolerite along its base. The basal 5 m is a dark-grey to dark-green tuff and tuffaceous siltstone which fractures conchoidally. This is overlain by grey to green flaggy, laminated siltstone which grades upwards with an increasing proportion of fine feldspathic sandstone into the Lansdowne Arkose. The siltstone, which contains much less mica than siltstone in adjacent formations, forms regular 5–10 m thick units. The Valentine Siltstone appears to be conformable with the underlying Tunganary Formation and the overlying Lansdowne Arkose.

Lansdowne Arkose (ⱣSo)

The Lansdowne Arkose comprises pink to red-brown, grey and green, medium-grained, feldspathic sandstone which grades to arkose; subordinate, prominently outcropping, medium- to coarse-grained, poorly sorted quartz sandstone; and recessive, green to red-brown, micaceous siltstone, shale and phyllite. The feldspathic sandstones are characterized by small-scale, low-angle, trough cross-sets, commonly 10–30 cm high. Planar bedding characterizes the quartzites. The Lansdowne Arkose near 'The Rocks' is 400 m thick which is comparable with its thickness throughout most of the East Kimberley (Gellatly et al., 1975). Previous reference to a more quartz-rich and thicker sequence on LENNARD RIVER (Derrick and Playford, 1973) was due to the inclusion of the Bedford Sandstone and lowermost King Leopold Sandstone into the Lansdowne Arkose.

Luman Siltstone (ⱣSl)

The Luman Siltstone is a recessive unit comprising 30 m of red-brown to grey-green micaceous siltstone and phyllite, and interbedded fine-grained feldspathic sandstone. Ripple marks are ubiquitous. It is gradational with the Lansdowne Arkose and Bedford Sandstone. The Luman Siltstone is not preserved below the King Leopold Sandstone northwest of Bold Bluff.

Bedford Sandstone (PSb)

The newly mapped Bedford Sandstone was previously incorporated in the Lansdowne Arkose on LENNARD RIVER and in the King Leopold Sandstone on LANSDOWNE (Derrick and Playford, 1973; Gellatly et al., 1975). The Bedford Sandstone has a gradational contact with the conformably underlying Luman Siltstone, and is unconformably overlain by the King Leopold Sandstone. It is not preserved beneath the unconformity northwest from Bold Bluff. On LENNARD RIVER the Bedford Sandstone is about 200 m thick, compared with about 600 m in central LANSDOWNE (Williams, 1969, unpublished report to Broken Hill Pty Co. Ltd; Gellatly et al., 1975), and it is distinctly finer grained and much less pebbly than it is farther east.

The Bedford Sandstone on LENNARD RIVER typically comprises massive outcrops of yellow-brown, coarse-grained, siliceous, argillaceous, and slightly feldspathic, quartz sandstone containing sparse pebbles of quartz, chert, and claystone. Large-scale (1–2 m) trough and channel cross-bed sets are ubiquitous. The lowest 50 m comprises a distinctive scarp-forming unit of blocky, red to purple-brown, medium-grained quartzite which is characterized by medium-scale planar cross-beds, or planar bedding with current lineations. A few metres of flaggy, purple-brown, micaceous fine-grained sandstone at the base which is gradational into the underlying Luman Siltstone is included as part of the Bedford Sandstone (previously King Leopold Sandstone; Gellatly et al., 1975).

Kimberley Group

King Leopold Sandstone (PKl)

The King Leopold Sandstone is about 1000 m thick and is dominated by white to pink quartz sandstone which forms the prominent ridges and cliffs of the King Leopold Ranges. Minor coarse-grained sandstone and granule to pebble conglomerate are present. Ripple marks and cross-bedding are abundant. The King Leopold Sandstone is unconformable on either the Bedford Sandstone or Lansdowne Arkose of the underlying Speewah Group and is conformably overlain by the Carson Volcanics.

A prominent recessive unit about 150 m above the base of the newly defined King Leopold Sandstone had been previously mapped as Luman Siltstone on LENNARD RIVER. This recessive shaly unit consists of about 30 m of flaggy to blocky, green, grey-green and purple-brown, chloritic, feldspathic siltstone and fine sandstone with shaly partings. The 150 m of sandstone below was mapped previously as Lansdowne Arkose (Derrick and Playford, 1973). The major rock type in this lowest interval is buff to red-brown, medium-grained, slightly feldspathic quartz sandstone with large-scale (1–2 m) trough cross-beds and scattered pebbles, and superficially resembles the Bedford Sandstone. It is distinguished from the Bedford Sandstone by overall finer grainsize, regular interbedded intervals of white to pink, medium-grained, well-sorted orthoquartzite, and accessory amounts of black tourmaline.

A basal conglomerate which is prominent in the East Kimberley is represented on LENNARD RIVER by a recessive unit, only a few metres thick, of cross-bedded granule sandstone with scattered quartz pebbles, interbedded with half-metre intervals of black shale. This basal unit is generally covered by scree or obscured by shearing along the unconformity. In practice, the base of the King Leopold Sandstone is commonly identified by the first outcrop of white to pink, medium-grained, well-sorted, 'sugary' orthoquartzite.

Carson Volcanics (PKc)

The Carson Volcanics consist mainly of poorly exposed, greyish-green, altered tholeiitic basalt and minor feldspathic sandstone and brown to green micaceous siltstone. Numerous flows with interflow sedimentary rock units which are more prominent at the top of the formation are characteristic of this unit. Disseminated hematite, pyrite, and chalcopyrite are widespread in the Carson Volcanics. This formation is approximately 720 m thick (Derrick and Playford, 1973) and includes amygdaloidal basalt and pyroclastics including bombs and basaltic fragments. Polymictic conglomerate with accessory pyrite is reported by Derrick and Playford (1973) to be associated with coarse pyroclastics.

Warton Sandstone (ƁKw)

The Warton Sandstone is a mainly buff-coloured, massive to blocky quartz and feldspathic sandstone unit, 250 m thick, which lies conformably on the Carson Volcanics and is overlain conformably by the Elgee Siltstone. Purplish-brown hematitic siltstone and fine-grained feldspathic sandstone are abundant in the middle of the Warton Sandstone. The base grades up from tuffaceous siltstone of the Carson Volcanics (Derrick and Playford, 1973). A prominent scarp, south of the Gibb River Road and running east from Rifle Point is formed by Warton Sandstone.

Elgee Siltstone (ƁKe)

The Elgee Siltstone is 170 m thick and on LENNARD RIVER consists of reddish brown and grey siltstone, with minor phyllite and feldspathic sandstone interbeds. In the Precipice Range the uppermost beds are purple, hematitic, fine-grained, ripple-marked sandstone with clay pellets, which contrasts sharply with the conformably overlying Pentecost Sandstone.

Pentecost Sandstone (ƁKp)

The lower unit of the Pentecost Sandstone (*ƁKpl*) is about 200 m of massive, strongly cross-bedded purple-brown, white and buff quartz sandstone and feldspathic sandstone with minor micaceous siltstone. The middle Pentecost Sandstone unit (*ƁKpm*) is about 1300 m thick (Derrick and Playford, 1973) and is the uppermost unit of the Kimberley Group on LENNARD RIVER. It consists of a higher proportion of micaceous siltstone than the underlying unit and its base is marked by a purple-brown glauconitic sandstone and siltstone unit.

Hart Dolerite (*Ɓdh*)

The Hart Dolerite is a massive composite sill of tholeiitic dolerite and less extensive granophyre (*Ɓdhg*). It intruded the lowest parts of the Kimberley Basin succession, particularly the Speewah Group. The highest stratigraphic level reached by the Hart Dolerite on LENNARD RIVER is the King Leopold Sandstone, whereas on adjacent sheets it intruded units as high as the Pentecost Sandstone (Plumb, 1968; Sofoulis et al., 1971; Gellatly et al., 1975; Tyler and Griffin, 1993). It has a combined total thickness of about 1500 m on LENNARD RIVER, although this may include some structural stacking. It is part of an enormous sill complex which occupies an area of 160 000 km^2 with a thickness of up to 3 km (Plumb and Gemuts, 1976) and has an estimated total volume of 250 000 km^3.

The sill is thickest where it intrudes and separates the Tunganary Formation low in the Speewah Group. The development of granophyre is also restricted to this stratigraphic level where it has formed on the upper contact with the overlying feldspathic sandstone of the Tunganary Formation. The granophyre has pyroxene and plagioclase in a granophyric matrix together with characteristic pegmatoid intergrowths of altered pyroxene, amphibole and plagioclase. Country rock xenoliths are locally abundant in the granophyre. Fine banding, indicative of igneous flow lamination, is present in the dolerite.

Conventional U–Pb zircon geochronological data from samples of Hart Dolerite granophyre, 2 km north of Inglis Gap, indicate an intrusive age of c. 1800 Ma (Page et al., in prep.). This is slightly older than the whole rock and mineral Rb–Sr isochron age of 1762 ± 15 Ma reported by Bofinger (1967) and Page et al. (1984). Hence the Kimberley Basin rocks intruded by the Hart Dolerite are at least 1800 Ma.

YAMPI OROGENY — ?MIDDLE PROTEROZOIC

The Yampi Orogeny on LENNARD RIVER affected rocks of both the Hooper Complex and the Kimberley Basin succession. It did not affect the late Proterozoic glacigene rocks nor does it appear to have deformed the Oscar Range Group. The Yampi Orogeny produced northeast-facing folds and thrusts in the Kimberley Basin succession on YAMPI (Sofoulis et al., 1971; Gellatly and Sofoulis, 1973; Tyler and Griffin, 1990; Tyler and Griffin, 1993). On LENNARD RIVER large-scale open warps of the Kimberley Basin succession rocks in the northeast of the sheet must have been present prior to deposition of the late Proterozoic glacigene rocks, with the basal tillite crossing a broad syncline from Carson Volcanics at Mount House to Pentecost Sandstone in the Precipice Range, and back to Carson Volcanics southwest of Mount Hamilton. Tyler and Griffin (1990) attributed these structures to deformation during the Yampi Orogeny. Deformation seen in the Kimberley Basin succession along the northeastern margin of the Hooper Complex has also affected the Late Proterozoic glacigene rocks and is related to the younger King Leopold Orogeny (D_4), which is discussed later.

The major effect of the Yampi Orogeny in the Hooper Complex crystalline basement was the formation of northwest-trending, southwest-dipping, ductile thrusts.

The Yampi orogeny post-dated the Hart Dolerite and pre-dated the Mount House glacigene rocks.

Deformation (D_3)

The third deformation event (D_3) recognized on LENNARD RIVER has affected all rocks within the Hooper Complex. The most obvious structures are large-scale shear zones which trend west-northwest (Fig. 1). These probably represent reactivation of pre-existing D_2 structures. Shear zones dip steeply to the south-southwest throughout most of the Hooper Complex, but dip to the north-northeast in the southwestern part of the complex. A reverse, south-side-up sense of movement on the south-southwest-dipping shear zones is clearly indicated by igneous K-feldspar phenocrysts with well-developed asymmetrical tails and broken and displaced textures (Simpson and Schmid, 1983). Between the shear zones, most exposures of granitoid and felsic volcanic rocks, which lack an early tectonic fabric, show evidence of deformation in the form of a well-developed mineral-stretching lineation defined by secondary biotite and recrystallized quartz phenocrysts. Many of these rocks also contain a strong west-northwest-trending foliation which is parallel to the large-scale shear zones.

Granitoids and felsic volcanic rocks within shear zones are mylonitic, comprising finely laminated bands (< 1 mm) rich in quartz, feldspar or biotite which wrap augen of K-feldspar or recrystallized quartz. Sheath folds and rootless, intrafolial folds (1 to 5 m across) of the mylonitic banding occur in an outcrop 3.5 km northeast of Wombarella Creek on the Gibb River road.

Rootless intrafolial folds, usually of early quartz and pegmatite veins, are commonly seen in the shear zones in metasedimentary rocks. Porphyroblasts of garnet, andalusite and staurolite are wrapped by the foliation.

Rocks within the shear zones such as the Sandy Creek Shear have foliations and mineral lineations parallel to the regional trends. However, some lineations have a more southerly plunge direction and are less steep and therefore possibly indicate a strike-slip component to these structures. Modification or overprinting of D_3 structures by later more brittle fault movements, which have reactivated these zones, has occurred.

The main west-northwesterly shear zones are linked by, or branch into, north-northwesterly shears that show a dextral strike-slip movement indicated by deformed quartz veins in the shears rather than by any significant displacement.

East of Waggon Flat, the easterly trending Granite Range Shear has steep south-dipping lineations and a sinistral sense of movement. This structure is interpreted as a lateral ramp which links two west-northwest trending segments of the Sandy Creek Shear. This is consistent with an overall north-northeast transport direction (Tyler and Griffin, 1990).

In the southwestern part of the Hooper Complex near Napier Downs and in the Hooper Hills area, foliations dip steeply (generally 70°–80°) to the north-northeast and the plunge directions on stretching lineations vary from north-northeast to east. Tails on K-feldspar phenocrysts indicate the sense of movement was north side up. Tyler and Griffin (1990) interpreted this as the result of back-thrusting.

Refolding of D_2 structures is recognized in the Marboo Formation only in the vicinity of the shears where a second crenulation cleavage (S_3) dips at gentle to moderate angles into the shear zones. This is particularly well developed in the area between McSherry Gap and Black Hills Yard. In the back-thrusted zone near Napier Downs, folds in the Marboo Formation have moderately to gently plunging axes which trend west-northwest and an axial-plane schistosity that dips to the northeast. Folds with axial surfaces dipping moderately to the north-northeast outcrop in the Hooper Hills.

Reactivation of D_2 structures during D_3 appears to have decreased to the east with both the Mondooma Thrust and the Sandy Creek Shear failing to displace the Kimberley Basin Succession on LENNARD RIVER or LANSDOWNE, in contrast to relationships on YAMPI (Tyler and Griffin, 1993). This lack of reactivation during D_3 coincides with a more easterly trend to the structures.

Metamorphism (M_3)

Deformation of the Hooper Complex during the Yampi Orogeny was accompanied by a low- to medium-grade metamorphic event (M_3). This is equivalent to the event referred to by Tyler and Griffin (1990) as M_2. The relationship of metamorphic mineral growth to deformation is summarized in Figure 4.

Fine- to medium-grained, low-grade (greenschist facies) metasedimentary rocks (*Ꝑm*) are exposed between McSherry Gap and Black Hills Yard, and to the northeast of the Van Emmerick Range. They have the assemblage muscovite–chlorite–quartz (–biotite). Some contain biotite porphyroblasts up to 2 mm across, which are wrapped by an S_3 crenulation cleavage but overgrow S_2. Psammitic layers also contain plagioclase and K-feldspar.

In the Hooper Hills fine-grained metasedimentary rocks have the assemblage muscovite–quartz (–chlorite). An S_3 crenulation cleavage is locally well developed.

Medium-grade (amphibolite facies) metasedimentary rocks (*Ema*) occur north of the Van Emmerick Range, in the vicinity of Napier Downs Homestead, in the vicinity of Billyara Yard, and to the north of the Granite Range. They also occur to the east of Mount Joseph. They have the general assemblage biotite–muscovite–quartz (–andalusite–kyanite–staurolite–garnet–chloritoid–chlorite–plagioclase–K-feldspar) with accessory Fe-oxides, tourmaline, apatite, and zircon.

Andalusite, staurolite, garnet and biotite occur as subhedral porphyroblasts, some of which are very large. The subhedral nature of the crystals is in contrast to the poikiloblastic crystals produced during contact metamorphism. Andalusites reach 5 cm in length, and garnets 3.5 cm in diameter. East of Carpenter Gap, garnet porphyroblasts overgrow two cleavages (S_1 and S_2) and are wrapped by a third (S_3). The Billyara and Sandy Creek Shear Zones to the north shows a strong, spaced, S_3 foliation — defined by biotite, muscovite and chlorite — which develops gradually as the shear zone is approached. S_2 is preserved between the S_3 foliation planes. Garnet and staurolite porphyroblasts are wrapped by S_3 and show sigmoidal inclusion trails consistent with growth syntectonic with the crenulation of S_2 to form S_3 (Bell, 1985; Bell et al., 1986). The inclusion trails are truncated by S_3. Garnet porphyroblasts displaying spiral inclusion trails are seen in an outcrop where the Lennard River is crossed by the Sandy Creek Shear. Sigmoidal inclusion trails are also developed in garnet and staurolite porphyroblasts north of the Van Emmerick Range.

North of the Granite Range, staurolite, andalusite and biotite porphyroblasts are wrapped by a S_3 crenulation cleavage. The foliation becomes more intense as the Granite Range Shear Zone is approached. The porphyroblasts are randomly oriented within the plane of S_3. Staurolite and andalusite crystals preserve straight inclusion trails of S_1 and S_2 similar to those seen in garnets east of Carpenter Gap.

North of the Van Emmerick Range, and in the vicinity of Napier Downs Homestead, some andalusite is partially replaced by intergrowths of staurolite, kyanite and/or muscovite.

