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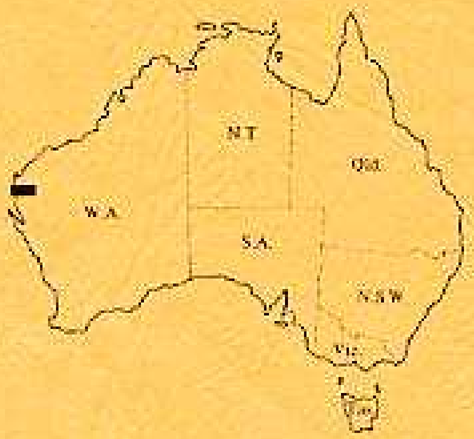
WINNING POOL-MINILYA
WESTERN AUSTRALIA



SHEET SF/49-16 AND SF/50-13 INTERNATIONAL INDEX

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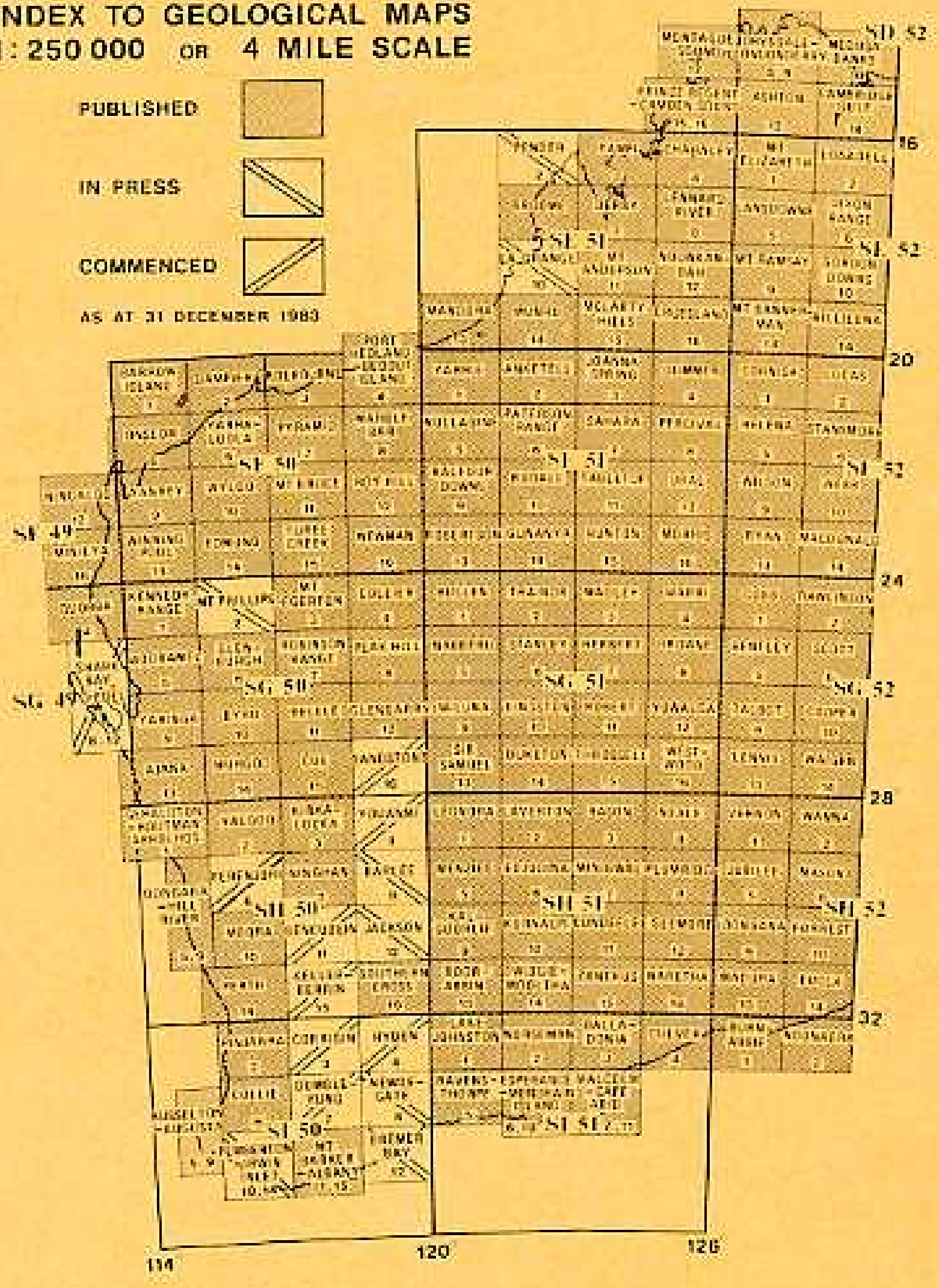

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

WINNING POOL-MINILYA

WESTERN AUSTRALIA

SHEET SF/49-16 AND SF/50-13 INTERNATIONAL INDEX

COMPILED BY R. M. HOCKING, S. J. WILLIAMS, I. H. LAVARING AND P. S. MOORE

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32985—1

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EXPLANATORY NOTES ON THE WINNING POOL - MINILYA GEOLOGICAL SHEET

Compiled by R. M. Hocking, S. J. Williams, I. H. Lavaring and P. S. Moore.

INTRODUCTION

The WINNING POOL - MINILYA* geological sheet, SF 50-13 and part of SF 49-16, is bounded by latitudes 23°00′S and 24°00′S, and longitudes 113°25′E and 115°30′E. The only settlements are Coral Bay, a small coastal holiday resort, Minilya Roadhouse on the North West Coastal Highway, and several station homesteads. The highway and the Exmouth road are the only sealed roads, but several shire roads and numerous station tracks offer generally good access to most of the area. The climate is Mediterranean, with average annual rainfall between 200 mm and 300 mm, and potential annual evaporation approaching 2 400 mm. In January, average daily maximum and minimum temperatures are about 31°C and 22°C, and in July 22°C and 11°C.

An open to dense shrub-steppe vegetation, including spinifex (*Triodia*), covers most of the area, and tall trees line the major watercourses. Ride and others (1974) give details on the fauna and flora.

PREVIOUS GEOLOGICAL WORK

Sytematic geological mapping of the Carnarvon Basin was done by the Bureau of Mineral Resources between 1948 and 1955, and the first edition of the Minilya geological sheet, was published in 1955 (Condon, 1955). Earlier work, covering isolated aspects of the Phanerozoic geology of the area, is summarized therein and in Condon (1954). The geology of the Giralia and Marrilla Anticlines was described by Condon and others (1956), and an integrated view of the Carnarvon Basin as a whole was presented by Condon (1965, 1967, and 1968). Geologists from West Australian Petroleum Pty Ltd (WAPET) also studied the area in the 1950s and 1960s, and this work culminated in the drilling of several petroleum exploration wells on coastal anticlines and in the Wandagee area. A number of unpublished reports were compiled during Wapet's investigations, and these were utilized in the compilation of a general overview of the basin by Thomas and Smith (1976).

Other recent summaries of the geology of the Carnarvon Basin are by Playford and others (1975) and Johnstone and others (1976). A study of the Carnarvon Basin by the Geological Survey of Western Australia (GSWA) commenced in 1975, and WINNING POOL - MINILYA was remapped in 1978. Relevant publications to date are by van de Graaff, Hocking, and Denman (1977); Lavaring (1979); Cockbain (1980, 1981); Megallaa (1980); Moore, Denman, and Hocking (1980); Moore, Hocking, and Denman (1980); Hocking and others (1980); and Moors (1981a). Geological bibliographies of the Carnarvon Basin are by Ozimic (1970) and Moors (1981b). A bulletin on the Carnarvon Basin is in progress, and a report on the adjacent Precambrian Gascoyne Province is nearly complete.

*To avoid confusion with place names, sheet names are written in full capitals.

There is a large amount of unpublished information, primarily on the subsurface geology obtained through petroleum exploration. Much of this information, where subsidized under the Petroleum Search Subsidy Acts, is available to the public. Results of mineral exploration by mining companies, in Phanerozoic and Precambrian rocks, are contained within the GSWA M-file system, and much of this information is also available to the public.

GEOMORPHOLOGY

The physiographic divisions are shown in Figure 1. Concepts similar to those of Finkl and Churchward (1973) have been extended north from their study area. Three broad groups of physiographic units can be distinguished, and these are reflected in the named physiographic regions.

(1) The MacLeod Region, in the west, is characterized by anticlinal domes onlapped by Pleistocene marine and eolian sediments.

(2) The Marrilla and Mardathuna regions are low relief, calcrete-duricrusted areas with dune fields commonly covering the duricrust. Small etchplains are locally developed at the margins of the regions where the duricrust has been breached. The Minilya Plain consists of the intermediate areas where the calcrete duricrust has been breached, and is dominated by alluvial processes.

(3) The Lyons and Nanutarra Regions were previously part of an extensive laterite/silcrete plateau, of which Moogooloo Hill is the most prominent remnant. They are now semi-stripped etchplains characterized by flat to gently undulating terrain interspersed with strike ridges (Lyons Region) and mesas and buttes (Nanutarra Region). Isolated duricrust remnants are present. In some areas underlain by Precambrian bedrock, intensely dissected terrain has developed with a dense dendritic drainage pattern. In the Wandagee Region, no resistant rocks are present and an etchplain has formed, with the duricrust completely stripped.

Lateritization and silcretization on WINNING POOL - MINILYA must have taken place in the Oligocene because the Eocene Giralia Calcarenite and Merlinleigh Sandstone are lateritized, but the overlying Upper Oligocene to Middle Miocene Cape Range Group is not. Some topographic highs in areas of Precambrian outcrop are erosional remnants, which are at a higher elevation than the general level of the duricrusted surface. The uplift of the coastal anticlines of the MacLeod Region also commenced in the Oligocene, although they were still largely submarine features.

The duricrusted surface was breached after the Middle Miocene (because the Cape Range Group shows no terrigenous contamination, other than the Lamont Sandstone which may reflect stripping of loose sand at the top of the laterite profile), but probably no later than the Early Pliocene. Development of the Lyons, Nanutarra and Wandagee Regions commenced, with drainage patterns and rates of denudation strongly dependent on bedrock lithology.

A number of alternately arid and humid phases followed, associated with the gradual drying-out of Western Australia (van de Graaff and others, 1977). Only some of the deposits and surfaces which indicate these phases can be dated relative to one another, and so the described sequence of events is largely intuitive, and the ages uncertain.

Calcrete duricrusting took place in an arid phase during the Pliocene, forming the ancestral Marrilla and Mardathuna Regions. Following this, more humid conditions saw the development of major drainages and the breaching of the calcrete surface.

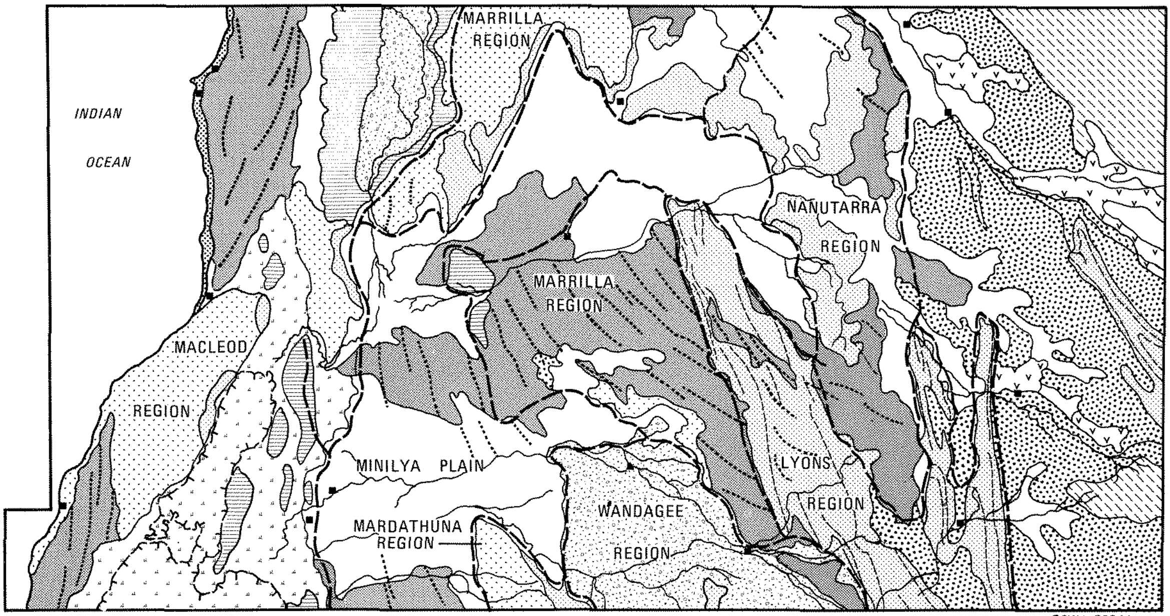

FIGURE 1

PHYSIOGRAPHY

WINNING POOL–MINILYA, SHEETS SF 50-13 AND PART SF 49-16

0 10 20 30 km

REFERENCE

- Etchplain
- Dissected terrain: Gently undulating with local rugged outcrop, rare duricrust remnants
- Dissected terrain. Mesas, buttes, strike ridges, duricrust remnants
- Intensely dissected terrain with dendritic drainage, formed on Precambrian rocks
- Anticlinal ranges and domes, locally dissected
- Sandplains and dunefields, quartzose other than in MacLeod Region
- Calcareous coastal dunes
- Saline coastal lakes and lacustrine sediments
- Fluvial outwash plains, includes valley calcrete where not apparent at surface.
- Major areas of valley (groundwater) calcrete
- Calcareous duricrust, relatively undissected.
- Strike ridge
- Sand dune crestal trend
- Major drainage
- Present border of Lake MacLeod
- Homestead, settlement
- Boundary, named physiographic region

The formation of valley calcretes in eastern WINNING POOL - MINILYA probably commenced at the end of this humid phase. Bowler and Jones (1979) noted that arid conditions in southeastern Australia commenced less than 700 000 years ago, and Mann and Horwitz (1979) suggested that valley calcrete began to form more than 36 500 years ago, and this gives some indication of the age of the oldest valley calcretes. The marine and eolian deposits of the MacLeod Region were also developing at this time, as doming of the anticlines (by now emergent) continued.

A wet phase (25 000-40 000 years B. P.) has been recognized in eastern Australia (Bowler and others, 1976). During this phase the Minilya Plain probably approached its present extent, much of the widespread veneer of now-consolidated *Czc* was deposited, and major headward erosion of the margins of the Marrilla and Mardathuna Regions took place. Major eolian reworking of surface sand occurred in the immediately following arid phase (16 000-25 000 years B. P.; Bowler, 1976; Bowler and others, 1976), forming sizable longitudinal dune fields which locally obscure the boundaries of physiographic regions.

The land surface of WINNING POOL - MINILYA has since been largely static: only the development of the evaporitic sequence in Lake MacLeod, coastal erosion (in the south) and dune-building (in the north) took place. It is not known whether uplift of the coastal anticlines is continuing, although the Cape Range Anticline (on YANREY - NINGALOO to the north) shows evidence of continued growth.

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GASCOYNE PROVINCE

EARLY PROTEROZOIC METAMORPHIC ROCK TYPES

The early Proterozoic metasedimentary rocks on WINNING POOL - MINILYA have similar lithological features to the Morrissey Metamorphic Suite on MOUNT PHILLIPS, and most are so mapped. Some rocks related to this suite, but of conspicuously lower metamorphic grade, have been separately indicated on the map reference and given sedimentary rock names. No unconformity is implied to exist between the two rock groups, and they are both probably equivalent to the Wyloo Group. This distinction is made to accommodate the possibility that the sequence may be fitted to a formal stratigraphy at some future date, for already the rudiments of a stratigraphic sequence are recognizable.

Stratigraphic interpretation

Stratigraphically, the lowermost unit is a thick sequence of paragneiss (*Ᵽng*) with intercalated pelitic schist (*Ᵽnp*). This is probably a metamorphosed greywacke-shale association. It is overlain by conglomerate (*Ᵽlr*) which is more arenaceous at the top. The conglomerate is overlain by beds of mafic sediments (*Ᵽsm*) which probably were tuffs derived from mafic or intermediate volcanics. Both the conglomerate and the mafic sediments are discontinuous units and are present only on the western side of the Kimbers Syncline. The mafic sediment is overlain by argillite, now phyllite (*Ᵽsp*), which contains some thin beds of fine-grained sandstone or possibly chert (*Ᵽsq*) horizons. The argillite is, in turn, overlain by a thick wedge of arkose and quartz wacke (*Ᵽsa*), which has pebble beds near its base. A lens of arkosic calcarenite and dolomite (*Ᵽsd*) occurs within this unit, and similar calcareous rocks overlie the arkose.

LOW-GRADE METAMORPHIC ROCKS

A distinctive, dark, fine-grained schist with abundant porphyroclasts of detrital feldspar and quartz in a matrix of quartz, chlorite, epidote, calcite and sericite (*Ᵽsm*) occurs 2 km east of Emu Creek Bore. This sediment could have been derived from mafic or intermediate volcanic rocks. The schist is overlain by glossy, dark-green phyllite (*Ᵽsp*) which contains quartz, sericite, chlorite, and smaller amounts of magnetite, tourmaline and apatite. It has a penetrative slaty cleavage defined by polygonized quartz ribbons and aligned flakes of chlorite and sericite. A narrow unit of finely banded, fine-grained quartzite or metamorphosed chert (*Ᵽsq*) occurs within the phyllite. In some places, the quartzite contains thin bands of epidote. Laminae of iron oxides are also present.