Assemblages in the Mount Joseph Migmatite generally appear to have been metastable during M_3. However, samples collected 8 km west-northwest of Mount Joseph contain kyanite (replacing andalusite and cordierite), fine-grained staurolite, and chlorite (replacing biotite and garnet). All are interpreted as products of the M_3 event.

Most granitoid rocks, and the Whitewater Volcanics, were partially to substantially recrystallized during M_3. In hand specimens, secondary biotite and quartz rodding define a tectonic fabric. In thin section, primary mafic biotite and minor hornblende are generally completely replaced by fine-grained mosaics of biotite, sphene and opaques (mainly ilmenite) which form elongate clusters parallel to the schistosity. K-feldspar and plagioclase retain many igneous features (perthitic texture, simple and multiple twinning, and oscillatory zoning) although the cores of large plagioclase grains are commonly altered and recrystallized. Coarse quartz exhibits a range of recrystallization textures from uneven extinction to fine-grained granular mosaics with well-developed triple-point junctions. Myrmekite is widespread in the granitoid rocks where it has developed on the edges of large K-feldspar grains adjacent to plagioclase, and appears to be the result of M_3. Minor secondary phases present include epidote, zoisite, muscovite and secondary straw-yellow to blue-green hornblende. Ilmenite dominates the opaque phases and is accompanied by minor magnetite.

The Ruins Dolerite north of the Van Emmerick Range is thoroughly recrystallized, and has the assemblage hornblende–plagioclase–quartz, with accessory titanite and Fe-oxide, consistent with medium-grade (amphibolite facies) metamorphism. Metagabbro within the

Sandy Creek Shear Zone has the assemblage hornblende–epidote–plagioclase–biotite–quartz, consistent with metamorphism at slightly lower grade (albite–epidote amphibolite facies).

Mafic dykes that have been deformed during D_3 intrude the metasedimentary rocks exposed between McSherry Gap and Black Hill Yard. They contain assemblages consistent with low-grade (greenschist facies) metamorphism. Hornblende, rather than actinolite, accompanied by epidote, plagioclase and quartz in dykes intruded into the McSherrys Granodiorite indicate slightly higher grade conditions.

The sequence of mineral growth in metasedimentary rocks is consistent with early low pressure–medium temperature growth of randomly oriented andalusite, staurolite, garnet and biotite porphyroblasts overgrowing pre-existing S_1 and S_2 fabrics. Growth of garnet and staurolite continued during D_3. Andalusite was replaced by kyanite, muscovite and staurolite consistent with evolution to higher pressures during the Yampi Orogeny. Movement on D_3 shear zones continued locally at low grade with chlorite growing parallel to S_3, and resorption of garnet and staurolite.

?MIDDLE TO LATE PROTEROZOIC SEDIMENTARY SEQUENCES

Oscar Range Group

The Oscar Range Group is a succession of low-grade metasedimentary rocks exposed in the Oscar Range Inlier (Fig. 1), and at Mount Wilson and The Twins. Small outcrops are present within the Devonian reef complex between the southwest end of the Oscar Range Inlier and Mount Wilson. The rocks were mapped in detail by Derrick and Gellatly (1971), and their descriptions form the basis of the following summary.

Stratigraphic relationships in the Oscar Range Inlier are difficult to establish due to the presence of shear zones that disrupt the succession. Derrick and Gellatly (1971) recognized seven informal units ('beds'), which together made up the Oscar Range succession. In this report they are raised to formation status and five — the Mount Wilson, Christopher, Le Lievre, Ellendale, and Linesman Formations — make up the Oscar Range Group. The stratigraphic relationships between the lower three formations (Mount Wilson, Christopher, and Le Lievre Formations) are not exposed and, being lithologically similar, they may represent tectonically separated parts of the same formation. The unconformably overlying, possibly glacigenic, Elimberrie and Ninety Seven Mile Formations will be discussed in a later section.

No reliable isotopic age data are available for the Oscar Range Group. Bennett and Gellatly (1970) reported a two-point Rb–Sr isochron of 568 Ma, but one of the samples analysed was from the Elimberrie Formation. This date cannot, therefore, be regarded as recording the age of deposition of the Oscar Range Group.

The Oscar Range Group has lithological similarities with rocks deposited in the Kimberley Basin, and Tyler and Griffin (1990, fig. 2) suggested that the succession represented an outlier of the basin. However, rocks in the Oscar Range Inlier appear to have undergone only one major period of folding, which has also affected the Elimberrie and Ninety Seven Mile Formations. Deformation that can be attributed to the Yampi Orogeny of Tyler and Griffin (1990) is not recognized. Until more reliable isotopic age data are obtained, the age of deposition of the Oscar Range Group will remain uncertain, but deformation must have taken place between the end of the Yampi Orogeny and the deposition of the Elimberrie and Ninety Seven Mile Formations in the Late Proterozoic. This suggests that the Oscar Range Group is of Middle or Late Proterozoic age and is probably equivalent to rocks deposited in relatively small sedimentary basins in the Halls Creek Orogen (e.g. Glidden Group, Carr Boyd Group and Osmond Range succession, Dow and Gemuts, 1969).

Mount Wilson Sandstone (ꝐOw)

The Mount Wilson Sandstone outcrops around Mount Wilson and The Twins. Although separated from the main exposure of the Oscar Range Group by Devonian rocks, Derrick and Gellatly (1971) cited the lithological and stratigraphic similarities and proximity to the Oscar Range as reasons for including the unit within their Oscar Range succession.

The unit dips steeply to the southwest, and is unconformably overlain by Devonian rocks. At Mount Wilson it is separated from the Hooper Complex by a steeply dipping shear zone. At The Twins the contact is a steeply dipping unconformity. The formation consists of at least 666 m of coarse-grained quartz sandstone, feldspathic sandstone, and minor arkose. Detrital tourmaline and zircon are abundant. The basal part of the unit is strongly cross-bedded. Graded bedding is also present. Quartz and feldspar grains are commonly angular, consistent with local derivation from the adjacent Hooper Complex. The feldspar content of the sandstones decreases up the sequence. Fine-grained, ripple-marked micaceous sandstones occur near the top.

Christopher Formation (ꝐOc)

The Christopher Formation outcrops along the northeastern edge of the Oscar Range Inlier. It is lithologically similar to the Mount Wilson Sandstone. Derrick and Gellatly (1971), however, regarded it as younger because, on the basis of measured dips, it appears to occur above the Mount Wilson Sandstone. The formation is unconformably overlain by Devonian rocks. Contacts with other formations of the Oscar Range Group are not exposed, but are probably tectonic. Derrick and Gellatly (1971) estimated the total thickness of the Christopher Formation to be 2300 m.

The unit consists of interbedded pebble to boulder conglomerate, grey to white quartz sandstone, feldspathic sandstone, locally tuffaceous phyllitic siltstone, and minor carbonate, intruded by minor thin dolerite sills. Locally the sandstone units are cross-bedded.

Le Lievre Formation (ꝐOv)

The Le Lievre Formation occupies the central and northwestern parts of the Oscar Range Inlier, outcropping as the core of a major anticline. In the vicinity of the Le Lievre Ridge it is overlain, slightly unconformably, by the Ellendale Formation. The base of the formation is not seen, and Derrick and Gellatly (1971) record a total exposed thickness of about 800 m.

The lowest part of the formation consists of red-brown to grey phyllite with minor sandstone interbeds. This is overlain by massive thick-bedded, medium- to coarse-grained quartzite and quartz sandstone, with minor phyllite. Cross-bedding and ripple marks are present. At the top of the formation is a magnetite-bearing phyllite.

Ellendale Formation (ꝐOe)

The Ellendale Formation outcrops on either side of the Le Lievre Ridge and extends to the northwest across Ninety Seven Mile Creek. It includes outcrops that Derrick and Gellatly (1971) included as part of the Christopher 'beds'. The formation overlies the Le Lievre

Formation. The relationship is partly obscured by faulting; however, Derrick and Gellatly (1971) noted an overlap of the base of the Ellendale Formation on the upper part of the Le Lievre Formation, suggesting that the contact was at least partly unconformable.

A measured section of the unit consists of 1464 m of cobble and boulder conglomerate, quartzite, quartz sandstone, feldspathic sandstone, and siltstone. Cross-bedding and ripple marks are present. Quartzite, minor siltstone and chert constitute the clasts in the conglomerates. The upper part of the sequence consists of 400 m of laminated siltstone.

Linesman Formation (ꝐOl)

The Linesman Formation consists of about 1300 m of interbedded siltstone, feldspathic sandstone, quartz sandstone, and pebble and cobble conglomerate which outcrops between Mount Hardman Creek and the Tunnel Creek road. The unit is in fault contact with the Christopher Formation to the northeast and the Elimberrie Formation to the southwest. Because of the lithological similarity between the top of the Ellendale Formation and lower part of the Linesman Formation, Derrick and Gellatly (1971) suggested that these two formations are conformable.

LATE PROTEROZOIC GLACIGENE ROCKS

Oscar Range Inlier

Elimberrie Formation (Ꝑb)

The Elimberrie Formation outcrops in the Oscar Range Inlier between Mount Wynne Creek and the Tunnel Creek road. The formation has been described in detail by Derrick and Gellatly (1971). It is up to 1400 m thick and is characterized by the occurrence of carbonate at the base, with rocks of probable glacigene origin in the middle and upper parts.

The Elimberrie Formation unconformably overlies the Ellendale Formation of the Oscar Range Group. The unconformity is well exposed 4.5 km north of Stumpys Bore (Derrick and Gellatly, 1971). Contacts between the Elimberrie Formation and the Linesman Formation to the northeast, and the Whitewater Volcanics to the southeast, are faulted or sheared. The occurrence of glacigene rocks suggests a correlation between the Elimberrie Formation and one of the two Late Proterozoic glacigene sequences recognized throughout the Kimberley region (Dow and Gemuts, 1969; Plumb and Gemuts, 1976; Coats and Preiss, 1980; Plumb, 1981).

The lower part of the formation is characterized by dolomitic limestone, dololutite, dolarenite, quartzite, feldspathic sandstone, siltstone, and chert, with ironstone lenses. Above the carbonate the formation consists of phyllite, quartzite, quartz sandstone, feldspathic sandstone, diamictite, and thin ironstone interbeds. The diamictite occurs towards the top of the unit and consists of cobbles and boulders of quartzite up to 1 m in diameter in a sandy to silty matrix. The clasts are typically striated and may show percussion marks.

Ninety Seven Mile Formation (Ꝑn)

The Ninety Seven Mile Formation outcrops in the northwestern part of the Oscar Range Inlier, and has been described in detail by Derrick and Gellatly (1971). It consists of 1700 m of quartzite, diamictite, phyllite, amygdaloidal basalt and ?tuff. It is faulted against the Ellendale Formation. Based on the occurrence of acid tuff similar to the 'Spielers Volcanics' in the upper part of the succession, Derrick and Gellatly (1971) suggested that the succession might be equivalent to the Elimberrie Formation. In this study the 'Spielers Volcanics' are regarded as part of the Early Proterozoic Whitewater Volcanics. However, the possible glacigenic origin of parts of the sequence is consistent with the Ninety Seven Mile Formation being, at least in part, a lateral equivalent of the Elimberrie Formation.

The lowest part of the succession consists of phyllite, quartzite and conglomerate together with thin amygdaloidal basalt lavas and acid tuff. The conglomerate has a coarse sandy matrix. Higher in the sequence, diamictite is interbedded with phyllite, thick-bedded and cross-bedded quartzite, pebbly quartz sandstone, and feldspathic sandstone. Cobble- and boulder-sized clasts are typically quartzite, and are striated, grooved and locally polished. They are up to 0.5 m in diameter. Towards the top of the succession a green phyllite occurs that contains augen of quartz, and probably represents a felsic volcanic.

Mount House Group

The Mount House Group outcrops in the northeastern part of LENNARD RIVER. It unconformably overlies Kimberley Group rocks. It has been described by Derrick and Playford (1973), Coats and Preiss (1980), and Plumb (1981). Derrick and Playford (1973) tentatively correlated the lowest unit, the Walsh Tillite, with the Late Proterozoic Landrigan and Moonlight Valley Tillites recognized in the east Kimberley (see also Plumb and Gemuts, 1976, Plumb, 1981).

Coats and Preiss (1980) reassessed the stratigraphy and geochronology of the Late Proterozoic glacigene sequences of the Kimberley region. On lithological grounds they correlated the Mount House Group with the Louisa Downs and Duerdin Groups in the east Kimberley, and together these form the upper of two glacial sequences. The lower sequence is represented only by the Kuniandi Group. The upper sequence corresponds to the Marinoan glaciation, and the lower sequence to the Sturtian glaciation in central Australia. A Rb–Sr date of 670 ± 84 Ma has been obtained from the Throssel Shale (Bofinger, 1967; Coats and Preiss, 1980).

The Walsh Tillite outcrops above striated glacial pavements that indicate ice movement from the north and northeast. The tillite is of unequivocal terrestrial origin, being deposited by a continental ice sheet in an area of low relief (Plumb, 1981). Deposition took place close to the edge of a marine basin where transgression accompanied glacial retreat.

Walsh Tillite (ꝐUw)

The Walsh Tillite is exposed from east of Mount House Homestead to the Precipice Range. The formation ranges in thickness from 10 m to more than 185 m. The lower part is a diamictite made up of striated pebbles, cobbles and boulders that are predominantly quartzite, with lesser amounts of siltstone, dolomite and igneous rocks, in a green sandy, or purple silty matrix. The upper part of the unit has a purple shaly matrix with scattered pebbles and cobbles. The tillite is overlain by a thinly laminated, pale cream, yellow or pink dolomite up to 10 m thick. Plumb (1981) reports the occurrence of stromatolitic dolomite in the Mount Caroline area, near the northeast corner of the sheet.

A conglomerate outcropping on the northeast flank of the Isdell Range may be part of the Walsh Tillite (cf. Derrick and Playford, 1973).

Traine Formation (ⱣUa)

The Traine Formation conformably overlies the Walsh Tillite northeast of Mount House Homestead. South of the homestead it is overlapped by the Throssel Shale. The unit is up to 15 m thick and consists of massive medium- to coarse-grained lithic sandstone containing scattered glacial erratics. Ice-rafted boulders up to 2.5 m across are present (Plumb, 1981).

Throssell Shale (ⱣUt)

The Throssell Shale overlaps from the Traine Formation onto the Walsh Tillite southwest of Mount House Homestead. The unit is 230 m thick and consists of blue-grey, poorly laminated micaceous siltstone, with minor shale interbeds. The upper part is more sandy, with fine-grained, flaggy, grey-green laminated micaceous sandstone interbeds.

Estaughs Formation (ⱣUe)

The contact between the Throssell Shale and the overlying Estaughs Formation is gradational. The unit is at least 110 m thick and consists of purple-grey, fine- to medium-grained micaceous sandstone beds up to 50 cm thick, interbedded with green siltstone beds. The highest unit preserved is a blocky, white orthoquartzite exhibiting tabular cross-bedding.

KING LEOPOLD OROGENY

The spectacular folds and faults in the King Leopold Ranges are in rocks of the Early Proterozoic Kimberley Basin succession and Late Proterozoic glacigene rocks above the Hooper Complex. The King Leopold Orogeny was responsible for this deformation (D_4). It also reactivated faults and shears in the Hooper Complex basement, and folded and faulted the ?Middle Proterozoic sedimentary sequences and Late Proterozoic glacigene rocks in the Oscar Range Inlier.

The age of D_4 is constrained by the age of Late Proterozoic glacigene rocks at about 670 Ma and the initiation of the Canning Basin during the Early Ordovician (Yeates et al., 1984).

Precipice Fold Belt (D_4)

The fourth deformation event involved southwest-directed thrusting and large-scale folding. It produced the Precipice Fold Belt along the southwest margin of the Kimberley Basin (Griffin and Myers, 1988a,b; Griffin, 1989; Tyler and Griffin, 1990). This belt is generally less than 25 km wide although it reaches a maximum width of 40 km near Mount Ord. The intensity of the deformation decreases to the northeast. Folding extends to the northwest as far as Mount Hart Homestead on CHARNLEY and to the southeast onto LANSDOWNE and MOUNT RAMSAY.

Large-scale open warping of the Kimberley Basin succession, which predates the unconformity beneath the Mount House Group, occurs in the northeast corner of the sheet and has been attributed to D_3. Within the Precipice Fold Belt the orientations and styles of folds in both the Kimberley Basin succession and the Mount House Group are consistent with only one major deformation, which affected both groups of rocks. An axial-plane cleavage (S_4) in the underlying Kimberley Basin rocks can be traced through the unconformity into the overlying glacigene rocks.

The Inglis Fault (Griffin and Myers, 1988a, b) is a low-angle thrust which forms the contact between the Hooper Complex and the Kimberley Basin. It is the sole thrust to the Precipice Fold Belt and follows the pre-existing unconformity, which is preserved on LANSDOWNE to the east. Nowhere is an unconformable relationship preserved on LENNARD RIVER, and the thrust contact extends over a distance in excess of 300 km (Griffin and Myers, 1988a, b; Griffin, 1989; Tyler and Griffin, 1990). Older D_3 foliations which dip steeply to the southwest in the Hooper Complex have been deflected by the Inglis Fault so that they now dip steeply to the northeast. Shear zones, which can display S–C fabrics (Berthe et al., 1979), are developed on bedding surfaces in the sedimentary rocks which overlie the Inglis Fault. The S_4 cleavage is deflected by the shear zones to give a consistent sense of movement to the south-southwest (Griffin and Myers, 1988a, Griffin, 1989).

Folds and thrusts trend west-northwest and fold axial surfaces dip, gently to steeply, to the north-northeast. Axial surfaces may also dip steeply south-southwest but the folds maintain a southwest vergence, and this oversteepening is interpreted as the result of ramping of both the Inglis Fault and the Broadhurst Fault. Fold axes tend to be sub-horizontal. An S_4 axial-plane cleavage is well developed. Immediately above the thrusts, folds are recumbent and display rounded hinges. At higher levels above thrusts, folds are more upright with sharp hinges. This relationship is well exposed in the Lennard River Gorge where the O'Donnell Formation has been thrust over Hart Dolerite.

The next major fault structure above the Inglis Fault is the Broadhurst Fault, which extends along the front of the King Leopold Sandstone outcrop from Mount Chalmers to The Rocks. This fault is steep and places younger rocks on older rocks which, as pointed out by Stewart (1988), is a relationship typical of normal faults. However, small-scale structures associated with the fault are consistent with southwest-directed thrusting. Movement on the Broadhurst Fault appears to post-date that on the Inglis Fault, and it can be interpreted as an out-of-sequence thrust (Coward, 1980) developed above the footwall ramp. Out-of-sequence thrusts can place younger rocks on already folded and thrusted older rocks. K. A. Plumb (pers. comm., 1991) has reported a rotated early cleavage south of Mount Ord and Bold Bluff, which is consistent with this interpretation.

Backthrusts, and associated synclinal structures (Silent Grove Syncline, Bold Bluff Syncline) have developed above the Broadhurst Fault at Mount Frank and around Mount Ord (the Honeysuckle Fault). At this relatively high structural level, medium-scale box folds and kink bands are developed and are well exposed where gorges cut through the ranges. Elsewhere these structures form small scarps in otherwise flat-lying beds and are recognizable as distinct lineaments on aerial photographs. At Pittard Bluff a similar thrust–backthrust–syncline system has developed (Pittard Fault–Pandanus Fault–Fitzroy Syncline).

Fault sets which appear to have steep dips, and which trend north-northwest, north, east-northeast and east, are also present. The north-trending faults pass into older faults in the Hooper Complex and may have developed from slight movement on these older structures during erosion and uplift.

Oscar Range Inlier

The Oscar Range Inlier is cut by several west-northwest-trending shear zones (Fig. 1). The most northeasterly of these separates the Christopher Formation from the rest of the inlier. The Linesman Formation is entirely fault-bounded. At the southwest margin of the inlier the Spielers Shear Zone separates the Elimberrie, Ellendale and the Ninety Seven Mile Formations from the Whitewater Volcanics. A splay from this structure separates the Ninety

Seven Mile Formation from the Ellendale Formation. A shear zone truncates the northwest end of the Le Lievre Anticline.

Highly flattened and lineated diamictite is associated with shear zones cutting the Ninety Seven Mile Formation (Derrick and Gellatly, 1971). Shearing is also prominent in the Elimberrie Formation and the Whitewater Volcanics with lineations plunging, at shallow to moderate angles, to the southeast.

Only one phase of folding has been recognized which affects the Oscar Range Group, the Elimberrie Formation and the Ninety Seven Mile Formation. Tight to isoclinal folding is well developed at all scales. The principal large-scale fold structure is the Le Lievre Anticline (Fig. 1). This structure is a west-northwest-trending overturned anticline. Its axial surface dips steeply to the west-southwest, and its axis plunges at a moderate angle to the east-southeast. To the northwest associated medium-scale structures plunge to the west-southwest, although the main fold is truncated by faulting. Northwest-trending medium-scale folds deform the Linesman Formation.

Small-scale folding is well developed in the Ellendale and Elimberrie Formations. An axial-plane cleavage (S_4) dips moderately to steeply to the west-southwest. Folds typically plunge at moderate angles to the east-southeast or, less frequently, to the west-northwest.

Folds of the Linesman Formation are oriented en echelon to adjacent shear zones (Fig. 1), consistent with sinistral strike-slip movement (Wilcox et al., 1973). Elsewhere in the inlier, the trends of the fold axial planes and the shear zones are subparallel and consistent with a strong compressional component to the deformation. Tyler and Griffin (1990) reported asymmetrical tails on pebbles in conglomerates indicating south-block-up movement.

Shaw et al. (1992) report that the last movement on the Spielers Shear produced a weak fabric asymmetry and down-dip stretching lineation consistent with northeast-directed thrusting.

Metamorphism (M_4)

In the Hooper Complex, east of Mount Joseph and to the north of the Granite Range, andalusite is locally replaced by intergrowths of chloritoid and muscovite. Throughout the medium-grade rocks, large, randomly oriented chlorite crystals are present overgrowing all foliations, and some garnet porphyroblasts are partially replaced by chlorite intergrowths. Biotite porphyroblasts in low-grade metasedimentary rocks show partial replacement by chlorite, muscovite, and quartz.

In the Oscar Range, Derrick and Gellatly (1971) reported assemblages in pelites characterized by chlorite, muscovite, and biotite. Assemblages in reactivated fault zones such as the Spielers Shear are consistent with metamorphism under greenschist facies conditions (Shaw et al., 1992).

Discussion

The King Leopold Orogeny (D_4) is related to Late Proterozoic to Early Palaeozoic sinistral strike-slip movements on northeast-trending faults in the Halls Creek Orogen, described by Dow and Gemuts (1969). Southwestward movement of the Kimberley Basin has reactivated southwest-dipping Yampi Orogeny structures. A sinistral transpressive regime (Sanderson and Marchini, 1984) developed in the King Leopold Orogen as a result of clockwise rotation of the Kimberley Basin (Tyler et al., 1991), with blocks within the Hooper Complex moving to the west and being thrust under adjacent Precambrian basement rocks that presumably underlie the Canning Basin. This probably occurred in the latest Proterozoic consistent with K–Ar ages of c. 560 Ma for cleavage formation reported by Shaw et al. (1992).

The structure of the Precipice Fold Belt is a regional-scale ramp anticline (Boyer and Elliott, 1982). The Inglis Fault varies from a steep to a relatively flat-lying structure. Where the contact is steep the granitoid rocks in the underlying Hooper Terrane contain steeply dipping D_2/D_3 shear zones and an associated foliation. But, where the contact is shallow-dipping, the underlying Hooper Complex rocks show little evidence of shearing. This implies that the pre-existing shear zones in the Hooper Complex have controlled the orientation of the Inglis Fault (Tyler and Griffin, 1990). Relative uplift of some 4 km of the base of the Kimberley Basin succession can be inferred between Mount Broome and Mount House, and probably reflects the presence of an open D_3 monocline that controlled ramping of the thrust system. There is no evidence that D_3 fault structures cut up into the Kimberley Basin succession on LENNARD RIVER. Late thrusting on the Spielers Shear apparently occurred in the latest Cambrian to Early Ordovician, giving K–Ar ages of c. 500 Ma (Shaw et al., 1992).

Dolerite dykes

A second suite of dolerite dykes (d_2) is recognized on LENNARD RIVER. They intruded both the Hooper Complex and the deformed Kimberley Basin succession, and are distinguished from the earlier suite (d) because they are unmetamorphosed, i.e. they post-date M_2. Two major orientations are recognized; those parallel to the north-northwesterly D_3 shear zones, and those with a northerly trend which cut the early dykes east of McSherry Gap. One of the most prominent is the dyke which cuts through Bell Gorge, located on the northern edge of LENNARD RIVER. It extends 200 km from Hooper Creek in the south to Doubtful Bay, across CHARNLEY to the north. A d_2 dolerite dyke, which intrudes the Kimberley Basin succession, outcrops west of Rifle Point. This dyke trends roughly northwest and is parallel to similar dykes on YAMPI (Tyler and Griffin, 1993) and CHARNLEY (Gellatly and Halligan, 1971).

There appears to be a complex period of dolerite dyke intrusion for these dykes that post-date the King Leopold Orogeny but do not intrude the Canning Basin succession. The freshest are olivine bearing and are the preferred material that is quarried as ‘black granite’ ornamental stone. These dykes generally trend north-northwest. The dyke at Bell Gorge is an unusual coarse-grained rock containing pyroxene surrounded by pale-green amphibole, together with graphic intergrowths of quartz and feldspar. Some other dykes are possibly older with evidence of alteration involving secondary chlorite and albite, together with saussuritized feldspar cores and uralitized cores.

PHANEROZOIC GEOLOGY

Upper Palaeozoic and Triassic sedimentary rocks outcrop unconformably on the Proterozoic rocks, and underlie the surficial sediments in the southwestern half of LENNARD RIVER. They form part of the Lennard Shelf and Fitzroy Trough which in turn are part of the much larger Canning Basin (Purcell, 1984b; Middleton, 1990).

Devonian rocks are exposed as an exhumed reef complex around the Oscar Range, to the north on the Oscar Plateau, and in the Napier Range (Guppy et al., 1958; Playford and Lowry, 1966; Derrick and Playford, 1973; Playford, 1980, 1984; Playford et al., 1989).

Three prominent conglomerate units are associated with the reef complex. Scattered outcrops of the Late Devonian to Early Carboniferous Fairfield Group occur on the plains in front of the ranges (Derrick and Playford, 1973). Further to the southwest scattered low outcrops of sedimentary rocks occur amongst sand plains and shallow stream courses.

Cainozoic rocks include the diamond-bearing Miocene lamproite pipes, small outcrops of conglomerate, and the largely unconsolidated surficial sediments.

STRUCTURE OF THE NORTHEASTERN MARGIN OF THE CANNING BASIN

Deep seismic profiles across the northeastern margin of the Canning Basin (Drummond, 1989; Drummond et al., 1990) show that shallow, southwest-dipping structures define the contact with the underlying basement (Fig. 6). These are interpreted as normal faults which controlled the development of the northeastern margin of the Fitroy Trough. They have the same orientation as the major Early Proterozoic D_3 thrusts, thus indicating that these faults have been reactivated with normal displacements in the early Phanerozoic. The oldest sedimentary rocks in the Canning Basin are Ordovician (Middleton, 1990,) and their base, from the seismic profiles, is at a maximum depth of 12 km.

The Fitzroy Trough is structurally asymmetric with its northeastern margin clearly defined by the Oscar Fault which follows the southwestern edge of the Oscar Range. Very deep reflectors on line with this fault appear to cross the Moho (Fig. 6). The Lennard Shelf, which is much shallower than, and northeast of, the Fitzroy Trough, is probably also controlled by similar southeast-dipping faults that are parallel to the earlier D_3 faults. Relatively little movement is apparent on faults on the northeastern margin of the Canning Basin (e.g. Oscar Fault), whereas the Fenton Fault (southwest of LENNARD RIVER) on the southwestern margin of the Fitzroy Trough is clearly listric and caused sedimentary sequences within the trough to thicken and rotate towards the fault (Fig. 6). Listric faults extend into a horizontal detachment at 10–15 km depth which possibly makes use of an older, Yampi Orogeny (D_3), mid-crustal detachment (Fig. 1; Tyler and Griffin, 1990).

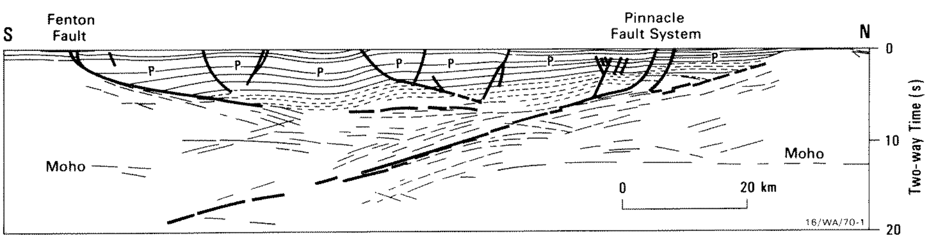


Figure 6. Interpreted line drawing of the easternmost seismic section across the Fitzroy Trough. Faults and detachments are shown in thick lines, and formation boundaries are shown in thinner lines (after Drummond, 1989; Drummond et al., 1990)

DEVONIAN

Reef complexes

Overview

Devonian limestones forming part of the Devonian 'Great Barrier Reef' of the Canning Basin are well exposed in the rugged Napier and Oscar Ranges, the Oscar Plateau, and the plains fronting the ranges. The best section through the reefal limestones is exposed in Windjana Gorge, but there are many other excellent exposures, including those at Dingo Gap and around Elimberrie Spring.

Early references to the Devonian geology are quoted by Playford and Lowry (1966), and Playford (1980). There have been a number of contributions since then of relevance to LENNARD RIVER, principally those by Buchhorn (1986), Cockbain (1984), Hurley (1986), Hurley and Van der Voo (1987, 1990), Hurley and Lohman (1989), Kerans (1985), Kerans et al. (1986), Playford (1981, 1984), Playford et al. (1976, 1989), Rigby (1986), and Wallace (1987). The regional geology of the basin is described by Towner and Gibson (1983), and much relevant information is contained in the Canning Basin Symposium volume edited by Purcell (1984a).

The oldest dated reef complexes on LENNARD RIVER are of Frasnian (early Late Devonian) age, although it is possible that they first developed in this area during the Givetian (Middle Devonian). The Napier and Oscar Range reef complexes formed as reefal limestone platforms fringing a mountainous landmass of Precambrian rocks — the King Leopold Orogen and Kimberley Basin — and around a large island of Precambrian rocks now forming the core of the Oscar Range. Basement topography, commonly fault controlled, is thought to have been important in localizing the platforms.

Most of the complexes grew as reef-rimmed platforms flanked by steep marginal slopes which descended to depths of as much as several hundred metres in the adjoining basins. Depositional dips in the marginal-slope deposits were commonly up to 35°–40° in loose debris, and up to near-vertical where cyanobacterial binding was involved. Water depths on the platforms were generally less than 5 m, and some areas were intertidal.

The morphology and facies nomenclature of the complexes are illustrated in Figure 7, which also shows the extent of strong, early, submarine cementation around the platform margins and upper marginal slopes. This cementation was very important in developing and maintaining the high-relief reef margins and very steep reefal slopes (Playford, 1980; Kerans et al., 1986).

Three basic facies are recognized in the reef complexes: platform, marginal-slope, and basin facies. The platform facies is subdivided into reef-margin, reef-flat, back-reef, and bank subfacies, and the marginal-slope facies into reefal-slope, fore-reef, and fore-bank subfacies.

The reef-margin and reef-flat subfacies form narrow zones around most platform margins. The reef-margin deposits are massive limestones, which were subject to strong early cementation, and were constructed by frame-building stromatoporoids and cyanobacteria, with some corals, in the Givetian and Frasnian, and by cyanobacteria alone in the Famennian. They show little or no bedding, and are generally only 10–50 m wide, whereas the reef-flat deposits are bedded and may extend for hundreds of metres behind the platform margins. Contacts between the various subfacies are generally gradational and interfingering.

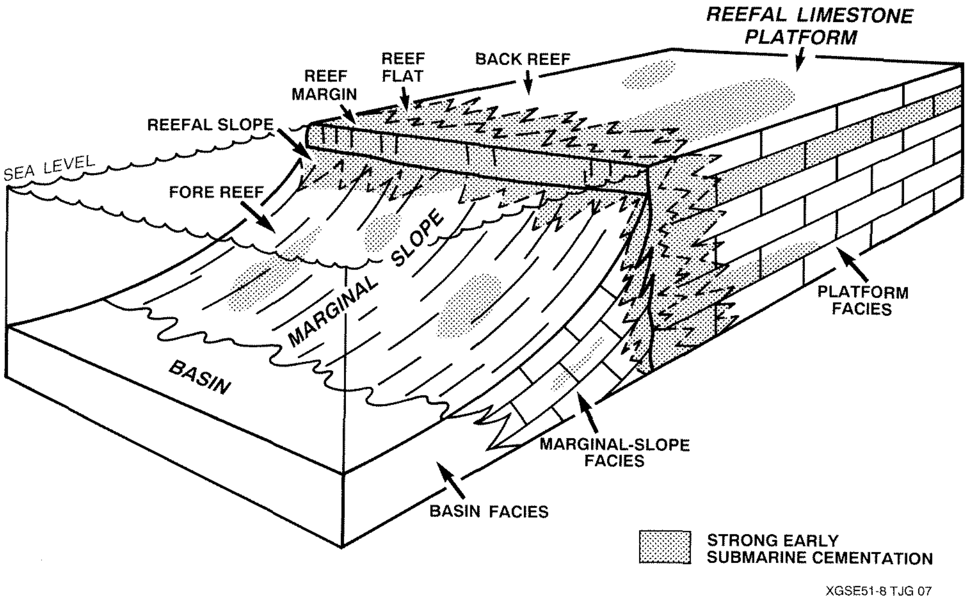


Figure 7. Block diagram illustrating morphology of the reef complexes, facies subdivisions, and distribution of early submarine cementation (after Playford et al., 1989).