Coarse-grained, foliated arkose and quartz wacke with conglomerate lenses (*Ᵽsa*) overlie the phyllite. The arkose consists of quartz, detrital feldspar (partly sericitized), muscovite (including books of detrital muscovite), sericite and tourmaline. Isolated gravel-sized to cobble-sized clasts of vein quartz are present throughout the arkose, and some beds of conglomerate are present. Pebbly beds are more common near the base of this unit where it is in contact with the underlying phyllite. The arkose overlies and partly interfingers with crystalline, metamorphosed dolomite and arkosic dolomite (*Ᵽsd*). The latter is an isotropic coarse-grained aggregate of quartz, microcline, carbonate, phlogopite, and minor tourmaline. The impure dolomite has numerous conglomeratic horizons containing angular to sub-rounded quartz granules.

MORRISSEY METAMORPHIC SUITE

Schists

The dominant schist (*Ꝑls*) is a medium-grained, semipelitic metasediment, containing quartz, muscovite, and lesser amounts of chlorite, epidote, sericite, biotite and garnet. Accessories include tourmaline, magnetite, apatite and carbonate. Epidote and sericite form clots within polygonal-quartz mosaics, suggesting alteration of detrital plagioclase. Porphyroclasts of plagioclase, quartz and lithic fragments are preserved in some lower grade varieties. The constituent minerals are usually well crystallized, but, in areas of strong deformation, the schist is retrogressive: muscovite is partly sericitized, and biotite and garnet are down-graded to chlorite. The schistosity is defined by elongate, polygonal quartz and foliae of aligned muscovite.

Some varieties of schist (*Ꝑls*) were originally feldspar rich, possibly greywacke, and these now consist of abundant sericite or epidote intergrown with medium-grained, granoblastic quartz and chlorite. This possible metagreywacke is abundant in the Jailor Belt (Fig. 2) where it is associated with mafic sediment and possible metavolcanics (*Ꝑla*). Fine-grained granoblastic quartzite (*Ꝑqm*) is interlayered with

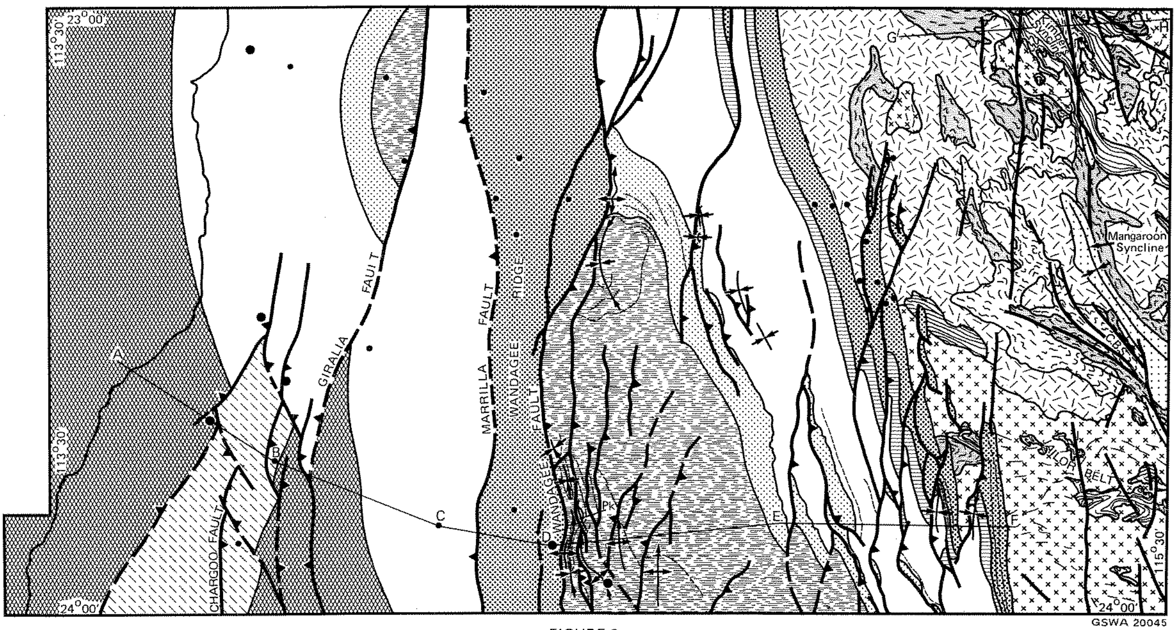

FIGURE 2

INTERPRETED PRE-CRETACEOUS GEOLOGY

WINNING POOL - MINILYA, SHEETS SF 50-13 AND PART SF 49-16

0 10 20 30 km

REFERENCE

PERMIAN
- Pk Kennedy Group
- Byro Group
- Wooramel Group
- Lyons and Callytharra Formations

- Lower Carboniferous
- Devonian
- Devonian and Carboniferous undifferentiated
- Silurian

PROTEROZOIC
- Bangemall Group
- Uaroo Group
- Anatectic granitoid suite
- Minnie Creek Batholith granitoid

PROTEROZOIC
- Minnie Creek Batholith granitoid, foliated
- Morrissey Metamorphic Suite: Low-grade metasediments; Schist; Paragneiss; Migmatite
- Geological boundary

- Fault or shear zone
- Syncline axis showing plunge
- Anticline axis showing plunge
- Bedding trend
- Petroleum exploration well
- Borehole penetrating pre-Cretaceous sequence
- C.B.S. Coolicer-Brown straightening zone

schist in the Jailor Belt. The quartzite is commonly laminated and contains sericite and minor feldspar. Well-laminated, fine-grained quartzite (*Ꞓqi*) with distinct magnetite-rich bands—a metamorphosed banded iron-formation—also occurs in the Jailor Belt.

Rafts of schist within granitoid, south of the Lyndon River, are commonly well-crystallized, medium-grained, quartz-muscovite-biotite schist (*Ꞓlu*). The presence of biotite distinguishes this from lower grade schist (*Ꞓls*).

Dark-grey, fine-grained, quartz-biotite-muscovite-garnet schist (*Ꞓlb*) is interlayered with medium-grained quartz-muscovite schist and forms a distinct northerly trending belt 4 km east of 12 Mile Bore. Some of the biotite schist has porphyroclastic, quartz-chlorite-epidote schist (*Ꞓsm*).

Metamorphosed conglomerate

Metamorphosed schistose conglomerate (*Ꞓlr*) occurs in the Emu Creek Bore area, in beds up to 5 m wide interlayered with pelitic schist, micaceous quartzite and quartzite. The conglomerate beds contain cobble- to granule-size, cigar-shaped, stretched quartzite clasts in an open or closed framework arrangement with a matrix of quartzite or mica schist. The conglomerate has a steep metamorphic gradient, increasing to the southwest. On the northeastern side of this unit metamorphosed argillites are represented by low-grade, fine-grained chlorite schist and quartz-sericite schist. The chlorite schist is upgraded to fine-grained quartz-biotite-garnet schist and the sericite becomes medium-grained quartz-muscovite schist on the southwestern side of the unit.

Mafic schist and amphibolites

Fine-grained, dark, mafic schist (*Ꞓla*), composed of blue-green hornblende, quartz, epidote, magnetite and small amounts of biotite and chlorite, occurs in the Mount Hamlet area and in the southern part of the Jailor Belt. Epidote is derived from plagioclase and, in some places, plagioclase is preserved. However, quartz is the dominant mineral is all cases. This schist may be a basalt-derived metasediment of a metamorphosed intermediate volcanic rock.

Amphibolite (*Ꞓna*) consists of an aligned, granoblastic intergrowth of hornblende and plagioclase. The plagioclase may be completely saussuritized. Amphibolite represents metamorphosed basalt or dolerite.

Calc-silicate quartzite and marble

Calc-silicate quartzite (*Ꞓnc*) in low-grade areas is predominantly quartz, epidote and tremolite, and lesser amounts of magnetite, microcline, sphene and tourmaline. A distinctive type of calc-silicate rock occurs east of Marbia Well near the EDMUND boundary. It consists of sigmoidal-shaped granules and pebbles of quartz in a matrix of epidote, quartz, tremolite, and accessory sphene, apatite and carbonate. This represents metamorphosed pebbly calc-arenite. In areas of higher metamorphic grade, the calc-silicate quartzite consists of foliae of quartz, hornblende and clinopyroxene with secondary epidote and tremolite.

Green, dolomitic marble (*Ęmn*) is associated with calc-silicate quartzite 11.5 km southeast of Marbia Well and with chlorite-carbonate schist in the Boundary Well area. The marble consists of carbonate, magnesian chlorite and tremolite with minor quartz, magnetite and tourmaline.