Contemporary fracturing of the strongly cemented limestones around the platform margins and upper marginal slopes caused periodic submarine landsliding of large sections of reef, giving rise to massive debris flows and large allochthonous reef blocks in the marginal-slope deposits, and turbidites in the basin deposits (Fig. 8), which are especially well displayed in the Dingo Gap area of the Napier Range. Where the fractured limestone remained in place, fissures were variously filled at an early stage with cement, detrital sediment, and organic growths, to form extensive networks of neptunian dykes (Playford, 1984; Playford et al., 1989; Hurley, 1986; Kerans et al., 1986; Wallace, 1987).

Early cementation and contemporary earthquakes are believed to have been the most important factors controlling this early fracturing, combined with one or more of the following: unsupported reef scarps, compaction of basin sediments, and periodic slippage along marginal-slope bedding. In some parts of the Napier and Oscar Ranges, discrete marginal-slope beds with abundant debris flows and allochthonous beds can be traced for many kilometres. It is thought that most reflect periods of strong seismicity causing extensive platform-margin collapse and associated neptunian fissuring. However, some may represent lowstand deposits associated with intervals of lowered sea level.

Contemporary faulting is also believed to have led to mountainous topography in the adjoining landmass of the King Leopold Orogen and Kimberley Basin, which was the source of the enormous masses of terrigenous boulder conglomerate that interfinger with some Frasnian and Famennian reef complexes (Playford and Lowry, 1966; Playford, 1984; Botten, 1984). These fanglomerate complexes reflect environments ranging from proximal alluvial fans through fan deltas to submarine fans. In some places the conglomerates extended right through the reefal platforms, reaching into the deep water of the adjoining basins. Sandstones and finer terrigenous deposits also interfinger with all facies of those reef complexes in some areas.

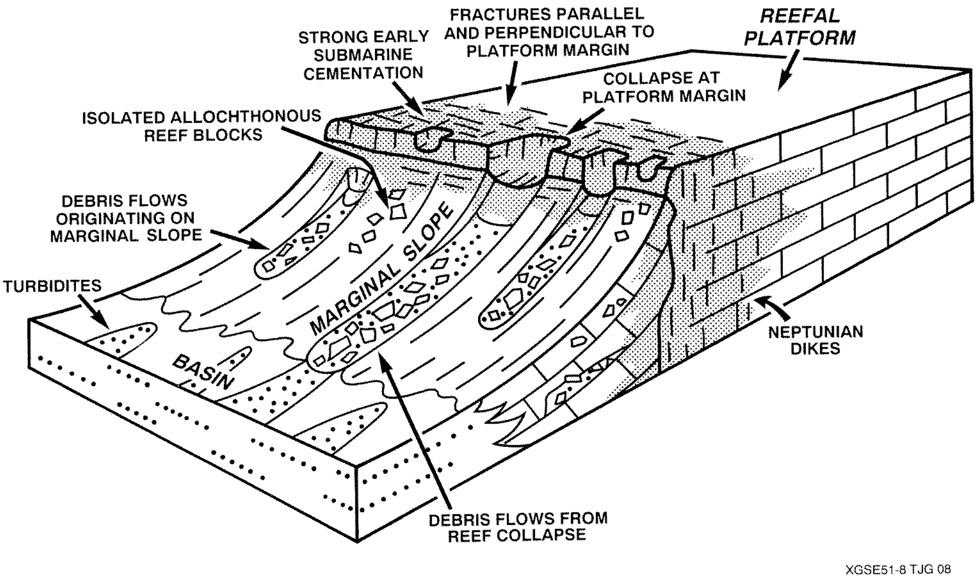


Figure 8. Block diagram illustrating the development of debris flows, allochthonous reef blocks, turbidites, and neptunian dykes (after Playford et al., 1989)

The evolution of the Oscar Range and Napier Range reef complexes through time is illustrated diagrammatically as a model cross section in Figure 9. Two cycles of platform development are recognized: the Frasnian Pillara cycle, characterized by essentially vertical platform growth followed by widespread drowning and backstepping; and the Famennian Nullara cycle, characterized by strongly advancing platforms. Elsewhere on the Lennard Shelf the Pillara cycle can be shown to have begun in the Middle Devonian (Givetian), and this may also have been the case on LENNARD RIVER. However, as noted previously, no definitive evidence of Givetian rocks has been found on this Sheet area.

The total maximum thickness of platform deposits of the two cycles on the Lennard Shelf is about 2000 m, while seismic data suggest that contemporary basinal facies, largely comprising terrigenous clastics and turbidites, are up to 2500 m thick. However, the total maximum thickness of these deposits exposed on LENNARD RIVER seems unlikely to exceed 1000 m.

History of reef development

As outlined by Playford et al. (1989), the growth history of the reef complexes was one of continuing relative rise in sea level, reflecting major subsidence during deposition. Eustatic sea-level changes were also thought to have been important, but their overall effects were subordinate to those of basin subsidence. Emergence of the platforms probably occurred only briefly and rarely; the most significant regression that has been identified was at the Frasnian–Famennian boundary, when the platforms emerged briefly several tens of metres above sea level, while deposition continued without break in the adjoining basins (Hurley, 1986; Playford et al., 1989).

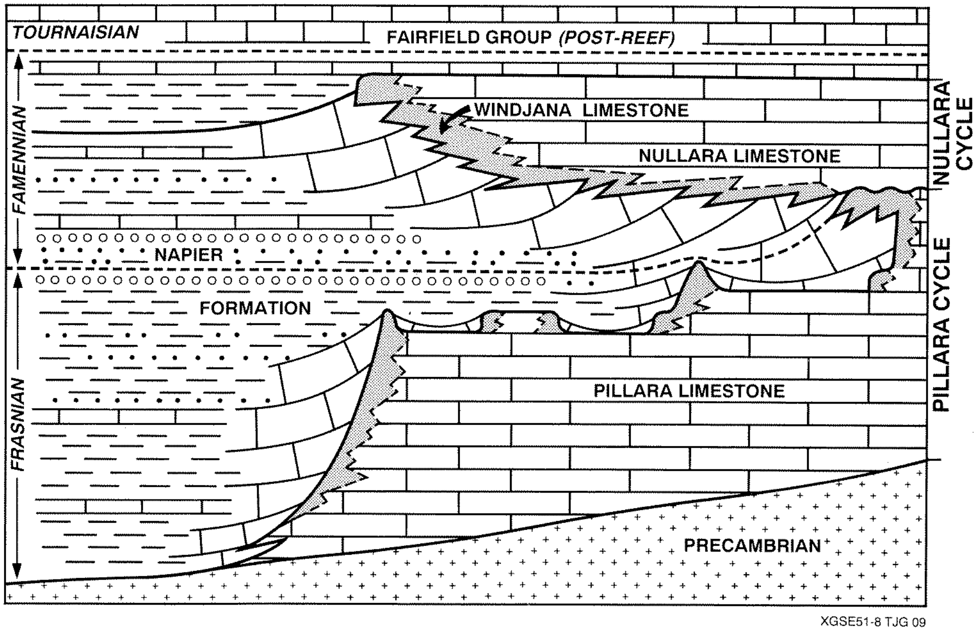


Figure 9. Diagrammatic section illustrating the development of the reef complexes through time (modified after Playford et al., 1984)

The oldest platforms of the Pillara cycle began growth as low-relief stromatoporoid, coral, and cyanobacterial banks and biostromes, with little or no reef around their margins. They were flanked by, and interfingered with, gently dipping marginal-slope limestone and shale, which extended into shallow basins (water depths a few tens of metres) containing dark shales. Early bank deposits of this type, of early Frasnian (and conceivably late Givetian) age, are exposed in the Devonian embayment near the southern boundary of LENNARD RIVER, immediately north of Brooking Creek (Hurley, 1986).

The rate of relative rise in sea level increased significantly during the early to mid-Frasnian, when the platforms generally grew vertically upward, with well-developed reef margins, adjoining progressively deeper basins, with water depths of up to several hundred metres (Playford, 1980). These high-relief platforms were flanked by steeply dipping marginal-slope deposits, with large amounts of reef-derived debris, including spectacular debris-flow deposits. The marginal-slope deposits progressively mounted up the reef scarps, forming platform-margin depositional unconformities.

In the late Frasnian there were two major and several lesser episodes of abrupt relative sea-level rise associated with widespread drowning of platforms, backstepping of platform margins, and the development of isolated platform atolls and pinnacle reefs.

A small backstepping episode in the late Frasnian is evidenced at the 'Classic Face' in Windjana Gorge, where the margin retreated by only some 10 m compared with hundreds of metres in examples at some other localities (Playford et al., 1989).

In latest Frasnian times, when most of the platform areas had been drowned, there was a marked deceleration in the rate of relative rise in sea level, and the remaining platforms advanced nearly horizontally.

This short interval was followed, at the Frasnian–Famennian boundary, by a very brief sea-level fall of a few tens of metres which exposed the upper surfaces of the platforms to subaerial erosion. The total amount of section eroded away at that time probably amounted to only a few metres, while deposition, although condensed, continued without break on the adjoining marginal slopes and basin floors (Druce, 1976; Playford et al., 1984). The erosion surface on the platforms is generally planar in the northwestern Oscar Range (Hurley, 1986), but at the only other locality where it is exposed, behind Chedda Cliffs in the Napier Range, it shows evidence of mild karstification, with the development of small sinkholes as much as a metre deep.

The Famennian platforms of the Nullara cycle were established on the eroded Frasnian platforms of the Pillara cycle, maintaining the same style of reefal sedimentation with comparable platform, marginal-slope, and basin facies. The main change was in the platform-building reefal biota. The reef-building stromatoporoid–cyanobacteria–coral association of the Pillara cycle was replaced almost entirely by cyanobacteria in the Nullara cycle (Playford et al., 1989).

During most of the Famennian there was a moderate relative rise in sea level and the cyanobacterial platforms advanced basinward for as much as 3 km, interfingering with the marginal-slope deposits over which they grew. Water depths in the adjoining basins became progressively shallower, but are thought to have exceeded 100 m in many areas.

The rate of relative sea-level rise increased near the end of the Nullara cycle, so that the platform margins grew vertically upward, forming steep reef scarps. Termination of the Nullara cycle and initiation of the mixed siliciclastic–carbonate depositional sequence of the Fairfield Group probably resulted from a sudden rise in sea level. The steep scarps in reef limestone that now form the margins of the Oscar and Napier Ranges at several localities, including Morown Cliff, Chedda Cliffs, and Windjana Gorge, are believed to be essentially the exhumed reef scarps from the final phase of late Famennian reef growth. Cessation of reef growth may have resulted from an abrupt fall in sea level.

Four formations are recognized in the reef complexes on LENNARD RIVER; the Pillara Limestone, Napier Formation, Windjana Limestone, and Nullara Limestone (Fig. 9).

Pillara Limestone (Dp)

The Pillara Limestone consists of well-bedded back-reef deposits, fringed by bedded reef-flat and massive reef-margin subfacies. It ranges from mid-Givetian to late Frasnian in age elsewhere on the Lennard Shelf, but the oldest dated part of the formation on LENNARD RIVER is of Frasnian age.

Most of the back-reef part of the unit consists of stromatoporoid biostromes (dominated by *Amphipora* and *Actinostroma*), fenestral limestone, oolite, and peloidal limestone interbedded in areas adjoining Precambrian rocks with terrigenous deposits of sandstone, siltstone, and conglomerate. These well-bedded limestones are commonly fringed around the platform margins by a narrow belt of bedded reef-flat and massive reef-margin limestones. The reef limestones were constructed by frame-building stromatoporoids (mainly *Actinostroma* and *Stachyodes*) and cyanobacteria (mainly *Renalcis* and lesser *Sphaerocodium*), with only minor corals on LENNARD RIVER.

The backreef deposits of the Pillara Limestone commonly include well-developed cycles, notably at Windjana Gorge (Read, 1973; Playford, 1981; Playford et al., 1989). At this locality, 31 carbonate–terrigenous cycles have been measured over 153 m of section, ranging in thickness from 1.3 to 12.6 m, and averaging about 5 m. The lower part of each cycle consists of stromatoporoid limestone and dolomite, containing large heads of *Actinostroma* and abundant *Amphipora*. This grades up into fenestral limestone with large gastropods and becomes progressively more sandy, passing at the top of each cycle into laminated red and yellow calcareous sandstone, some of which exhibits fenestral fabrics and root casts. These are shoaling-upward cycles, beginning in each case with an abrupt relative rise in sea level followed by gradual shallowing through sedimentation until the sediment surface was built up to sea level or slightly above.

The average duration of each cycle is estimated to be about 50 000 years, based on time-averaging of the Frasnian section, assuming that the latest Frasnian section exposed at Windjana Gorge was deposited over an interval of about 1.5 million years (Playford et al., 1989).

Napier Formation (Dn)

The Napier Formation on LENNARD RIVER consists of crudely bedded to well-bedded limestone, with some dolomite and interbeds of terrigenous clastics. Terrigenous interbeds are developed mainly in the Napier Range area, adjoining Precambrian rocks of the King Leopold Orogen. On LENNARD RIVER the unit ranges from early Frasnian to late Famennian in age.

The Napier Formation constitutes the marginal-slope facies (reefal-slope and fore-reef subfacies) of the Napier Range and Oscar Range reef complexes.

The fore-reef subfacies consists largely of debris derived by contemporary erosion of the Pillara platforms during the Frasnian, and the Windjana–Nullara platforms during the Famennian. It includes large allochthonous reef blocks and massive debris-flow deposits that resulted from collapse of parts of the platform margin, or of early lithified parts of the marginal-slope limestones (Playford, 1981; Playford et al., 1989).

The reefal-slope subfacies was deposited at the top of the marginal slopes, immediately adjoining the limestone platforms. Depositional dips ranged up to near vertical and resulted from the growth of layers of cyanobacteria (some forming columnar stromatolites) and sponges, which formed the reefal frameworks and trapped and bound platform-derived sediments.

In places the sponges and cyanobacteria built up large biohermal mounds on the marginal slopes or on top of drowned Frasnian pinnacle reefs. The Elimberrie Bioherms (*Dns*) formed in this way over drowned pinnacle reefs on the north side of the Oscar Range reef complex. Similar, although generally smaller, biohermal developments occur in the Napier Formation along the Napier Range, where they range from small 'antiform' stromatolites to large depositional anticlinal noses.

The sponge–stromatolite bioherms and reefal slopes were principally developed in the late Frasnian and early Famennian part of the Napier Formation, and may have flourished at that time because of the mass extinction of metazoans (and possibly of the higher plants) that occurred at or near the close of the Frasnian (Playford et al., 1989; Hurley and Van der Voo, 1990).

Windjana Limestone (Dw)

The Windjana Limestone consists of massive to crudely bedded reef limestone and minor dolomite, of Famennian age. The reefs were built primarily by cyanobacteria, principally *Renalcis* and *Sphaerocodium*, with only minor contributions from stromatoporoids. There was contemporaneous deposition of large volumes of microcrystalline calcite in the reefs (Kerans, 1985; Kerans et al., 1986; Hurley, 1986; Hurley and Lohman, 1989) to form rigid, wave-resistant structures. The type section of the formation is at the west end of Windjana Gorge, where it is very well exposed in cliffs up to 70 m high.

The Windjana Limestone reefs grew outwards, at low angles, over the equivalent marginal-slope deposits of the Napier Formation, the contacts being interfingering and gradational. Passing into the platform interior in the other directions the Windjana Limestone also interfingers and grades into back-reef deposits of the Nullara Limestone.

The front of the Windjana reefs was commonly a near-vertical scarp, up to several tens of metres high. The reef scarp, as it was developed when reef growth ceased in the late Famennian, is exhumed at a number of places along the front of the Oscar and Napier Ranges, notably at Morown Cliff, Chedda Cliffs, and Windjana Gorge.

Nullara Limestone (Dl)

The Nullara Limestone consists of fenestral limestone and oolite of Famennian age, which have been partly dolomitized in some areas. The Nullara Limestone is the back-reef equivalent of the Windjana Limestone.

The type section of the Nullara Limestone is at the northwestern end of the Oscar Range, where it is 134 m thick (Hurley, 1986). The formation is also exposed at various localities along the Napier Range, notably behind Chedda Cliffs, but it has been stripped off by erosion over most of the range. The original total thickness of the unit in this area is estimated to have been about 400 m.

Shoaling-upward cycles occur in the Nullara Limestone in some areas, including the type section in the northwestern Oscar Range (Hurley, 1986).

Conglomerates

Three areas of Late Devonian boulder conglomerate adjoin the southwestern limit of exposure of the Precambrian Hooper Complex (Derrick and Playford, 1973). They are unconformable on (and in part faulted against) the Precambrian rocks, and have complex interfingering and unconformable relationships with limestone of the Late Devonian reef complex (Playford, 1980; Botten, 1984). Residual boulders obscure outcrop of the conglomerate units which form large, rounded, spinifex-covered hills rising up to 200 m (in the case of Mount Behn) above the plains.