Paragneiss-schist association (Ęnp)

Dark-grey, granodioritic, biotite-muscovite-(garnet) microgneiss is interfoliated with lesser amounts of coarse-grained pelitic schist. The pelitic schist has coarse-grained muscovite and biotite with, in some places, knots of muscovite and sericite after possible andalusite. The microgneiss and pelitic schist association is probably a higher grade equivalent of the semipelitic and pelitic schist (*Ęls*) association. With increasing metamorphic grade, biotite and plagioclase become more abundant in semipelitic schist, apparently at the expense of chlorite, sericite, muscovite and quartz. In this way, microgneiss is eventually formed.

Metamorphosed arkose (Ęng)

Coarse- and medium-grained granodioritic or adamellitic paragneiss represents metamorphosed arkose and feldspathic arenite. Coarse muscovite is prominent, along with finer biotite and, in altered varieties, sericite and chlorite. Good exposure of the meta-arkose occurs at Bangoona Pool, where persistent, regular lamination and layering defined by mica-rich layers, imparts a flaggy appearance to outcrops. Cross-lamination is preserved in some areas, and the layering is interpreted as bedding. A strong foliation is generally subparallel to the layering except in the core zone of tight folds. Some meta-arkose layers contain scattered, deformed pebbles of quartz and granitoid. Porphyroblasts of microcline, plagioclase and muscovite are also present.

In the northwest-trending zone between Kelly Corner Bore and Winning Well, the meta-arkose (and migmatite derived from it) commonly shows the effects of a static phase of retrograde metamorphism, in which feldspars and muscovite were sericitized, followed by a dynamic phase of retrograde metamorphism. The result of these processes is a phyllonite characterized by coarse-grained, elongate, partially polygonized quartz and aligned, comminuted biotite set in fine sericite. The phyllonite is particularly well developed in discrete shear zones, but is not necessarily restricted to these zones.

Migmatite (Ęmb)

With increasing metamorphic grade the paragneiss units (*Ęnp*, and, *Ęng*) show the development of adamellite or granodioritic leucosome viens with granitic textures. The veins are invariably bounded by a narrow selvage of biotite which suggests *in situ* anatectic differentiation of the paragneiss leucosome.

At advanced stages of anatexis, the unmelted paragneiss is difficult to distinguish from the melted portion, and the newly generated granitoid has ghost structures inherited from the paragneiss. These include biotite schlieren, and light and dark patches; the light patches usually have biotite clots. In this type of migmatite there are broad-scale zones, centimetres or metres wide, of veined, incipiently melted paragneiss merging into zones where melting is more advanced and melted portions can no longer be distinguished from the unmelted. The zonal arrangement becomes disrupted where partial melting is more complete and only fragments of the original paragneiss, enriched in biotite, remain within nebulously swirled granitoid. Migmatite structures are extensive over large areas of paragneiss and are not merely developed adjacent to granitoid plutons.

PROTEROZOIC METAMORPHISM

Prograde metamorphism

The main phase of metamorphism is prograde, and accompanied the development of schistosity in the metasedimentary rocks.

Metamorphic grade increases with a steep gradient southwesterly and southeasterly from the core of the Kimbers Syncline (Fig. 2). Across the southwestern limb of the syncline, the grade increases from lowermost greenschist facies to amphibolite facies over a distance of 3 km.

Low Grade: The metamorphic assemblages of the low-grade metasediments include quartz-sericite-chlorite, and quartz-chlorite-epidote-sericite-calcite. These assemblages are typical of the lower part of the greenschist facies (chlorite zone). Carcareous rocks within this zone contain dolomite, calcite, quartz, and phlogopite.

Intermediate to low grade: Pelitic and semipelitic schist (*Ɇls*) and metaconglomerate of the Morrissey Metamorphic Suite fall within greenschist-amphibolite facies transition, and are characterized by biotite and garnet. However, the upper part of the schist unit is low grade and well down in the greenschist facies. The mineral assemblage here is quartz-sericite-albite-chlorite. In the biotite portion of the greenschist-amphibolite transition zone the typical primary assemblage is quartz-muscovite-biotite-plagioclase. Garnet-bearing assemblages include quartz, biotite, garnet (probably almandine), muscovite and plagioclase. Plagioclase is altered so that its composition is indeterminable. Biotite is generally more abundant in the garnet zone than in the biotite zone.

Mafic schist intercalated with quartz-muscovite-biotite-garnet schist 2.5 km east of Bulga Well has the primary assemblage of hornblende-quartz-calcic plagioclase-biotite. Calc-silicate quartzite has the primary assemblage quartz-epidote-hornblende-clinopyroxene. These assemblages both indicate amphibolite facies. Conditions transitional from the greenschist to amphibolite facies are indicated by blue-green hornblende, epidote, quartz, plagioclase, biotite and chlorite schist in the Jailor Belt.

Intermediate to high grade: Amphibolite facies is inferred for the assemblage of quartz-plagioclase (about An_{30})-biotite-muscovite-garnet in microgneiss and pelitic schist (*Ɇnp*). Biotite is more abundant than muscovite in the less aluminous quartzofeldspathic gneiss. The coarse- and medium-grained paragneiss (*Ɇng) has quartz,* plagioclase, microcline, muscovite and biotite. The plagioclase is more calcic than albite (commonly andesine) and probably also belongs to amphibolite facies. Upper amphibolite facies is inferred for the widespread, partial melting involved in migmatite *(Ɇmb*) formation, which, in the presence of an aqueous fluid, required a temperature greater than 620°C (Wyllie, 1977).

Amphibolite facies is confirmed by hornblende, calcic plagioclase and biotite in amphibolite which occurs sporadically throughout the paragneiss. Calcareous rocks within the paragneiss have carbonate (probably dolomite), tremolite and Mg-chlorite.

Static and dynamic retrograde metamorphism

The main phase of metamorphism was followed by a phase of static, retrograde metamorphism, the effects of which are variable. Strongest retrogression is recorded in paragneiss and migmatite in a northwest-trending zone between Brown Bore and Coolicer Bore. Phyllonite in this area contains unrecrystallized, coarse-grained quartz, but feldspar is heavily saussuritized and sericitized. Muscovite is partly recrystallized to sericite, but biotite, although partly downgraded from a brown to a green variety, is preserved. The lack of significant quartz recrystallization and the random orientation of secondary sericite indicates little or no strain accompanying this secondary metamorphism. The preservation of biotite and garnet suggests that this static, retrograde metamorphism took place in the upper part of the greenschist facies or lower part of the amphibolite facies.

Similar effects, on a less intensive scale, occur throughout the Morrissey Metamorphic Suite. In amphibolite, the plagioclase is heavily saussuritized, but blue-green hornblende is preserved. Hornblende is preserved in calc-silicate rocks but clinopyroxene is altered to feathery tremolite and secondary epidote is developed.

The fabric containing these statically altered assemblages was subsequently folded and sheared by a later deformation phase. Low greenschist-facies retrograde metamorphism accompanied this deformation. This dynamic, retrograde metamorphism is strongest in fold cores and shear zones. Biotite and garnet are recrystallized and partly altered to chlorite. Aligned foliae of sericite cut through pre-existing muscovite and altered feldspar. Elongate polygonal quartz defines the new foliation.

PROTEROZOIC GRANITOIDS

Two contrasting granitoid suites on WINNING POOL consist of muscovite-bearing, heterogeneous granitoid apparently derived from anatexis of the Morrissey Metamorphic Suite; and homogeneous biotite granitoid (e.g. Minnie Creek type) probably derived from remelting (or remobilization) of Archaean or Proterozoic crustal rocks.

Granitoids derived from metasediment anatexis

In areas of advanced anatexis, migmatite (*Ꝑmb*) of the Morrissey Metamorphic Suite progressively merges into heterogeneous granitoid which has numerous rafts and xenoliths of paragneiss and schist, clots and schlieren of biotite, and nebulous, light and dark zones. One variety is dark-grey, medium- to coarse-grained, muscovite-biotite granodiorite to adamellite (*Ꝑgmt*). Another type is pink, or light-grey, coarse- to fine-grained, muscovite-biotite(-tourmaline) adamellite to granite (*Ꝑgmb*). Both of these granitoids have seriate textures mainly due to the presence scattered microcline laths.

Some phases of muscovite-biotite granite are porphyritic (*Ꝑgml*) and are generally more homogeneous than other granitoids of this suite. Porphyritic granite does not merge transitionally into migmatite, but forms discrete plutons. The more homogeneous pluton-forming granitoids have probably moved from their zone of generation to be emplaced at higher crustal levels.

The anatectic, metasediment-derived granitoids are characterized by coarse, intergranular muscovite and compositionally resemble the metamorphosed arkose.

All of these granitoids have hypidiomorphic-granular texture indicating crystallization from a melt. Recrystallization is common, but foliation is only present in zones of high strain. In the domain between Winning Well and Kelly Corner Bore, anatectic granodiorite, as well as the associated migmatite and paragneiss, has undergone intense plagioclase sericitization. The static event was followed by shearing which, in the more intense phases, resulted in elongation and polygonization of quartz, crumpling of muscovite, and partial retrogression of muscovite to sericite, biotite to chlorite, and plagioclase to epidote and sericite.