Van Emmerick Conglomerate (Dv)

The Van Emmerick Conglomerate in the northwest occupies an area up to 14 km long and 8 km wide. It consists of a basal boulder conglomerate overlain by a conglomerate and sandstone sequence up to 300 m thick. The clasts in the basal unit average 35 cm and range to 1 m in diameter, and are mainly quartzite and sandstone from the Kimberley Basin succession (Botten, 1984). Clasts in the upper unit average 10 cm across and include mainly granitoid, schist and acid volcanics from the Hooper Complex. The conglomerate is clast supported (up to 75%) with a sandstone matrix derived from granitoid.

Behn Conglomerate (Db)

The Behn Conglomerate is in the central part of LENNARD RIVER and is about 7 km wide and up to 300 m thick. Boulders are mainly quartzite and volcanics, lesser schist and granitoid, and minor limestone and vein quartz. Most are rounded to well rounded. The matrix is fine- to very coarse-grained, poorly sorted, lithic sandstone, part of which includes fossil debris.

Stony Creek Conglomerate (Ds)

The Stony Creek Conglomerate in the southeast corner of LENNARD RIVER is an elongate unit 12 km long which consists of boulder and pebble conglomerate dominated by granitoid clasts and lesser amounts of quartzite, vein quartz and foliated acid volcanics. Botten (1984) equates this unit with the Van Emmerick Conglomerate because both have a massive basal conglomerate overlain by a mixed conglomerate and sandstone unit.

Relationships

The basal unit of the Behn and Stony Creek Conglomerates interfingers with the Pillara Limestone (Derrick and Playford, 1973; Botten, 1984) and must be of Frasnian age. However, the upper unit of the Van Emmerick Conglomerate is regarded by Botten (1984) as upper Famennian to Tournaisian in age. This unit in the Van Emmerick and Stony Creek areas appears to both interfinger with and unconformably overlie the Famennian reef complex (Botten, 1984). Further work is needed to clarify these relationships.

The basal conglomerates are interpreted as fanglomerates, whereas the upper, finer grained units may be fluviatile and deltaic deposits (Botten, 1984).

LATE DEVONIAN TO EARLY CARBONIFEROUS

Fairfield Group (*DCf*)

The Fairfield Group is a poorly exposed unit of late Famennian to Tournaisian age, comprising an interbedded sequence of limestone, shale, siltstone, and sandstone. Some of the limestones are richly fossiliferous with a fauna of brachiopods, corals, and bryozoans. The thickness of the unit exceeds 1600 m in Ellendale 1 in the southwest part of LENNARD RIVER.

The Fairfield Group was originally defined by Playford and Lowry (1966) as the 'Fairfield Formation' which included the Carboniferous Laurel Formation of Thomas (1959) and the Devonian 'Fairfield Beds' of Guppy et al. (1958). Playford and Lowry (1966) found no basis for subdivision of their 'Fairfield Formation' in outcrop on LENNARD RIVER so consequently mapped it as a single depositional unit. Druce and Radke (1979) redefined the unit as the Fairfield Group, divided into three formations; the Gumhole Formation (latest Famennian), the Yellow Drum Sandstone (straddling the Devonian–Carboniferous boundary) and the Laurel Formation (Tournaisian).

The Fairfield Group is interpreted as a shallow-water deposit laid down conformably on the Devonian reef complexes. Extinction of the reef is now thought to have resulted from an abrupt fall in sea level. Previously it had been ascribed to either the infilling of the inter-reef basins by terrigenous sedimentation (Derrick and Playford, 1973), or an abrupt relative rise in sea level (Playford et al., 1989).

?EARLY CARBONIFEROUS

Conglomerate (*?Cg*)

A massive, poorly sorted, thin-bedded pebble conglomerate, conglomeratic sandstone, and quartz sandstone unit up to 20 m thick which forms small mesas above Scrutons Monzogranite north and east of Scrutons Yard, and low rounded outcrops are unconformable on the Oscar Range Group in the Oscar Range. These are possibly alluvial-fan deposits (Derrick and Playford, 1973) that developed adjacent to scarps of Early and Middle Proterozoic quartz-rich sedimentary sequences.

LATE CARBONIFEROUS TO EARLY PERMIAN

Grant Group (*CPg*)

The Grant Group forms small scattered outcrops within a large area of sandy soil in front of the Oscar Range and to the northwest up to Mount North. The Grant Group is interpreted to be up to 20 km wide beneath the cover along this northwest-trending zone.

Derrick and Playford (1973) described the Grant Group as predominantly massive, aqueoglacial, pale-brown, friable pebble sandstone which lies unconformably above the older rocks. Rock types include unsorted silty sandstone, conglomeratic sandstone, tillite, siltstone, shale, and varved rocks. A few marine fossils and wood fragments have been found (Derrick and Playford, 1973). The group is exposed as inselbergs such as Mount Percy, and also occurs as karst infillings in the Devonian reef complex. It is an excellent aquifer and artesian flow has been recorded from it in the Sixty-Seven Mile Bore. The Grant Group gradually thickens in the subsurface from the margins of the Devonian into the Fitzroy Trough to the south. A thickness of over 750 m was intersected in Ellendale 1.

PERMIAN

Poole Sandstone (*Pp*)

The Poole Sandstone is very poorly exposed in a zone up to 8 km wide southwest of the Grant Group. It consists of micaceous silty sandstone which is thinly bedded and generally contains cross-beds and ripple marks. The thickness is 103 m in Boronia 1. Plant remains have been found and the formation is partly marine in origin. The Poole Sandstone has some unconformable relationship with the Grant Group (Derrick and Playford, 1973).

Noonkanbah Formation (*Pn*)

The Noonkanbah Formation outcrops in low scattered ridges and underlies sandy soil southwest of the Poole Sandstone in a zone up to 20 km wide in the southwest quarter of LENNARD RIVER. It is 349 m thick in Philydrum 1, and consists of shale, siltstone, limestone, and sandstone which is conglomeratic towards the margin of the basin. This marine formation contains the richest Permian faunal assemblage of the Fitzroy Trough, and includes brachiopods, bryozoans, corals, crinoids, foraminifera and a few molluscs (Derrick and Playford, 1973). Minor disconformities exist with the underlying Poole Sandstone. The Noonkanbah Formation is gently folded and is affected by small transverse faults.

Liveringa Group (*Pl*)

Undivided rocks of the Liveringa Group (Middleton, 1990) dominate outcrop in large open folds in the southwest corner of LENNARD RIVER. Outcrop comprises extensively ferruginized micaceous silty sandstone and conglomeratic sandstone that lie conformably on the Noonkanbah Formation (Derrick and Playford, 1973). The Liveringa Group is 288 m thick in Kennedia 1. The uppermost part is most abundant on LENNARD RIVER, and contains a rich marine fauna.

TRIASSIC

Blina Shale (*Ꞧb*)

The Blina Shale is poorly exposed in the southwest corner of LENNARD RIVER; largely as float material in black-soil plains. It is a grey and brown siltstone, shale and sandy shale, and a bluish-grey shale in drillholes. It is about 300 m thick, contains marine fauna (e.g. *Ligula* sp. and fish vertebrae) and is probably unconformable on the Liveringa Group (Derrick and Playford, 1973).

CAINOZOIC

Fitzroy Volcanics (*Tfv*) (by J. D. Lewis)

About sixty small lamproite volcanic vents are known from LENNARD RIVER. They were previously regarded as being of Jurassic age (Derrick and Playford, 1973) but more recent K–Ar geochronology has established that they are 18–22 Ma and of Miocene age (Jaques et al., 1984b). A few are well exposed and form prominent landmarks (e.g. *Mount North, Prairie Hill East*) but most are concealed beneath several metres of Quaternary sand and were discovered during exploration for diamonds by a combination of stream-sediment sampling and airborne magnetic survey (Atkinson et al., 1984). Forty-six intrusions are present in the Ellendale Field; they intrude a northwest-trending subsurface extension of the Oscar Range block. A small concentration of large, unexposed vents occurs at Calwynyardah, on the southern margin of the sheet, and is associated with the Pinnacle Fault, the northeastern boundary fault of the Fitzroy Trough. Isolated lamproites intrude the granites of the Hooper Complex and the sedimentary rocks of the Lennard Shelf.

The vents are mostly filled by fine-grained lamproite lapilli tuffs, either bedded base-surge deposits in the larger vents, or chaotic tuff in the small vents. A central core of massive lamproite is present, and probably formed as a blister or lava lake in the open vent. Lamproite dykes or sills are rare.

Petrographically, the massive lamproites are of two varieties: leucite lamproite, in which leucite is the most abundant mineral; and olivine lamproite, with abundant olivine, and leucite rare or absent. The leucite lamproites are basic, fine to medium grained, and contain one or more of the following minerals: leucite, diopside, olivine, phlogopite, and K-Ti-richterite, with accessory apatite, chromite, priderite, jeppeite, wadeite, perovskite and shcherbakovite. Olivine lamproites are ultrabasic, porphyritic, and contain two phases of olivine (large anhedral macrocrysts of mantle origin, and euhedral microphenocrysts), poikilitic phlogopite, diopside, and K-Ti-richterite, with accessory apatite, chromite, perovskite, and wadeite. Both varieties have a formerly glassy or cryptocrystalline groundmass, commonly characterized by small flakes of tetraferriphlogopite. Rare diamond is present in many of the lamproite tuffs, but is found in potentially commercial quantities only in the olivine lamproite tuffs.

The lamproite magma is a small-volume melt of a metasomatized mantle, generated at depths of 150–200 km (Jaques et al., 1984a, 1986). It is ultrapotassic, and characterized by high contents of K, Ti, Zr, P, Ba, Rb, Sr, Ni, Cr, and LREE, and low Na, Ca, and Al; the K_2O/Al_2O_3 ratio is commonly greater than 1, and the K_2O/Na_2O ratio exceeds 10.

Mount North is a prominent small hill, about 90 m high, south of the Napier Range. It consists of a large central core of columnar jointed olivine–diopside–phlogopite–leucite lamproite, emplaced in bedded lamproite lapilli tuffs with thin sills of vesicular olivine–leucite lamproite. The central core is layered, with an upper tier of large columns 1–2 m in diameter, and a lower tier of smaller columns 30–60 cms in diameter. This is a cooling phenomenon in a single body of rock, and the upper surface of the core contains collapse structures over the former magma conduit.

Eighty One Mile Vent is similar in structure to Mount North, with a central core of phlogopite–leucite lamproite, and sills of richterite–phlogopite–leucite lamproite intruding bedded tuff deposits. The topography is reversed, with the central core forming a depression, surrounded by a low outcrop of sills and tuff about 20 m high. Volcanic structures identifiable in the tuff deposits include dropstones, cross-bedding, slumping and lahars.

Mount Percy is a hill of Permian Grant Formation sandstone which formed the vent wall for a small intrusion of phlogopite–leucite lamproite and lamproite tuffs on its eastern side. The hill is veined by small lamproite dykes, and large concentric dykes of brecciated sandstone. Much of the lower slopes on the eastern side of the hill are underlain by similar sandstone breccia of volcanic origin.

A number of unexposed lamproite vents in the Ellendale area are also associated with low mesas or partially outcropping rings of baked Grant Formation sandstone, which originally formed the vent wall. The diamondiferous olivine lamproite of *Ellendale 4* is surrounded by an almost complete ring of sandstone, while the olivine lamproites of *Ellendale 7, 9, 11 and 16*, and the leucite lamproite of *Ellendale 6,* are associated with partly exposed rings of indurated sandstone. *Ellendale 38* is a small plug of olivine–phlogopite–leucite lamproite intruding the reef limestone of the Oscar Range.

To the east of Ellendale, in the area of Leopold Downs Station, *Big Spring* is exposed as a low mound of brecciated granitic rock, with the characteristic green staining and veins of lamproite breccia and tuff. The outcrop is part of a large xenolithic mass enclosed within a concealed olivine lamproite vent 350 m in diameter, the largest of five vents in the immediate vicinity.

Prairie Hill East consists of two vents intruded along a probable fault line. A plug of olivine–diopside–leucite lamproite, 70 m in diameter, forms a small hill and intrudes Lennard Granite to the west and Devonian arkose and conglomerate to the east. One hundred and fifty metres to the north, a second small vent consists of a coarse breccia of partially remelted granite and small sills of olivine–richterite–leucite lamproite, with vent walls of brecciated granite and sandstone.

Old Leopold Hill is a dyke-like body of coarse richterite–diopside–phlogopite–leucite lamproite, with prominent small phenocrysts of diopside. The bulbous western termination of the intrusion forms a small dark hill in the surrounding pink granite. *Old Leopold West* is a poorly exposed vent, 800 m northwest of Old Leopold Hill, and forms a small depression on top of a granite 'whaleback'. The vent is filled with granitic breccia and olivine-rich leucite lamproite.

McKinnrick Hill lies on the Sandy Creek Shear and is a small plug of olivine–richterite–leucite lamproite, about 50 m in diameter. The lamproite contains abundant xenoliths of Whitewater Volcanics, the local country rock. *Mount Rose* is a zoned plug, 80 m in diameter, with an outer zone of fine-grained diopside–richterite–leucite lamproite and an inner zone of coarser diopside–phlogopite–leucite lamproite. The plug intrudes phyllites, which are undeformed and only slightly metamorphosed.

A complete description of the West Kimberley Lamproite Province is given in Jaques et al. (1986).

Warrimbah Conglomerate (*Tw*)

The Warrimbah Conglomerate is associated with the major present-day rivers in the southwest and outcrops on gentle hill slopes of granitoid north of Scrutons Yard where it forms low ridges. It is up to 20 m thick and consists of poorly consolidated boulder and pebble beds made up of water-worn quartzite (Derrick and Playford, 1973). Locally it is overlain by thin (< 2 m) ferruginous sandstone and pisolitic sandstone which in places outcrop independently of the boulder conglomerate.

Surficial deposits

Lateritic material (*Czl*), up to 2 m thick, consisting of ferruginous sandstone and pisolitic ironstone forms a thin cap over peneplained surfaces in southwest LENNARD RIVER (Derrick and Playford, 1973).

Semi-consolidated slope deposits and valley-fill (*Czc*) outcrop below scarps and in valleys where erosion has produced terraces above the current alluvium-filled stream channels.

Surficial deposits of travertine and tufa (*Czt*) form platforms and low ridges which have developed on Devonian calcareous formations.

Colluvial and alluvial material which is generally composed of unconsolidated, yellow and reddish brown soil, silt, sand, and gravel (*Czs*) covers valley floors and large plains. It is interspersed with treeless black soil plains (*Qb*) which are composed of heavy textured clay and silt.

Windblown sand (*Qs*) consisting of well-rounded quartz sand and minor iron oxides forms flats and aeolian seif dunes (Derrick and Playford, 1973)

Unconsolidated alluvium (*Qa*) consisting of silt, sand, and gravel occupies the channels and flood plains of the intermittent streams and rivers.

ECONOMIC GEOLOGY

LEAD AND ZINC

Production from the Narlarla Mine openpit (in Devonian limestone on the Barker River), which was operating between 1948 and 1966, included 2115 t of lead, 2867 t of zinc and

162 kg of silver from 11 033 t of ore (Blockley, 1971; Ringrose, 1989). Recent exploration has taken place along the length of the Devonian reef complex, in particular at Wagon Pass, 16 km to the northeast of Narlarla. This is Mississippi Valley-type mineralization similar to that currently mined at Cadjebut Mine located 40 km southeast of Fitzroy Crossing (Buchhorn, 1986; Ringrose, 1989; Murphy, 1990).

Galena and sphalerite occur in a vein 1 km northwest of the Top Spring copper prospect on the northeast limb of the Richenda Anticline. The galena gives Pb–Pb dates of between 350 and 400 Ma (Fletcher I. R., 1988, pers. comm.), slightly older than the post-Famennian to Permian age of the mineralization in the Devonian limestones (Ringrose, 1989). Lead isotope studies by Vaasjoki and Gulson (1986) indicate a heterogeneous source for the lead in the Wagon Pass and Narlarla deposits which contrasts with an homogeneous source for lead in the Cadjebut area.

Galena has also been recorded from Macs Jumpup, Bigelleas Yard and Old Leopold (Gellatly et al., 1974).

COPPER

Three copper prospects occur along the northeast limb of the Richenda Anticline and have been described by Marston (1979) as stratabound, polymetallic deposits. At the Turtle Creek prospect a copper gossan 270 m long and 6 m wide is present, developed on carbonaceous metasedimentary rocks and felsic volcanics of the Marboo Formation. A zone 100 m long was defined by percussion drilling with Pb values up to 6.5%, Ag at 347 g/t, but with Cu < 1% except for a 15 m long area of limonitic gossan. Diamond drilling intersected massive sulphides with the best intersection being 2.38 m assaying 2.1% Cu, 3.5% Pb, 4.2% Zn, and 162 g/t Ag.

The Colemans Creek prospect occurs 9.5 km along strike to the southeast. The mineralized zone occurs in Marboo Formation rocks and is parallel to bedding. It comprises 1 to 3 cm thick gossanous lenses, cupriferous quartz veins and lenses, and small areas of malachite staining extending over 75 m of strike. Percussion drilling identified minor disseminated pyrite and pyrrhotite mineralization with very low copper, lead and zinc assays.