Minnie Creek Batholith and related types

The dominant granitoid type of the Minnie Creek Batholith is coarse-grained biotite (10 per cent, or less) granodiorite (*Ꝑgbr*) which commonly has scattered laths of microcline. This granodiorite is generally homogeneous, although there are some fine-grained varieties. Foliation is generally absent except in shear zones, but varying degrees of recrystallization are evident towards the margins of the batholith, where the massive core may be wrapped by a zone of foliated, biotite granodiorite and biotite-hornblende tonalite (*Ꝑgbt*). The foliated granodiorite (*Ꝑgbt*) is intruded by the unfoliated granodiorite (*Ꝑgbr*). Saussuritization of plagioclase is present throughout, but is strongest in the foliated granodiorite. Small, scattered mafic xenoliths are commonly present in both types of granodiorite, but are more common in the foliated variety. Discrete plutons of foliated biotite granodiorite also intrude the Morrissey Metamorphic Suite in the northeastern part of WINNING POOL.

A small pluton of foliated, even-grained granite to adamellite (*Ꝑgbl*) with some porphyritic phases intrudes the Morrissey Metamorphic Suite 6 km south-southwest of Bulga Well. The porphyritic phases contain up to 20 per cent rounded phenocrysts of microcline. A mass of foliated porphyritic granitoid (*Ꝑgbl*) also forms part of the Minnie Creek Batholith in the area 18 km southeast of Lyndon homestead. The northern part of this body is biotite granodiorite with microcline augen and is strongly foliated. It appears to merge northwards into foliated, even-grained biotite granodiorite (*Ꝑgbt*). However, the central-western part of this body, near Munabia Bore, is weakly foliated, and is biotite-muscovite granite.

Pink biotite-muscovite granite to adamellite (*Ꝑgbm*) forms a thick selvage around the outer margin of the Minnie Creek Batholith. This is coarse to medium grained and has a partly recrystallized texture, but is not foliated. Some phases, particularly around the northern margin of the batholith, have minor tourmaline and coarse clots of biotite. The muscovite-bearing granitoid intrudes older foliated and unfoliated granodiorite phases. In contact areas narrow dykes of microcline-quartz-albite-muscovite granite (with or without biotite) intrude the granodiorite. A swarm of these dykes also intrudes granodiorite in the area west of Hongs Corner Bore.

The muscovite-bearing granitoid is relatively homogeneous and probably forms a late phase of the Minnie Creek Batholith. It straddles the boundary between the batholith and metasediment-derived, anatectic granitoids, and in some areas (for instances around Baltic Bore), it is not always clear whether muscovite-bearing granitoid belongs to the Minnie Creek Batholith or to the anatectic suite. In such areas, mixing of both types may be involved. There are clear relationships in the area south of Kelly Corner Bore where heterogeneous granodiorite of the anatectic suite is intruded by homogeneous granite of the Minnie Creek Batholith. However, in the Kimbers Well area, a pluton of gneissic biotite granodiorite, related to the batholithic granitoids, is intruded by less strongly deformed muscovite-biotite-tourmaline granite of the anatectic suite. Emplacement of the two suites seems to have proceeded concurrently throughout the orogenic episode.

Relationships within the Minnie Creek Batholith suggest that there is an intrusive series from strongly foliated biotite tonalite, to porphyritic and partly foliated biotite granodiorite, then biotite granodiorite and adamellite, and finally unfoliated but recrystallized biotite-muscovite(-tourmaline) adamellite and granite. Late-stage, unrecrystallized granodiorite dykes (*Ꝑgt*) in the Strossed Well area are an exception to the general trend.

STRUCTURE

Early deformation (D_1)

Proterozoic structure can be considered in terms of two phases of deformation. The first phase (D_1) occurred concomitantly with the main phase of prograde metamorphism and produced a stratiform schistosity in the Morrissey Metamorphic Suite. There are some minor, intrafolial folds, but no major folds of this generation have been recognized. The low-grade metasediments did not undergo any penetrative deformation at this stage. In general the low-grade metasediments form the upper part of the sedimentary succession and the Morrissey Metamorphic Suite forms the lower part; depth of burial therefore appears to have had a control on both metamorphism and the D_1 deformation.

In the northeastern part of WINNING POOL several dome-like granitoid plutons with arcuate foliation patterns were emplaced concordantly within the Morrissey Metamorphic Suite during the formation of the D_1 foliation. The steeply dipping arcuate foliation in these plutons suggests that they were injected as gneissic diapirs. In areas of higher metamorphic grade at presumably deeper crustal levels, migmatite of the Morrissey Metamorphic Suite merges into heterogeneous granitoid masses which appear to have been generated *in situ*. These autochthonous, anatectic masses represent the culmination of the main metamorphic episode. However, they are not generally foliated, which indicates metamorphism outlasted D_1 deformation.

During the second phase of deformation, the autochthonous granitoids and the gneissic diapirs acted as competent, large-scale, "augen". Most of the deformation was taken up in the surrounding, less competent metasediments, and in discrete, high-strain zones.

Secondary deformation (D_2)

Emplacement of later stage, allochthonous granitoid plutons of both the anatectic and Minnie Creek types caused widespread secondary deformation. The D_1 foliation in the Morrissey Metamorphic Suite is crumpled and warped between major D_2 granitoid bodies. Major D_2 folds are tight, upright structures with axial-surface crenulation cleavage in schist, and a penetrative secondary foliation in paragneiss. The hinge lines of these folds have moderate to steep plunges to the northwest and to the southeast. This incongruence is probably related to the shape of individual granitoid bodies which strongly control the D_2 deformation.

A feature of most of the granitoid plutons is that they are elongated in a northwesterly or west-northwesterly direction. This may reflect structural anisotropy of the D_1 deformation which may have been caused by an Archaean basement anisotropy. The granitoid masses further control the style and orientation of D_2 so that D_2 structures also trend northwest or west-northwest.

The Coolicer-Brown straightening zone

The term "straightening zone" is used for an elongate area of high, flattening strain, into which convoluted structural trends become progressively planar and oriented parallel to the zone.

A prominent, west-northwest trending straightening zone, about 8 km wide, occurs between Coolicer and Brown Bores. This is a zone of abundant, narrow shear zones, and tight, asymmetric folds with long, parallel limbs and narrow, intervening hinge zones.

These folds affect a pre-existing D_1 foliation, and D_1 mica foliae are crenulated, or completely transposed. There is some new mica and ribbon-quartz developed in the new orientation. This straightening zone is also the locus of retrograde phyllonite and sericite schist. It may be a high-strain zone related to the regional D_2 deformation, or the deformation here may even be a discrete episode which post-dates D_2.

The Minnie Creek Batholith

The Minnie Creek Batholith forms a distinct structural entity in the southern part of WINNING POOL. It contains arcuate and amoeboid-shaped rafts of metasediment. The shape of these rafts appears to be controlled by the emplacement of individual granitoid cells within the pluton. The bulk of the granitoid was emplaced after the formation of the D_1 event in the enclosing metasediments and caused tight, secondary folding and crenulation cleavage within the metasedimentary rafts. Early phases of the batholith have a strong, gneissic foliation indicating that they may have been intruded syntectonically to the D_1 deformation, but most of the granite emplacement post-dates the D_1 event.

UAROO GROUP

Several small areas of the Rouse Creek Arenite (*Ᵽur*) are present on northeastern WINNING POOL - MINILYA, extending south from the main outcrop area on YANREY - NINGALOO. The Rouse Creek Arenite is the basal formation of the Uaroo Group, and consists of quartz arenite with minor interbedded dolomite. To the north, the formation is of fluviatile origin, but the dolomite may indicate marginal evaporitic conditions on WINNING POOL - MINILYA. The Uaroo Group is thought to have developed in a local basin during folding and uplift of older rocks, and therefore probably has no direct correlation with other apparently comparable Proterozoic sediments (van de Graaff and others, 1980).

BANGEMALL GROUP

Stratigraphy and lithology

Sediments of the Bangemall Group unconformably overlie the Morrissey Metamorphic Suite. The stratigraphy is similar to that described on EDMUND (Daniels, 1969) and MOUNT PHILLIPS (Williams and others, 1979).

The Irregully Formation (*ᵽMi*), which forms the base of the succession, is laminated dolomite. In the Mangaroon Syncline (Fig. 2) the dolomite contains a thin arenite unit (*ᵽMi (a)*) and minor chert. The dolomite lenses out towards the southeast and here the arenite unit thickens and forms the base of the formation.

The Kiangi Creek Formation (*₽Mk*) is a quartz arenite with less than 10 per cent clay matrix. It is laminated, or finely bedded and has some thin, interbedded siltstone and shale units. This formation forms distinct ridges in the southern part of the Mangaroon Syncline, but it lenses out towards the northwest.