The Top Springs prospect occurs 3 km northwest of the Turtle Creek prospect and consists of a 30 m by 10 m gossan containing malachite and azurite in strongly sheared metadolerite. The gossan assayed 0.51% Cu, 0.9% Pb, 0.1% Zn, 2.35% As, and 6 ppm Ag. One percussion drillhole had a 3 m intersection assaying 1.67% Cu.

Copper has also been recorded from Ord Gap (Gellatly et al., 1974).

GOLD

Gold has been reported from quartz reefs in the Marboo Formation 2 km southwest of Colemans Yard (Finucane, 1939). Assays from the reefs ranged from 0.15 g/t to 206 g/t, with most being less than 1.5 g/t.

Finucane (1938) reports the occurrence of gold from quartz reefs in Whitewater Volcanics west of Mount Broome. Assay results up to 7.9 g/t were obtained from one of the reefs; however, values were generally very low.

CORUNDUM

A corundum deposit on the northwest limb of the Richenda Anticline was described by Gellatly et al. (1974). The deposit consists of massive, pale-grey corundum rock as veins or lenses up to 0.6 m across at the contact between Marboo Formation rocks and the Ruins Dolerite. The rock consists mainly of corundum and diaspore, with minor kyanite.

TIN

Tin occurrences have been reported from a pegmatite and alluvials in Dyasons Creek (Finucane, 1939; Gellatly et al., 1974).

MICA

A pegmatite dyke near Kongorow Pool was quarried for sheet muscovite during 1943 to 1944 (Gellatly et al., 1974). Beryl accompanies the mica and tourmaline is a common component of most late felsic dykes.

DIAMOND

Nine small diamonds were recovered from the Lennard River, at Police Camp Pool, in October 1969, but the discovery remains unexplained. The first recovery of diamonds found in situ was from the newly discovered olivine lamproite pipes at *Big Spring*, in May 1976, but the grade was very low. Testing of all known lamproites in the area has shown the presence of a few diamonds in the tuffs of many unexposed leucite lamproite pipes (but none in exposed leucite lamproites), and concentrations exceeding 1 ct/100 t in four olivine lamproite pipes of the Ellendale Field (Atkinson et al., 1984; Jaques et al., 1986). Exploration activity by CRA Exploration P/L recovered a total of 12 700 ct of diamond from tuffs of the two largest pipes, *Ellendale 9* (grade, 5 ct/100 t) and *Ellendale 4* (grade, 14 ct/100t). The diamonds are of high quality, with 60% gem content, and the largest stone recovered is 6.47 ct (Hall and Smith, 1985). A small-scale operation to mine *Ellendale 4* is currently (1991) under investigation.

ROAD METAL AND GRAVEL

A large road-metal and gravel quarry is situated in Devonian limestone 10 km northwest of the junction of the Tunnel Creek Road and the Great Northern Highway. Pisolitic gravel has been used extensively in road construction in southwest LENNARD RIVER.

LIMESTONE

The extensive outcrops of limestone are a potential source of building stone and gravel.

ORNAMENTAL STONE

A coarse, porphyritic, blue-grey monzogranite from an outcrop of Lennard Granite has been quarried on an experimental basis from the Kimberley Pearl Quarry, 4 km northeast of Wombarella Creek on the Gibb River Road.

In recent years quarrying of large dolerite dykes for 'black granite', a dense fine-grained black rock, has been taking place from bouldery outcrops and small quarries located 500 m north of Kimberley Pearl, south of Wombarella Creek 10 km west of the Gibb River Road, and 4 km east-northeast of Carpenters Gap. The best quality material comes from large boulders at the surface. These are split into rectangular blocks (preferably greater than 2 m across) to remove the thin zone of weathered material and trucked to Perth for cutting and polishing. 730 t of rock was produced in 1985 and 1986.

RADIOACTIVE MINERALS

Exploration on adjacent sheets has indicated significant concentrations of radioactive (mainly thorium-rich) heavy minerals in the King Leopold and Warton Sandstones on LANSDOWNE (Gellatly et al., 1975), and of pitchblende in sandstone-hosted deposits in the Fairfield Group on YAMPI (Botten, 1984).

OIL AND GAS

The Fitzroy Trough on the northern edge of the Canning Basin has attracted significant exploration interest from the oil industry, resulting in tens of thousands of kilometres of seismic traverses and several exploration wells. Oil has been encountered in five of the twelve exploration drill holes on LENNARD RIVER (Table 1); Blina 1, Blina 5, Blina 6, Boronia 1 and West Philydrum 1. Oil is currently being produced from the Blina Field, which straddles the central-western edge of LENNARD RIVER. The total production for the seven wells of this field was 214 000 kL up to the end of 1990. This oil reservoir is in carbonates of the Famennian reef complex and sands of the Yellow Drum Sandstone (Moors et al., 1984; Moors, 1986).

The most prospective units for petroleum are the Famennian Nullara Limestone and the Upper Carboniferous to Lower Permian Grant Group. Frasnian platform and pinnacle reef carbonates also have high potential for petroleum but there are no producing fields in these rocks anywhere in the Canning Basin. Predicting suitable porosities which occur sporadically in dolomitized zones of the carbonate platform and marginal slope facies (Playford, 1984) of the Devonian carbonate reservoirs is a major problem in exploration.

Table 1. Oil exploration drill holes on LENNARD RIVER

Well	*Operator*	*Year*	*Bottomed in*	*Total depth (m)*	*Total production Dec 1990 (kL)*
Blina 1	Home Energy	1981	Upper Devonian	2 498	73 000
Blina 5	Home Energy	1985	Lower Devonian	1 830	27 000
Blina 6	Home Energy	1985	Lower Devonian	1 260	31 000
Boronia 1	I.E.D.C.	1982	Upper Devonian	3 391	-
Crimson Lake 1	Kufpec Aust	1988	Lower Carboniferous	1 981	-
Ellendale 1	AMAX Pet.	1979	Upper Devonian	3 190	-
Harold 1	Home Energy	1987	Upper Devonian	1 550	-
Kennedia 1	I.E.D.C.	1985	Upper Devonian	3 382	-
Mimosa 1	WAPET	1973	Upper Devonian	4 117	-
Napier 1	Lennard Oil	1969	Precambrian	1 801	-
Palm Spring 1	WAPET	1972	Upper Devonian	1 067	-
West Philydrum 1	I.E.D.C.	1985	Lower Permian	1 109	-

The Grant Group and Anderson Formation have petroleum potential on LENNARD RIVER, although the only significant thickness in the subsurface occurs in the southwest corner. Oil is produced in adjacent areas from Sundown and West Terrace oilfields in the Grant Group, and Lloyd oilfield in the Anderson Formation, with a total production of 77 000 kL to the end of 1990.

WATER SUPPLY

Water for stock and domestic use is obtained from bores in black soil that overlies the Carson Volcanics in northeast LENNARD RIVER (Allen, 1966), and many streams in the King Leopold Ranges contain semi-permanent pools and springs. Groundwater in the area of the Hooper Complex is restricted to valley-fill over bedrock, weathered bedrock, and joints and shears. The best aquifers in the southwest are the Grant Group, Poole Sandstone and Liveringa Group (Derrick and Playford, 1973). Springs are associated with the Devonian limestone outcrops.

REFERENCES

ALLEN, A. D., 1966, The hydrogeology of the Kimberley Plateau: Western Australia Geological Survey, Record 1966/16.

ASHWORTH, J. R., 1985, Migmatites: Blackie, Glasgow and London.

ATKINSON, W. J., HUGHES, F. E., and SMITH, C. B., 1984, A review of the kimberlite rocks of Western Australia, *in* Kimberlites I: Kimberlites and related rocks, *edited by* J. KORNBROBST: Elsevier, Amsterdam. p. 195–224.

BEARD, J. S., 1979, The vegetation of the Kimberley area: Vegetation Survey of Western Australia, 1:1 000 000 Vegetation Series, Explanatory Notes to Sheet 1. University of Western Australia Press, Perth.

BEARD, J. S., 1981, The vegetation of Western Australia at the 1:3 000 000 scale, Explanatory Notes: Western Australia Forests Department, Perth.

BELL, T. H., 1985, Deformation partitioning and porphyroblast rotation in metamorphic rocks: a radical reinterpretation: Journal of Metamorphic Geology, v. 4, p. 109–118.

BELL, T. H., FLEMING, P. D., and RUBENACH, M. J., 1986, Porphyroblast nucleation, growth and dissolution in regional metamorphic rocks as a function of deformation partioning during foliation development: Journal of Metamorphic Geology, v. 4, p. 37–68.

BENNETT, R., and GELLATLY, D. C., 1970, Rb–Sr age determinations of some rocks from the West Kimberley Region: Australia BMR Geology and Geophysics, Record 1970/20 (unpublished).

BLOCKLEY, J. G., 1971, The lead, zinc and silver deposits of Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 9, 234p.

BOFINGER, V. M., 1967, Geochronology of the east Kimberley area of Western Australia: Australian National University, Ph.D. thesis (unpublished).

BOTTEN, P., 1984, Uranium exploration in the Canning Basin–A case study, *in* The Canning Basin, W.A., *edited by* P. G. PURCELL: Geological Society of Australia and Australian Petroleum Exploration Society; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 485–501.

BOYER, S. E., and ELLIOTT, D., 1982, Thrust systems: American Association of Petroleum Geologists, Memoir 66, p. 1196–1230.

BUCHHORN, I. J., 1986, Geology and mineralization of the Wagon Pass prospect, Napier Range, Lennard Shelf, Western Australia, *in* Geology and exploration *edited by* D. A. BERKMAN: Council of Mining and Metallurgical Institutions, 13th Congress publications, v. 2, p. 163–172.

COATS, R. P., and PREISS, W. V., 1980, Stratigraphic and geochronological reinterpretation of late Proterozoic glaciogenic sequences in the Kimberley Region, Western Australia: Precambrian Research, v. 13, p. 181–208.

COCKBAIN, A. E., 1984, Stromatoporoids from the Devonian reef complexes, Canning Basin, Western Australia: Western Australia Geological Survey, Bulletin 129, 108p.

COWARD, M. P., 1980, The Caledonian thrust and shear zones of N.W. Scotland: Journal of Structural Geology, v. 2, p. 11–17.

DERRICK, G. M., and GELLATLY, D. C., 1971, The Precambrian geology of the Oscar Range Inlier, Lennard River 1:250 000 sheet area SE/51-8, Western Australia: Australia BMR Geology and Geophysics, Record 1971/61.

DERRICK, G. M., and PLAYFORD, P. E., 1973, Lennard River, Western Australia: Western Australia Geological Survey, 1:250 000 Geology Series Explanatory Notes.

DOW, D. B., and GEMUTS, I., 1969, Geology of the Kimberley Region, Western Australia: The East Kimberley: Western Australia Geological Survey, Bulletin 120.

DOW, D. B., GEMUTS, I., PLUMB, K. A., and DUNNETT, D., 1964, The geology of the Ord River region, Western Australia: Australia BMR Geology and Geophysics, Record 1964/104 (unpublished).

DRUCE, E. C., 1976, Conodont biostratigraphy of the Upper Devonian reef complexes of the Canning Basin, Western Australia: Australia BMR Geology and Geophysics, Bulletin 158, 303p.

DRUCE, E. C., and RADKE, B. M., 1979, The geology of the Fairfield Group, Canning Basin, Western Australia: Australia BMR Geology and Geophysics, Bulletin 200.

DRUMMOND, B. J., 1989, Project 170.08. Tectonic evolution of the Canning Basin: 1989 Yearbook of the Australia BMR Geology and Geophysics, Canberra, p. 101–102.

DRUMMOND, B. J., SHAW, R. D., SEXTON, M. J., and BARTON, T. J., 1990, Project 112.04. Canning Basin: 1990 Yearbook of the Australia BMR Geology and Geophysics, Canberra, p. 111–113.

FINUCANE, K. J., 1938, The Mount Broome area, West Kimberley District: Aerial Survey of Northern Australia, Report 33.

FINUCANE, K. J., 1939, The granite range area, West Kimberley District: Aerial Survey Northern Australia, Report 44.

GELLATLY, D. C., 1971, Possible Archaean rocks of the Kimberley region, Western Australia: Geological Society of Australia, Special Publication no. 3, p. 93–102.

GELLATLY, D. C., and DERRICK, G. M., 1967, Lansdowne, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes.

GELLATLY, D. C., DERRICK, G. M., and PLUMB, K. A.., 1970, Proterozoic Palaeocurrent directions in the Kimberley Region, Northwestern Australia: Geological Magazine, v. 3, p. 249–257.

GELLATLY, D. C., DERRICK, G. M., and PLUMB, K. A., 1975, The geology of the Lansdowne 1:250 000 sheet area, Western Australia. Australia BMR Geology and Geophysics, Report 152.

GELLATLY, D. C., and HALLIGAN, R., 1971, Charnley, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes.

GELLATLY, D. C., and SOFOULIS, J., 1973, Yampi, W. A.: Western Australia Geological Survey, 1:250 000 Geology Series Explanatory Notes.

GELLATLY, D. C., SOFOULIS, J., DERRICK, G. M., and MORGAN, C. M.,1974, The older Precambrian geology of the Lennard River 1:250 000 sheet area, Western Australia: Australia BMR Geology and Geophysics, Report 153.

GEMUTS, I., 1971, Metamorphic and igneous rocks of the Lamboo Complex, East Kimberley Region, Western Australia: Australia BMR Geology and Geophysics, Bulletin 107.

GRIFFIN, T. J., 1989, A major thrust between the Gibb River and Hooper Terranes in the King Leopold Orogen, West Kimberley region, *in* Professional Papers: Western Australia Geological Survey, Report 26, p. 69–81.

GRIFFIN, T. J., and GREY, K., 1990a, King Leopold and Halls Creek Orogens; *in* Geology and Mineral Resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 232–253.

GRIFFIN, T. J., and GREY, K., 1990b, Kimberley Basin: *in* Geology and Mineral Resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 293–304.

GRIFFIN, T. J., and MYERS, J. S., 1988a, Geological Note: A Proterozoic terrane boundary in the King Leopold Orogen, Western Australia: Australian Journal of Earth Sciences v. 35, p. 131–132.

GRIFFIN, T. J., and MYERS, J. S., 1988b, Reply to discussion: A Proterozoic terrane boundary in the King Leopold Orogen, Western Australia: Australian Journal of Earth Sciences, v. 35, p. 591–593.

GRIFFIN, T. J., WHITE, A. J. R., and CHAPPELL, B. W., 1978, The Moruya Batholith and geochemical contrasts between the Moruya and Jindabyne suites: Journal of the Geological Society of Australia, v. 25, p. 235–247.

GUPPY, D. J., LINDNER, A. W., RATTIGAN, J. H., and CASEY, J. N., 1958, The geology of the Fitzroy Basin, Western Australia: Australia BMR Geology and Geophysics, Bulletin 36.

HALL, A. E., and SMITH, C. B., 1985, Lamproite diamonds–are they different?, *in* Kimberlite occurrences and origin *edited by* J. E. GLOVER and P. G. HARRIS: University of Western Australia, Geology Department, Publication 8, p. 167–212.

HANCOCK, S. L., and RUTLAND, R. W. R., 1984, Tectonics of an early Proterozoic geosuture: the Halls Creek Orogenic Sub-province, northern Australia: Journal of Geodynamics, v. 1, p. 387–432.

HURLEY, N. F., 1986, Geology of the Oscar Range Devonian reef complex, Canning Basin, Western Australia: University of Michigan, Ph.D. thesis (unpublished).

HURLEY, N. F., and LOHMAN, K. C., 1989, Diagenesis of Devonian reefal carbonates in the Oscar Range, Canning Basin, Western Australia: Journal of Sedimentary Petrology, v. 59, p. 127–146.

HURLEY, N. F., and VAN der VOO, R., 1987, Palaeomagnetism of Upper Devonian reefal limestones, Canning Basin Western Australia: Geological Society of America Bulletin, v. 98, p. 138–146.

HURLEY, N. F., and VAN der VOO, R., 1990, Magnetostratigraphy, Late Devonian iridium anomaly, and impact hypotheses: Geology, v. 18, p. 291–294.

JAQUES, A. L., LEWIS, J. D., and SMITH, C. B., 1986, The Kimberlites and lamproites of Western Australia: Western Australia Geological Survey, Bulletin 132, 268p.

JAQUES, A. L., LEWIS, J. D., SMITH, C. B., GREGORY, G. P., CHAPPELL, B. W., and McCULLOCH, M. T., 1984a, The diamond-bearing ultrapotassic (lamproitic) rocks of the West Kimberley region, Western Australia, *in* Kimberlites I: Kimberlites and related rocks, *edited by* J. KORNPROBST: Amsterdam, Elsevier, p. 225–254.

JAQUES, A. L., WEBB, A. W., FANNING, C. M., BLACK, L. P., PIDGEON, R. T., FERGUSON, J., SMITH, C. B., and GREGORY, G. P., 1984b, The age of the diamond-bearing pipes and associated leucite lamproites of the West Kimberley region, Western Australia: BMR Journal of Australian Geology and Geophysics, v. 9, p. 1–7.

KERANS, C., 1985, Petrology of Devonian and Carboniferous carbonates of the Canning and Bonaparte Basins, Western Australia: Western Australian Mining and Petroleum Research Institute, Report 12, 223p.

KERANS, C., HURLEY, N. F., and PLAYFORD, P. E., 1986, Marine diagenesis in Devonian reef complexes of the Canning Basin, Western Australia: *in* Reef diagenesis *edited by* J. H. SCHROEDER and B. H. PURSER: Springer Verlag, Berlin, p. 357–380.

KERRICK, D. M., 1972, Experimental determination of muscovite + quartz stability with $P_{H_2O} < P_{TOTAL}$: American Journal of Science, v. 272, p. 946–958.

MARSTON, R. J., 1979, Copper mineralization in Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 13.

MEHNERT, K. R., 1968, Migmatites and the origin of granitic rocks: Elsevier, Amsterdam, 393p.

MIDDLETON, M. F., 1990, Canning Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 425–457.

MOORS, H. T., 1986, The Yellow Drum Formation–a hydrocarbon reservoir, Canning Basin, Western Australia: The Petroleum Exploration Association Journal, v. 28, p. 310–318.

MOORS, H. T., GARDNER, W. E., and DAVIS, J., 1984, Geology of the Blina oilfield, *in* The Canning Basin, *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia Symposium, Perth, 1984, Proceedings, p. 277–283.

MURPHY, G. C., 1990, The Lennard Shelf lead–zinc deposits, *in* Geology of the mineral deposits of Australia and Papua New Guinea *edited by* F. HUGHES: Australasian Institute of Mining and Metallurgy, Monograph 14, p. 1103–1109.

MYERS, J. S., and HOCKING, R. M., 1988, Geological map of Western Australia — 1:2 500 000: Western Australia Geological Survey, Perth.

PAGE, R. W., 1976, Reinterpretation of isotopic ages from the Halls Creek Mobile Zone, northwestern Australia: BMR Journal of Australian Geology and Geophysics, v. 1, p. 79–81.

PAGE, R. W., 1988, Geochronology of early to middle Proterozoic fold belts in northern Australia: a review: Precambrian Research, v. 40/41, p. 1–19.

PAGE, R. W., GRIFFIN, T. J., and TYLER, I. M., in prep., Isotopic age constraints on the Early Proterozoic Hooper Terrane of the King Leopold Orogen, Western Australia.

PAGE, R. W., and HANCOCK, S. L., 1988, Geochronology of a rapid 1.85–1.86 Ga tectonic transition: Halls Creek Orogen, northern Australia: Precambrian Research, v. 40/41, p. 447–467.

PAGE, R. W., McCULLOCH, M. T., and BLACK, L. P., 1984, Isotopic record of major Precambrian events in Australia: Proceedings of the 27th International Geological Congress, Moscow, v. 5, VNU Science Press, Amsterdam, p. 25–72.

PETHERAM, R. J., and KOK, B., 1983, Plants of the Kimberley region of Western Australia: University of Western Australia Press, Perth.

PLAYFORD, P. E., 1980, Devonian 'Great Barrier Reef' of the Canning Basin, Western Australia: American Association of Petroleum Geologists Bulletin, v. 64, p. 814–840.

PLAYFORD, P. E., 1981, Devonian reef complexes of the Canning Basin, Western Australia: Geological Society of Australia, Fifth Australian Geological Convention Guidebook, 64p.

PLAYFORD, P. E., 1982, Devonian reef prospects in the Canning Basin: implications of the Blina oil discovery: Australian Petroleum Exploration Association Journal, v. 24, p. 258–271.

PLAYFORD, P. E., 1984, Platform-margin and marginal-slope relationships in Devonian Reef Complexes of the Canning Basin , *in* The Canning Basin *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia Canning Basin Symposium, Perth, 1984, Proceedings, p. 189–214.

PLAYFORD, P. E., COCKBAIN, A. E., DRUCE, E. C., and WRAY, J. L., 1976, Devonian stromatolites from the Canning Basin, Western Australia, *in* Stromatolites *edited by* M. R. WALTER: Developments in Sedimentology, Elsevier, v. 20, p. 543–563.

PLAYFORD, P. E., HURLEY, N. F., KERANS, C., and MIDDLETON, M. F., 1989, Reefal platform development, Devonian of the Canning Basin, Western Australia, *in* Controls on carbonate platform and basin development *edited by* P. D. CREVELLO, J. L. WILSON, J. F. SARG, and J. F. READ: Society of Economic Paleontologists and Mineralogists Special Publication 44, p. 187–202.

PLAYFORD, P. E., and LOWRY, D. C., 1966, Devonian reef complexes of the Canning Basin, Western Australia: Western Australia Geological Survey, Bulletin 118, 150p.

PLAYFORD, P. E., McLAREN, D. J., ORTH, C. J., GILMORE, J. S., and GOODFELLOW, W. D., 1984, Iridium anomaly in the Upper Devonian of the Canning Basin, Western Australia: Science, v. 246, p. 437–439.

PLUMB, K. A., 1968, Lissadell, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes.

PLUMB, K. A., 1981, Late Proterozoic (Adelaidian) tillites of the Kimberley–Victoria River region, Western Australia and Northern Territory, *in* Earth's pre-Pleistocene Glacial Record *edited by* M. J. HAMBREY and W. B. HARLAND: Cambridge University Press, Cambridge, p. 528–530.

PLUMB, K. A., ALLEN, R., and HANCOCK, S. L., 1985, Proterozoic evolution of the Halls Creek Province, Western Australia: Australia BMR Geology and Geophysics, Record 1985/25.

PLUMB, K. A., DERRICK, G. M., NEEDHAM, R. S., and SHAW, R. D., 1981, The Proterozoic of Northern Australia, *in* Precambrian of the Southern Hemisphere — Developments in Precambrian Geology 2 *edited by* D. R. HUNTER: Amsterdam, Elsevier, p. 205–307.

PLUMB, K. A., and GEMUTS, I., 1976, Precambrian geology of the Kimberley region, Western Australia. 25th International Geological Congress Excursion Guide no. 44C.

PLUMB, K. A., and JAMES, H. L., 1986, Subdivision of Precambrian time: recommendations and suggestions by the Subcommission on Precambrian Stratigraphy: Precambrian Research, v. 32, p. 65–92.

PURCELL, P. G., (editor), 1984a, The Canning Basin, Western Australia: Geological Society of Australia and Petroleum Exploration Society of Australia Canning Basin Symposium, Perth, 1984, 582p.

PURCELL, P. G., 1984b, The Canning Basin, W.A. — An introduction, *in* The Canning Basin, *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia Symposium, Perth, 1984, Proceedings, p. 3–19.

READ, J. F., 1973, Carbonate cycles, Pillara Formation (Devonian), Canning Basin, Western Australia: Canadian Petroleum Geology Bulletin, v. 21, p. 38–51.

RIGBY, J. K., 1986, Late Devonian sponges of Western Australia: Western Australia Geological Survey, Report 18, 59p.

RINGROSE, C. R., 1989, Studies of selected carbonate-hosted lead–zinc deposits in the Kimberley Region: Western Australia Geological Survey, Report. 24, 103p.

SANDERSON, D. J., and MARCHINI, W. R. D., 1984, Transpression: Journal of Structural Geology, v. 6, p. 449–458.

SHAW, R. D., TYLER, I. M., GRIFFIN, T. J., and WEBB, A., 1992, New K–Ar constraints on the onset of subsidence in the Canning Basin, Western Australia: Australian BMR, Journal of Australian Geology and Geophysics, v. 13, p. 31–35.

SIMPSON, C., and SCHMID, S. M., 1983, An evaluation of criteria to deduce the sense of movement in sheared rocks: Geological Society of America, Bulletin 94, p. 1281–1288.

SOFOULIS, J., GELLATLY, D. F., DERRICK, G. M., FAIRBRIDGE, R. A., and MORGAN, C. M., 1971, The geology of the Yampi 1:250 000 sheet area, SE/51-3, Western Australia: Australia BMR Geology and Geophysics, Record 1971/1.

STEWART, A. J., 1988, Discussion: A Proterozoic terrane boundary in the King Leopold Orogen, Western Australia: Australian Journal of Earth Sciences, v. 35, p. 598–591.

THOMAS, G. A., 1959, The Lower Carboniferous Laurel Formation of the Fitzroy Basin: Australia BMR Geology and Geophysics, Report 38, p. 21–36.

TOWNER, R. R., and GIBSON, D. L., 1983, Geology of the onshore Canning Basin, Western Australia: Australia BMR Geology and Geophysics, Bulletin 235, 51p.

TYLER, I. M., and GRIFFIN, T. J., 1990, Structural development of the King Leopold Orogen, Kimberley Region, Western Australia: Journal of Structural Geology, v. 12, p. 703–714.

TYLER, I. M., and GRIFFIN, T. J., 1993, Yampi , W.A. (second edition): Western Australia Geological Survey, 1:250 000 Series Explanatory Notes.

TYLER, I. M., GRIFFIN, T. J., and SHAW, R. D., 1991, Early Palaeozoic tectonism and reactivation of pre-existing basement structures at the margins of the Kimberley Craton, Western Australia, *in* Cratonic margins structural and tectonic processes: *6th Specialist Group in Tectonics and Structural Geology Field Conference*, Margaret River, Western Australia, September 1991: Geological Society of Australia, Abstracts.

VAASJOKI, M., and GULSON, B. L., 1986, Carbonate-hosted base metal deposits: lead isotope data bearing on their genesis and exploration: Economic Geology, v. 81, p. 156–172.

WALKER, R. G., 1984, Turbidites and associated coarse clastic deposits, *in* Facies Models (second edition), *edited by* R. G. WALKER: Geoscience, Toronto, p. 171–188.

WALLACE, M. W., 1987, Sedimentology and diagenesis of Upper Devonian carbonates, Canning Basin, Western Australia: University of Tasmania, Ph.D. thesis (unpublished).

WILCOX, R. E., HARDING, T. P., and SEELY, D. R., 1973, Basic wrench tectonics: American Association of Petroleum Geologists, Bulletin, v. 57, p. 74–96.

WRIGHT, R. L., 1964, Geomorphology of the West Kimberley area, *in* General Report on Lands of the West Kimberley area, W. A.: Australia CSIRO, Land Research Series no. 9, p. 103–118.

WYBORN, L. A., 1988, Petrology, geochemistry and origin of a major Australian 1880–1840 Ma felsic volcano-plutonic suite: a model for intercontinental felsic magma generation: Precambrian Research, v. 40/41, p. 37–60.

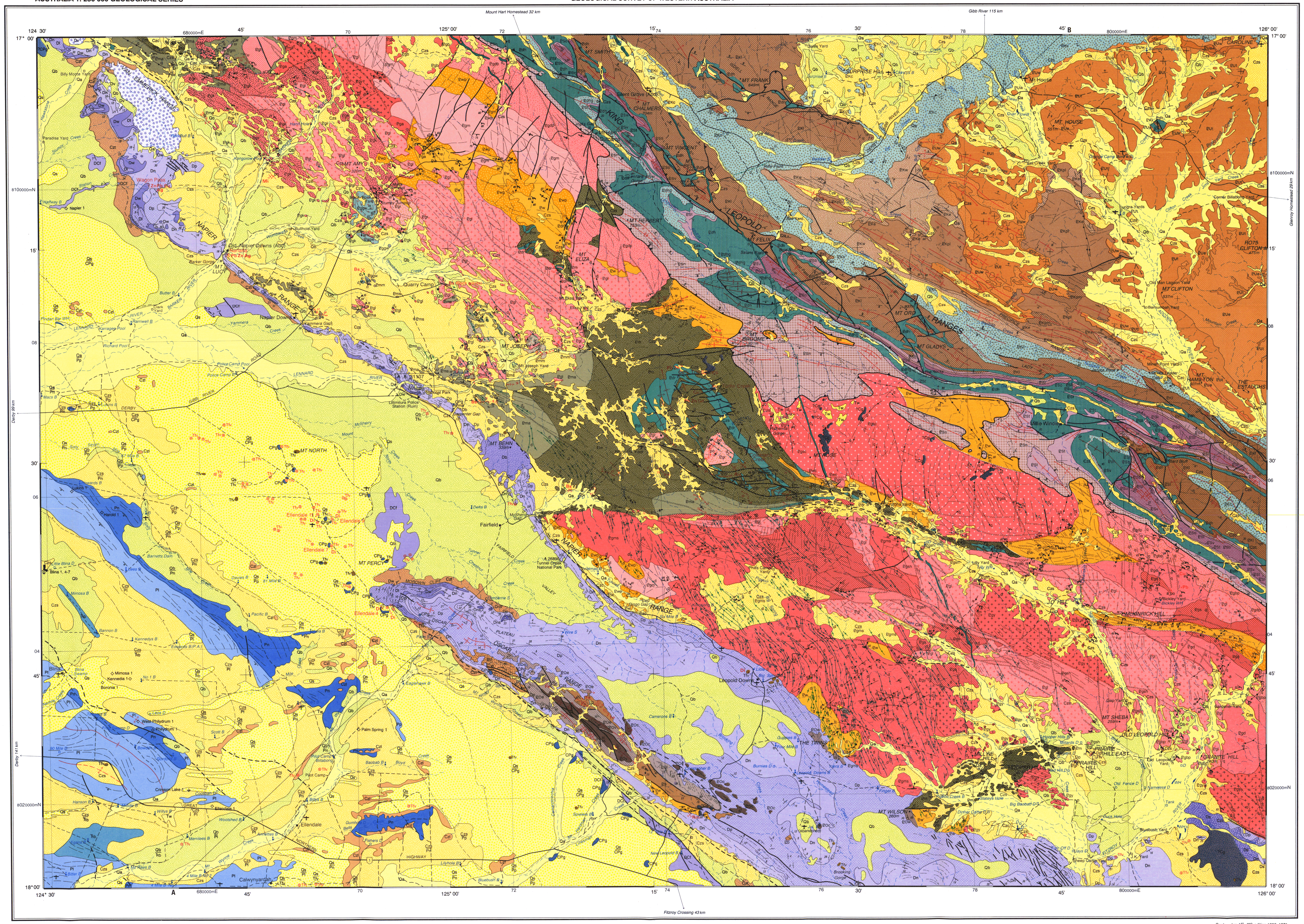
YEATES, A. N., GIBSON, D. L., TOWNER, R. R., and CROWE, R. W. A., 1984, Regional geology of the onshore Canning Basin, W. A., *in* The Canning Basin, W.A., *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia Symposium, Perth, 1984, Proceedings, p. 23–56.