The Jillawarra Formation (*₽Mj*) is a black, siliceous, locally pyritic shale which contains occasional thin chert, siltstone and dolomite lenses. It overlies the Kiangi Creek Formation or, where the latter has lensed out, the Irregully Formation.

The Discovery Chert (*₽Md*) is black and grey, laminated and bedded chert. It forms a prominent marker horizon in the Mangaroon Syncline. The Devil Creek Formation (*₽Mv*), which overlies the chert, is poorly exposed, but probably consists of laminated dolomite.

Structure

Sediments of the Bangemall Group occur in a tight, southeasterly plunging syncline (the Mangaroon Syncline, Fig. 2) which may have formed as a drape fold in the Bangemall Group in response to block faulting of the basement.

CARNARVON BASIN

The Phanerozoic sedimentary sequence exposed on WINNING POOL - MINILYA ranges in age from Devonian to Quaternary, and contains virtually all the major rock units of the Carnarvon Basin. In addition, Silurian sediments are present in the subsurface. Sediments lie within the Gascoyne and Merlinleigh Sub-basins, and the thickness of the sequence (as deduced from gravity and magnetic data) probably exceeds 5 km in the Giralia Anticline. The type sections of many units lie on WINNING POOL - MINILYA, and data concerning these are summarized in Table 1. Since the first edition of the sheet, some stratigraphy has been amended by Condon (1965; 1967; 1968); Playford and others (1975); van de Graaff, Hocking and Denman (1977); and Hocking and others (1980).

SUBSURFACE UNITS

Interpreted pre-Winning Group geology is shown in Figure 2. Some sequences encountered in the subsurface by petroleum-exploration wells are readily correlated with recognized units, but the correlation of other sequences remains doubtful.

Silurian

The Tumblagooda Sandstone and Dirk Hartog Formation are present in Quail 1 and Wandagee 1, and are known to extend further north and west (Marrilla 1, Pendock 1). The Tumblagooda Sandstone is a thick, arenaceous sequence which, from outcrop evidence to the south, was deposited in mixed fluviatile to shallow-marine enviroments (Hocking, 1981). Spores and simple microplankton indicate a Late Silurian age for the upper part of the unit in Wandagee 1 (Balme, *in* Playford and others, 1975). It is more than 2 500 m thick in the southern Carnarvon Basin, but is probably less on WINNING POOL - MINILYA.

TABLE 1. TYPE SECTIONS ON WINNING POOL - MINILYA

Unit	*Locality*	*Latitude* °	′	″	*Longitude* °	′	″	*Thickness (m)*		*Named by*	*Comments*
Windalia Radiolarite	Windalia Hill	23	16	10	114	47	10	(a)	36	Condon, 1954	Erosional top to section. Defined by Condon (1954).
Mungadan Sandstone	Wandagee Hill	23	50	10	114	25	50	(b)	36	Teichert, 1950	Defined by Condon (1954).
Coolkilya Sandstone	Wandagee Hill	23	50	10	114	25	49	(b)	58	Teichert, 1950	Defined by Condon (1954), amended by Hocking and others (1980).
Nalbia Sandstone	Wandagee Hill, 3.5 km N	23	48	10	114	25	10	(b)	40	Teichert, 1950	Base and top not exposed, poor exposure thoughout. Defined by Condon (1954).
Wandagee Formation	Coolkilya Pool, Minilya River	23	44	10	114	24	00	(d)	173	Condit, 1935	Defined by Condon (1954).
				to							
		23	44	20	114	23	30				
Quinnanie Shale	Coolkilya Pool, Minilya River	23	44	10	114	24	00	(d)	135	Teichert, 1950	Defined by Condon (1954).
Cundlego Formation	Midway between Coolkilya Pool and Wandagee homestead	23	35	20	114	27	10	(e)	332	Teichert, 1941	Defined by Condon (1954).
				to							
		23	34	00	114	26	30				
Bulgadoo Shale	Midway between Coolkilya Pool and Wandagee homestead	23	34	40	114	13	30	(d)	154	Teichert, 1941	Defined by Condon (1954).
				to							
		23	35	10	114	26	10				
Moogooloo Sandstone	NMF 575, south end of Gooch Range	23	51	10	114	48	30	(f)	57	Craig, 1950	Defined by Craig (1950), amended by Condon, *in* McWhae and others (1958).
Cordalia Sandstone	Round Hill, immediately E	23	20	50	114	39	30	(e)	61	Condon, 1954	Defined by Condon (1954), amended by Hocking and others (1980).

Harris Sandstone Member	Harris Bore, NNE	23	48	20	115	05	30	(e)	85	Condon, 1954	Defined by Condon (1954), amended herein.
Yindagindy Formation	Williambury homestead, W	23	51	40	115	06	20	(g)	76	Teichert, 1950	Poor exposure. Defined by Condon (1954).
Williambury Formation	Williambury homestead, ESE	23	52	40	115	10	20			Teichert, 1949	Defined by Condon (1954).
				to							
		23	52	40	115	09	50	(g)	235		
Moogooree Limestone	Williambury homestead, SE	23	54	40	115	10	40	(g)	326	Teichert, 1949	Consists of 3 partial sections. Defined by Condon (1954).
				to							
		23	53	50	115	10	50				
Willaraddie Formation	Williambury homestead, SE	23	54	30	115	11	20	(g)	294	Teichert, 1949	Consists of 2 partial sections. Defined by Condon (1954).
				to							
		23	54	40	115	10	40				
Munabia Sandstone	Gneudna Well, 1 km N	23	54	50	115	11	50	(g)	555	Teichert, 1949	Consists of 2 partial sections. Defined by Condon (1954).
				to							
		23	54	50	115	11	20				
Gneudna Formation	Gneudna Well, 6 km S	23	58	10	115	12	40	(g)	517	Teichert, 1949	Defined by Condon (1954).
				to							
		23	58	20	115	12	20				
Nannyarra Sandstone	Gneudna Well, 6 km S	23	58	10	115	12	40	(g)	59	Condon, 1954	Defined by Condon (1954), amended by Hocking and others (1980).

NOTES: 1. Where two coordinates are given for a section, the first marks the base, the second the top.
2. Thickness from: (a) Condon, 1968. (b) Moore, Hocking and Denman, 1980. (c) Condon, 1954. (d) Moore, Denman and Hocking, 1980. (e) Condon, 1967. (f) Measured during present study. (g) Condon, 1965.

The Dirk Hartog Formation conformably overlies the Tumblagooda Sandstone and has been dated from conodonts and brachiopods as Late Silurian (Opik, *in* Glenister and Glenister, 1957; Philip, 1969). In Quail 1 and Wandagee 1 the formation consists of dolomite, siltstone and anhydrite, and was deposited in shallow-marine conditions with little or no terrigenous input. It is 467 m thick in Quail 1. A sandstone member at the top of the Dirk Hartog Formation suggests a return to Tumblagooda Sandstone-type deposition.

Devonian

Devonian sediments are exposed along the eastern margin of the Carnarvon Basin, and extend in subcrop to the west where they were penetrated by Quail 1, Wandagee 1 and (on QUOBBA) Pelican Hill Bore, Grierson 1 and Cape Cuvier 1. Pendock 1, immediately west of the area, also intersected Devonian sediments. Units identified were the Nannyarra Sandstone, Gneudna Formation, Munabia Sandstone and Willaraddie Formation.

The Point Maud Member of the Gneudna Formation is present in Pendock 1. It is a (?)reefal limestone and dolomite sequence in the lower part of the Gneudna Formation and was originally named the Point Maud Formation by Geary (1970). The basal 56 m of the formation as defined by Geary is very similar to overlying carbonates assigned to the Gneudna Formation. Because the unit

(a) has rocks of Gneudna Formation lithology overlying and at its base,

(b) appears to be a facies variant of the Gneudna Formation, and

(c) has only been intersected in a single hole,

it is regarded as a member of the Gneudna Formation (H. T. Moors, pers. comm., 1981). Only the (?)reefal facies, and not the lowermost 56 m of Geary's formation, is inclined within the Point Maud Member.

Carboniferous

Lower Carboniferous carbonates were intersected by Quail 1 and probably correlate with the Moogooree Limestone (Pearson, 1964), although no definite palaeontological dating has been obtained. In Quail 1 (2 100 to 2 453 m), Warroora 1 (1 509 to 1 826 m, total depth) and Gnaraloo 1 (450 to 502 m, total depth), a siltstone and sandstone sequence was penetrated beneath the Lyons Formation and (in Quail 1) overlying the Moogooree Limestone. The age of the sequence is only poorly established as "pre-Permian" (Pearson, 1964; Johnstone and Pudovskis, 1955), and it is informally named the "Quail Formation" (Smith, 1967). The sequence in all cases appears to have been deposited in a shallow-marine environment, possibly tidal in part, and appears to correlate with the Williambury and Yindagindy Formations. The top of the "Quail Formation" may be younger than the Williambury Formation, the youngest unit in the outcrop sequence.