LENNARD RIVER

AUSTRALIA 1: 250 000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SE 51-8



SYMBOLS

Geological boundary
- accurate
- inferred and concealed

Fault
- accurate
- concealed
- inferred
- reverse
- shear zone, containing quartz

Fold (showing plunge)
- anticline, concealed
- syncline, concealed
- monocline
- overturned anticline
- overturned syncline
- minor anticline
- minor syncline

Small-scale folds showing orientation of axial surface, direction of plunge and nature of vergence (Z or M)
- D_1
- D_2
- D_3

Bedding
- inclined
- vertical
- horizontal
- strike and dip of overturned strata
- dip estimated from aerial photography
  - 0 – 15°
  - 15 – 45°
  - 45 – 90°
  - vertical
  - overturned 90 – 45°
  - 45 – 15°
  - general trend of bedding

Way-up indicator
- top of bed

Glacial striae, showing sense of movement

Cleavage, slaty or spaced
- inclined
  - D_2
  - D_3
  - D_4
- vertical
  - D_2
  - D_4

Bedding coincident with cleavage

Cleavage, crenulation
- inclined
  - D_2
  - D_3

Foliation
- vertical
  - D_3
- inclined
  - gneissic banding
  - D_2
  - D_3
  - D_4
  - igneous banding

Joints
- vertical

Lineation
- stretching lineation
- bedding intersection with cleavage/foliation
- axis of crenulation

Air photo lineament

Formed road
Track
Homestead
Yard
Landing ground
Horizontal control; major

Watercourse, intermittent
Bore — B
Waterhole — WH
Spring — S
Dam — D
Windpump

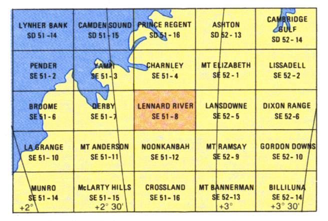
Petroleum exploration well
- Oil production well
- Suspended oil well
- Abandoned well, dry
- Abandoned well, show of oil

Opencut or quarry
Opencut or quarry, abandoned
Mineral prospect
Mineral exploration drillhole or other subsurface data — Tfv
Subsurface lithology — Tfv

Mineral occurrence
- Copper — Cu
- Corundum — Cn
- Diamond — Di
- Gold — Au
- Iron — Fe
- Lead — Pb
- Silver — Ag
- Zinc — Zn

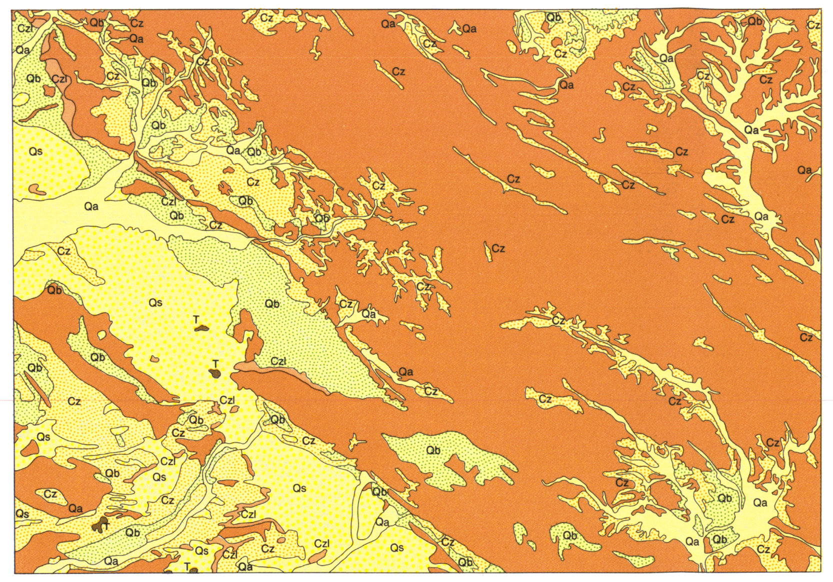
Industrial minerals
- Building stone — Bs
- Mica — Mi
- Road materials — Rm

INDEX TO 1 : 250 000 SHEETS



The lines indicate magnetic declination, 1980
+ means declination is east and correction must be added to compass bearing to give true bearing
- means declination is west and correction must be subtracted from compass bearing to give true bearing
Annual change is -1' westerly

CAINOZOIC GEOLOGY



Qa Alluvium
Qb Black soil
Qs Windblown sand
Czs Colluvium and alluvium — partly consolidated
Czl Duricrust — ferruginous or calcareous
T Tertiary rock
Pre-Cainozoic rock

Scale 1:1 000 000

0 10 20 30 40 50 Kilometres

DEPARTMENT OF MINERALS AND ENERGY
HON. GEORGE CASH, J.P., M.L.C. MINISTER FOR MINES
L.C. RANFORD, ACTING DIRECTOR GENERAL

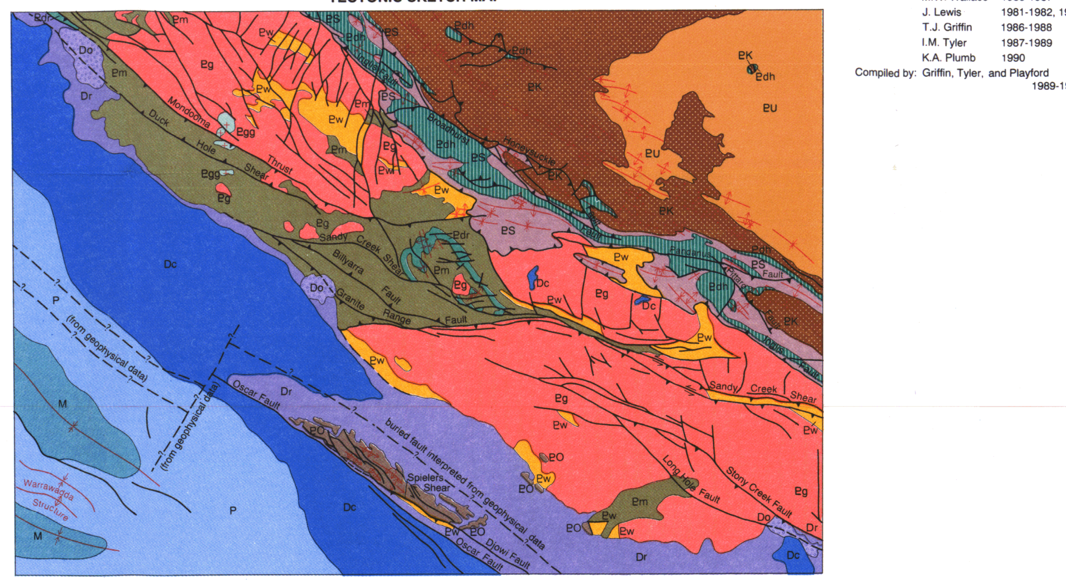
PIETRO GUJ
DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SCALE 1 : 250 000

5000 0 5 10 15 20 25 30
Metres Kilometres

TRANSVERSE MERCATOR PROJECTION
ZONE 51 AUSTRALIAN MAP GRID

TECTONIC SKETCH MAP



- Mesozoic
- Permian
- Devonian–Carbon-iferous post-reef
- Devonian conglomerate
- Devonian reef complex

CANNING BASIN

- Mount House Group
- Oscar Range Group
- Hart Dolerite
- Kimberley Group
- Speewah Group

KIMBERLEY BASIN

- Granitoid rocks
- Gabbroic rocks
- Whitewater Volcanics
- Ruins Dolerite
- Marboo Formation

HOOPER COMPLEX

Scale 1:1 000 000

0 10 20 30 40 50 Kilometres

Geology by: 1ST, 2ND edition 1956, 1971
P.E. Playford 1971, 1985-1989
N.F. Hurley 1984-1985
M.W. Wallace 1985-1987
J. Lewis 1981-1982, 1987
T.J. Griffin 1986-1988
I.M. Tyler 1987-1989
K.A. Plumb 1990
Compiled by: Griffin, Tyler, and Playford 1989-1990

REFERENCE

PHANEROZOIC

CAINOZOIC

QUATERNARY

Qa Alluvium — unconsolidated silt, sand, and gravel
Qb Black soil — clay and silt
Qs Windblown sand — residual sand

Czs Colluvium and alluvium — partly consolidated silt, sand, and gravel; cobble and boulder conglomerate
Czc Colluvium — partly consolidated scree and valley-fill deposits; cobble and boulder conglomerate
Czt Travertine; tufa (caliche)
Czl Laterite, pisolitic ironstone, ferruginous sandstone

TERTIARY

Tw **WARRIMBAH CONGLOMERATE:** poorly consolidated boulder and pebble beds

MIOCENE

Tfv **FITZROY VOLCANICS:** lamproite; fine- to medium-grained ultrapotassic, magnesia- and titania-rich volcanic plugs and associated pyroclastics; contains olivine, leucite, phlogopite, diopside, K-richterite, priderite, and diamond

MESOZOIC

TRIASSIC

Rb **BLINA SHALE:** grey and brown siltstone, shale, and sandy shale

PALAEOZOIC

PERMIAN

Liveringa Group

Pl Ferruginous, micaceous silty sandstone and conglomeratic sandstone

Pn **NOONKANBAH FORMATION:** shale, siltstone, limestone, and sandstone; conglomerate towards margin of basin

Pp **POOLE SANDSTONE:** micaceous silty sandstone and quartz sandstone; thin bedded; cross-bedding and ripple marks abundant

LATE CARBONIFEROUS TO EARLY PERMIAN

Grant Group

CPg Undivided: massive aqueoglacial deposits, poorly sorted silty sandstone, conglomeratic sandstone, siltstone, and shale

? EARLY CARBONIFEROUS

?Cg Conglomerate: massive, poorly sorted conglomerate and conglomeratic sandstone

LATE DEVONIAN TO EARLY CARBONIFEROUS — FAMENNIAN–TOURNAISIAN

Fairfield Group

DCf Undivided: silty limestone and calcarenite, calcareous shale and siltstone

LATE DEVONIAN

Db **BEHN CONGLOMERATE:** boulder conglomerate, consisting largely of rounded granitoid and quartzite clasts
Ds **STONY CREEK CONGLOMERATE:** boulder conglomerate, consisting largely of rounded granitoid clasts
Dv **VAN EMMERICK CONGLOMERATE:** boulder conglomerate, consisting largely of rounded granitoid clasts

Reef Complex

FAMENNIAN

Dl **NULLARA LIMESTONE:** back-reef to reef-flat subfacies; bedded cyanobacterial and oolitic limestone; subordinate dolomite

Dw **WINDJANA LIMESTONE:** reef-margin subfacies; massive cyanobacterial limestone

FAMENNIAN–FRASNIAN

Dn **NAPIER FORMATION:** reefal-slope to fore-reef subfacies; bedded limestone with some calcareous sandstone, large allochthonous reef blocks, and massive debris-flow deposits

Dns **Elimberrie bioherms:** stromatolite and sponge-stromatolite bioherms in the Oscar Range

FRASNIAN

Dp **PILLARA LIMESTONE:** reef-margin, reef-flat, and back-reef subfacies; massive to well-bedded stromatoporoid, cyanobacterial, and oolitic limestone; in part dolomitized, and interbedded calcareous sandstone

CANNING BASIN

PROTEROZOIC

q Quartz vein
d_2 Dolerite dyke

c. 670 Ma

Mount House Group

ЕUe **ESTAUGHS FORMATION:** purple-grey, fine-grained ferruginous sandstone and micaceous siltstone; white, fine-grained quartz sandstone and micaceous sandstone

ЕUt **THROSSELL SHALE:** grey-green shale interbedded with buff and grey-green, fine-grained sandstone; red-brown shale and ferruginous sandstone at base

ЕUa **TRAINE FORMATION:** green to brown, coarse-grained lithic sandstone; minor sandy dolomite and dolomitic sandstone; scattered glacial erratics

ЕUw **WALSH TILLITE:** tillite; pink, fine-grained pebbly sandstone; minor purple-brown siltstone and algal dolomite

Еb **ELIMBERRIE FORMATION:** quartz sandstone, feldspathic sandstone, diamictite, grey phyllitic siltstone, grey-brown limestone; ironstone lenses, and chert
Еn **NINETY SEVEN MILE FORMATION:** white to grey quartzite, diamictite, phyllite and phyllitic sandstone; amygdaloidal metabasalt, chlorite schist, epidotized quartzite; minor meta-tuff, meta-rhyolite

Oscar Range Group

ЕOl **LINESMAN FORMATION:** grey-green and purple-grey siltstone and shale, buff feldspathic sandstone; minor boulder conglomerate

ЕOe **ELLENDALE FORMATION:** grey-green to brown phyllitic sandstone and shale, cobble and boulder conglomerate, feldspathic sandstone, and minor siltstone; hematite lenses

ЕOv **LE LIEVRE FORMATION:** grey quartzite, grey-green and brown phyllite, quartz sandstone

ЕOc **CHRISTOPHER FORMATION:** white to purple-grey quartz sandstone, feldspathic sandstone, grey and red-brown shale and siltstone, pebble conglomerate; altered basic igneous rocks

ЕOw **MOUNT WILSON SANDSTONE:** grey to white granule sandstone, feldspathic sandstone, and arkose; buff, green and white quartz sandstone

c. 1800 Ma

Еdh **HART DOLERITE:** dark grey dolerite

Еdhg Pink to grey granophyre

c. 1800-1840 Ma

Kimberley Group

PENTECOST SANDSTONE:

ЕKpm Middle unit: pink and white quartz sandstone, grey-green micaceous shale and grey fine-grained sandstone; purple-brown sandstone at base

ЕKpl Lower unit: purple-brown and white quartz sandstone, buff feldspathic sandstone; minor micaceous siltstone

ЕKe **ELGEE SILTSTONE:** red-brown and grey siltstone; minor mudstone, feldspathic sandstone, hematitic sandstone

ЕKw **WARTON SANDSTONE:** white to buff quartz sandstone and feldspathic sandstone; minor hematitic siltstone

ЕKc **CARSON VOLCANICS:** tholeiitic basalt, amygdaloidal basalt, pyroclastic rocks; minor feldspathic sandstone, siltstone

ЕKl **KING LEOPOLD SANDSTONE:** white to pink medium-grained quartz sandstone, fine-grained sandstone, siltstone; minor coarse-grained sandstone, granule to pebble conglomerate

Speewah Group

ЕSb **BEDFORD SANDSTONE:** white to pale brown, well-sorted quartz sandstone

ЕSl **LUMAN SILTSTONE:** purple-brown and grey, ferruginous micaceous siltstone and fine-grained sandstone

ЕSo **LANSDOWNE ARKOSE:** purple-brown, grey, and white quartz sandstone and feldspathic sandstone, micaceous siltstone; minor fine arkose

ЕSv **VALENTINE SILTSTONE:** grey and green flaggy, laminated siltstone, minor fine-grained feldspathic sandstone interbeds

ЕSt **TUNGANARY FORMATION:** buff and grey feldspathic sandstone; brown and green siltstone and phyllite; minor shale and ferruginous quartz sandstone

ЕSn **O'DONNELL FORMATION:** grey, white, and purple-brown granule sandstone and coarse-grained quartz sandstone; minor phyllite, siltstone, arkose, and pebble conglomerate

KIMBERLEY BASIN

d Dolerite dyke — grey-green amphibolite; may be deeply weathered
a Aplite dyke
p Pegmatite dyke
po Porphyry dyke

c. 1840 Ma

Еga **MOUNT AMY GRANITE:** foliated, leucocratic, biotite-muscovite syenogranite; weakly porphyritic
Еgb **BARKER MONZOGRANITE:** medium- to fine-grained biotite monzogranite; contains minor small mafic xenoliths
Еgd **LERIDA GRANITE:** foliated, porphyritic biotite granodiorite; contains green plagioclase and small mafic xenoliths
Еgk **KONGOROW GRANITE:** foliated, porphyritic biotite-rich monzogranite and granodiorite; contains mafic xenoliths and gneissic bands
Еgl **LENNARD GRANITE:** foliated, coarse, porphyritic biotite monzogranite; minor syenogranite, granodiorite, and non-porphyritic varieties
Еgm **MONDOOMA GRANITE:** foliated, quartz-phyric biotite micromonzogranite; minor syenogranite and granodiorite
Еgr **RICHENDA MICROGRANODIORITE:** foliated, medium- to fine-grained granodiorite and tonalite
Еgs **DYASONS GRANITE:** recrystallized, leucocratic, medium- to fine-grained biotite monzogranite; contains muscovite
Еgt **TARRAJI MICROGRANITE:** porphyritic biotite micromonzogranite
Еgy **CHANEYS GRANITE:** foliated biotite monzogranite and granodiorite; weakly porphyritic; small mafic xenoliths
Еgbp **BICKLEYS PORPHYRY:** foliated, grey, fine-grained, quartz-feldspar porphyry and porphyritic micromonzogranite
Еgdp **MOUNT DISASTER PORPHYRY:** foliated, coarse, porphyritic biotite micromonzogranite
Еgms **McSHERRYS GRANODIORITE:** foliated, porphyritic to even-grained, biotite-hornblende granodiorite and tonalite; minor monzogranite; small mafic xenoliths are abundant
Еgsc **SCRUTONS MONZOGRANITE:** coarse, porphyritic biotite monzogranite; minor recrystallization; chloritized biotite is present
Еgsh Highly sheared granitoid
Еggw **WOMBARELLA QUARTZ GABBRO:** medium- to fine-grained, biotite- and pyroxene-bearing gabbro and quartz gabbro, and quartz norite; some recrystallization

c. 1850 Ma

Еw **WHITEWATER VOLCANICS:** foliated dacite and rhyodacite lava, tuff, agglomerate, and minor volcaniclastic sedimentary rocks; commonly crystal rich; thin pebble conglomerate at base

Еwp Foliated dacite and rhyodacite lava, tuff, agglomerate, and fine-grained quartz-feldspar porphyry; crystal rich

Еwc Coarse feldspathic sandstone and pebble conglomerate

c. 1880 Ma

Еdr **RUINS DOLERITE:** medium- to fine-grained metadolerite

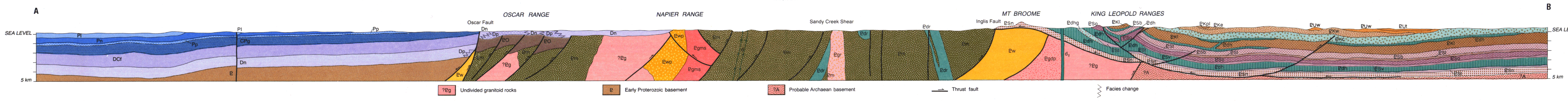
c. 1900 Ma

Еm **MARBOO FORMATION:** predominantly low-grade thin-bedded turbiditic metasandstone and quartz-chlorite-muscovite (-biotite-chloritoid) phyllite
Еma Medium-grade quartz-muscovite-biotite (-chlorite) metapsammite and quartz-muscovite-biotite (-chlorite-andalusite-kyanite-staurolite-garnet) pelitic schist
Еms Medium- to high-grade quartz-K-feldspar-biotite-muscovite-sillimanite (-garnet-tourmaline) metapsammite and metapelite
Еmm **MOUNT JOSEPH MIGMATITE:** high-grade quartz-K-feldspar-plagioclase-biotite-sillimanite-muscovite (-cordierite-garnet-andalusite) migmatitic metapsammite and metapelite; anatectic granitoid

HOOPER COMPLEX

DIAGRAMMATIC SECTION

NATURAL SCALE



Undivided granitoid rocks — Early Proterozoic basement — Probable Archaean basement — Thrust fault — Facies change

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