EXPOSED UNITS

Devonian

Devonian sediments are exposed in the Williambury-Lyndon area, on the eastern margin of the Carnarvon Basin. On Lyndon Station, they occur as elongate, structurally complex half-grabens in Precambrian rocks. Overall patterns in their occurrence are commonly obscured by Cretaceous and Cainozoic cover. The sequence consists of the Nannyarra Sandstone, Gneudna Formation, Munabia Sandstone and Willaraddie Formation, of which only the Gneudna Formation and Munabia Sandstone are accurately dated. The type sections of all units are in the Williambury area.

The Nannyarra Sandstone (*Dn*) rests unconformably on an undulating surface of Proterozoic rocks in the Williambury-Lyndon area, and consists of coarse- to fine-grained, poorly to well-sorted, thin-bedded sandstone. In the type area, the unit was probably deposited in a shallow-marine environment during the initial stages of a marine transgression. Probable braided-fluviatile sandstones are preserved southwest of Lyndon homestead.

The Gneudna Formation (*Dg*) is a calcareous and richly fossiliferous unit of Late Givetian to Frasnian age (Playford and others, 1975) which was deposited in a shallow-marine environment. The formation is 341 m thick in Quail 1, but only 98 m is preserved in Wandagee 1. Numerous fossiliferous horizons contain a diverse array of marine invertebrates including brachiopods (Coleman, 1951; Glenister, 1956; and Veevers, 1959), corals (Hill, 1954) conodonts (Seddon, 1969) and stromatoporoids.

The Munabia Sandstone (*Dm*) consists of well-sorted, fine- to coarse-grained sandstone with minor siltstone and dolomite and is conformable between the Gneudna Formation and Willaraddie Formation. Conodonts, recovered from a thin dolomite bed near the base of the sequence, suggest a Famennian age (R. S. Nicoll, pers. comm., 1979). The unit was deposited primarily in a sheet-braided fluviatile environment with minor marine incursions (Moors, 1981a).

The Willaraddie Formation (*Dw*) is a conglomeratic to sandy sequence which was deposited as an alluvial fan prograding over the Munabia Sandstone (Moors, 1981a). Within the type section, northwest of Gneudna Well, the degree of sorting of sandstone deteriorates upwards. Condon (1965) reported poorly preserved brachiopods and bryozoans from near the base of the type section, which may indicate a minor marine or estuarine incursion, but this locality could not be located again during our mapping. Plant fossils have been found at several localities.

Palaeocurrent data for both the Willaraddie Formation and the Munabia Sandstone indicate a westerly to northwesterly direction of sediment transport.

Carboniferous

Lower Carboniferous sediments, like the Devonian sequence, are exposed along the eastern margin of the Carnarvon Basin in the Williambury area. They are locally onlapped and obscured by Upper Carboniferous-Lower Permian sediments. The sequence, conformable throughout, consists of the Moogooree Limestone, Williambury Formation and Yindagindy Formation. The type sections for these units are in the Williambury area.

The Moogooree Limestone (*Cm*) rests, possibly unconformably, on the Willaraddie Formation. Coquinas of marine, shelly invertebrates, present in the middle and upper parts of the sequence, formed along strandlines and at wave base (Lavaring, 1979) while *Syringopora* colonies typify deeper, quiet water. Algal limestone is common within the formation, and is stromatolitic west of Harris Bore. Radke and Nicoll (1981) suggest that evaporitic conditions prevailed during deposition of the central part of the unit in the type area. Brachiopods, bivalves and corals, present as coquinas, are of Tournaisian age (Glenister, 1956; Thomas, 1971). The formation was deposited in a marine, carbonate-rich environment with little terrigenous supply.

The Williambury Formation (*Cw*) is restricted to the Williambury area and consists of sandstone, conglomeratic sandstone and siltstone. The formation is of fluviatile origin, and formed as an alluvial fan centred on the Williambury area.

The Yindagindy Formation (*Cy*) consists of medium- to coarse-grained sandstone with thin interbeds of oolitic and algal limestone. In the type section, 4 km west of Williambury homestead, only the resistant limestone beds are exposed. A poorly preserved fauna of marine invertebrates indicates a possibly Visean age (Thomas, 1971), and the unit was probably deposited in shallow-marine conditions with intermittent terrigenous input.

Late Carboniferous to Early Permian

The Lyons Formation (*CPl*) is a glacigene sequence consisting of poorly to moderately sorted feldspathic wacke, with minor quartz arenite and quartz wacke, siltstone, tillite and limestone to calcareous sandstone. It is poorly exposed, except in the Williambury area, and commonly outcrops as fields of weathered-out cobbles and boulders of varying composition. A reference section for the formation, near Coyango Well, is 1 380 m thick (Condon, 1967), and the section in Quail 1 is 1 478 m. The thickest known section of the Lyons Formation (2 310 m) is in Remarkable Hill 1 to the north on YANREY - NINGALOO (this thickness includes the lowermost 850 m of glacigene sediments which were not assigned to the Lyons Formation by Berven, 1969). A Sakmarian age has previously been assigned to the unit (Dickins, 1956, 1957, 1963; Dickins and Thomas, 1959), but correlation with other equivalent units in Western Australia (Kemp and others, 1977) suggests that a significant part of the Lyons Formation extends into the Late Carboniferous.

The Austin Member of the Lyons Formation (*Cla*) is a discontinuous basal sandstone, which consists of poorly to moderately sorted feldspathic wacke with lesser feldspathic arenite, quartz wacke, quartz arenite and siltstone. Locally, it contains boulder beds and soft-sediment ice-drag striae. Large-scale gravity sliding and slump structures are exposed on the south bank of the Minilya River, immediately east of Williambury homestead. The member is probably of fluviatile origin, with minor marine or lacustrine incursions.

The Harris Sandstone Member of the Lyons Formation (*Clh*) ("Harris Sandstone" of Condon, 1954, amended herein) is a moderately well to well-sorted quartz arenite, with minor quartz wacke, which outcrops only in the Yindagindy Syncline and locally contains lepidodendroid and other plant remains. The unit was retained as a separate formation by Hocking and others (1980) because no evidence of glacial influence (which would link it to the Lyons Formation) had been found, but since then, soft-sediment ice-drag striae have been discovered near the base of the Harris Sandstone Member in an outcrop immediately south of the Yindagindy Formation type section, together with what may be a glacigene boulder bed immediately beneath the sandstone. The greater maturity of the unit relative to the Austin Member suggests that it was deposited primarily in marine conditions, or in a lake of sufficient size to winnow the sand.

Permian

The Permian sequence on WINNING POOL - MINILYA can be divided into two depositional episodes. The glacigene first episode commenced with the Lyons Formation in the late Carboniferous, and ceased after deposition of the Callytharra

Formation in the late Sakmarian. The second episode commenced with fluviatile, deltaic and marine-shelf sedimentation in the mid-Artinskian and is represented by the Wooramel Group. It continued with marine-dominated, siliciclastic sedimentation in a periodically subsiding basin, which is represented by the Byro Group and lower Coolkilya Sandstone. The basin then stabilized and developed a broad marine shelf on which the remainder of the Kennedy Group was deposited.

The Carrandibby Formation is present on WINNING POOL - MINILYA but cannot be shown at 1:250 000 scale. It is a thin unit transitional between the Lyons Formation and the Callytharra Formation and contains features of both, being a polymictic, pebble-to-boulder conglomerate with a calcareous, fossiliferous matrix. Dickins (1963) and Dickins and Thomas (1959) regarded the unit as Sakmarian.

The Callytharra Formation (*Pc*) is a highly fossiliferous, calcareous sequence which conformably overlies either the Lyons or the Carrandibby Formation. The unit coarsens upwards from basal ferruginous siltstone with few calcarenite interbeds, to interbedded siltstone and calcarenite, and represents response to the melting of the Permian ice sheet. No glacial erratics have been found within the formation. The most abundant forms of the rich invertebrate fauna are brachiopods, crinoids and bryozoans. From ammonoids, the Callytharra Formation has been dated as late Sakmarian (Glenister and Furnish, 1961; Cockbain, 1980).

The Wooramel Group (*PW*) is a transgressive sandy and silty sequence which, on WINNING POOL - MINILYA, consists of the Cordalia Sandstone, Moogooloo Sandstone and Billidee Formation. Scarce marine fossils indicate an Artinskian age for the group (Condon, 1967), and rare glacial erratics in the Billidee Formation and immediately overlying Coyrie Formation indicate a cold climate. The type sections for the Cordalia and Moogooloo Sandstones are in the Gooch Range area.

The Cordalia Sandstone (*PWc*) is a thin-bedded, silty sandstone and sandy siltstone which was deposited in lower shoreface to shelf environments with relatively low terrigenous input. It overlies the Callytharra Formation with probable unconformity and commonly contains a basal bed of reworked Callytharra Formation fossils and sand grains. The unit is best developed in the Gooch Range and thins rapidly to the east and south. Cockbain (1980) suggests the Cordalia Sandstone is mid-Artinskian in age, which implies a significant hiatus between it and the Callytharra Formation.

The Moogooloo Sandstone (*PWm*) is a fine- to coarse-grained sandstone which was deposited primarily in a shallow-marine environment. The sandstone is generally well sorted, and sparkles because of authigenic overgrowths on quartz grains. Palaeocurrent data indicate a predominantly west to northwesterly direction of sediment transport from high-energy deltas which are preserved in more easterly outcrops on KENNEDY RANGE and GLENBURGH. The abruptness of the contact with the underlying Cordalia Sandstone indicates a rapid increase in the sediment supply rate.

The Billidee Formation (*PWb*) consists of fine-grained, in places calcareous, sandstone and siltstone interbedded with shale, and was deposited in lower shoreface to offshore environments. Discontinuous beds of fine-grained sandstone interbedded with siltstone to shale probably represent shoaling sand-waves similar to those described by de Raaff and others (1977). Fragments of calcareous or ferruginized wood are present in places, and near Round Hill may have assisted in rafting scattered glacial erratics. The formation has been dated as Artinskian from ammonoids (Glenister and Furnish, 1961).

The Byro Group (*PB*) is a fine-grained, locally fossiliferous shelf sequence which is conformable on the Billidee Formation. Environments of deposition interpreted for the group range from upper shoreface to offshore (Moore, Denman, and Hocking, 1980). Condon (1967) reviewed the formations of the Byro Group, which are of Artinskian age. Type sections for several of the formations are present on WINNING POOL - MINILYA. The group is generally very poorly exposed on the plains surrounding Wandagee Hill, and constituent formations are difficult to distinguish. Mapping in the area is based almost totally on aerial-photograph patterns and lineaments.

The Coyrie Formation (*PBc*) is the basal unit of the Byro Group, and is transitional from the underlying Billidee Formation. The lower half of the unit consists of black, carbonaceous siltstone to shale which crops out very poorly. This is overlain by fine-grained, silty sandstone with regular interbedding of bioturbated sandstone and laminated to low-angle cross-stratified sandstone.

The Mallens Sandstone (*PBm*) consists of quartzose and silty sandstone, and was deposited primarily in transitional to lower shoreface environments. On WINNING POOL - MINILYA, exposure of the unit is virtually limited to Burnerburnung Hill, where, 44 m of section is exposed. Some fossiliferous horizons containing an allochthonous fauna are present, and the unit is in general heavily bioturbated.

The Bulgadoo Shale (*PBb*) consists primarily of black, carbonaceous, pyritic shale and dark-grey siltstone. The unit is 215 m thick in the type section west of Wandagee homestead and was deposited under reducing conditions in a quiet-water, offshore, marine environment. Pyrite, gypsum, and phosphate nodules are present in some horizons and are of secondary origin. The unit is rarely well exposed.

The Cundlego Formation (*PBu*) consists of interbedded fine to very fine-grained sandstone and siltstone with varying amounts of carbonaceous siltstone, and was deposited in storm-dominated shoreface to offshore conditions. Thin, discontinuous, allochthonous coquinas of marine invertebrates are present in places. The calcareous nature of many of the sand lenses is due to surface enrichment and concentration of carbonate.

The Quinnanie Shale (*PBq*) is restricted to the Wandagee area, and consists of carbonaceous shale and siltstone with storm-deposited sandstone. Condon (1967) considered that the unit was a lateral variant of the upper part of the Cundlego Formation. The type section contains a varied fauna which is often preserved within secondary pyritic and phosphatic nodules. The unit formed in conditions similar to those in which the Bulgadoo Shale was deposited.

The Wandagee Formation (*PBw*) is a fining-upwards sequence of sandstone, silty sandstone, siltstone and shale, which was deposited in relatively quiet-water conditions in the offshore and transition zones. It is richly fossiliferous, especially in the lower part where storms have concentrated shells within sandstone horizons. The formation is poorly exposed except in the 130 m-thick type section, along the Minilya River, downstream from Coolkilya Pool.

The Nalbia Sandstone (*PBn*) consists of fine- to medium-grained sandstone and silty sandstone and was deposited principally in a shallow-marine, lower shoreface to transition-zone environment. The type section, north of Wandagee Hill, is poorly exposed, with no base or top: a better section is the "type section" of the "Norton Greywacke" (a synonym of the Nalbia Sandstone) in Blackheart Valley, on Northern KENNEDY RANGE. The Baker Formation (*PBk*) consists of carbonaceous and pyritic siltstone with minor silty sandstone, and was deposited in a quiet-water, offshore, marine environment, with sandstone lenses deposited during storms.

The Kennedy Group (*PK*) is only exposed at Wandagee Hill on WINNING POOL - MINILYA, where the type sections of the Coolkilya and Mungadan Sandstones are located. The sedimentology of the group was studied by Moore, Hocking and Denman (1980) primarily from outcrops on KENNEDY RANGE. The group was deposited on a broad, marine shelf which had stabilized after the recurrent subsidence which took place during deposition of the Byro Group.

The Coolkilya Sandstone (*PKc*) is the lowest formation of the Kennedy Group, and rests conformably on the Baker Formation of the Byro Group. At Wandagee Hill, the lower half of the unit was deposited primarily in a lower shoreface environment, and the upper half in a marine-shelf environment. The facies, as interpreted at Wandagee Hill, reflect increased distance from the shoreline relative to outcrops in Kennedy Range. The Coolkilya Sandstone is the only formation of the Kennedy Group from which age-diagnostic fossils have been recovered, and while Dickins (1963) and Playford and others (1975) regarded the age of the formation as Kungurian, Cockbain (1980) considered the formation to be of Artinskian age (based on revised Permian ammonoid zones).

The Mungadan Sandstone (*PKm*) consists of bioturbated sandstone to silty sandstone, and was deposited on a stable, broad, marine shelf under slightly higher energy conditions than the Coolkilya Sandstone. The type section of the unit extends from the first prominent ledge on Wandagee Hill to the trig point.

The Binthalya Formation (*PKb*) is represented by a solitary rubbly outcrop of ferruginized, fine-grained sandstone grading to siltstone west of the trig point on Wandagee Hill. Outcrops on KENNEDY RANGE were deposited in quiet-water, offshore to outer marine-shelf conditions, and an offshore depositional environment appears most probable for the outcrop on Wandagee Hill. The age of the unit has not been established, but is probably Kungurian by reference to the Coolkilya Sandstone.

Jurassic

Ultrabasic intrusive pipes, with kimberlitic affinities, intrude Permian sediments in the area immediately east of the Wandagee Fault and south of the Minilya River. To the south, more pipes are thought to be present beneath Cretaceous cover. They are probably of Jurassic age, when major tectonic activity associated with continental rifting was taking place in the Carnarvon Basin, and are probably related to the Wandagee Fault system. The pipes show no surface relief and are covered by Cainozoic wash in nearly all cases.

Cretaceous

Cretaceous sediments on WINNING POOL - MINILYA were deposited after the breakup of Gondwanaland, and sedimentation began during a major Neocomian transgression. The sequence consists of a basal sandstone overlain by fine-grained siliciclastics and siliceous pelagic sediments followed by an upper unit of calcareous pelagic sediments. The pelagic sediments reflect the very high Cretaceous sea levels, which resulted in considerably reduced land areas on the Australian continent and thereby largely eliminated the supply of terrigenous debris.

The Winning Group (*KW*) in the central Carnarvon Basin consists of, in ascending order, the Birdrong Sandstone, Muderong Shale, Windalia Radiolarite and Gearle Siltstone. Near the basin margin, the lower formations of the Winning Group interfinger with the Nanutarra Formation and Yarraloola Conglomerate.

The Birdrong Sandstone (*Kb*) is a widespread, weakly lithified sandstone to quartz sand that was deposited primarily as a shallow-marine, transgressive sand sheet. It is the principal artesian aquifer on WINNING POOL - MINILYA and although rarely exposed, has an intake area near the Pleiades where the Lyndon River anastomoses. Wiseman (1979) regarded the Birdrong Sandstone as entirely Neocomian, based on palynological work in the offshore northern Carnarvon Basin.

The Muderong Shale (*Km*) is a fine-grained unit deposited in a low-energy, offshore environment in the wake of the initial transgressive sand. It outcrops as a bioturbated, silty greensand in the Pleiades Hills-Sugarloaf Hill area, and includes minor ferruginized shales and ferruginized wood imprints. In both outcrop and subcrop the unit is mostly less than 10 m thick. Wiseman (1979) regarded the Muderong Shale as largely Neocomian in age, extending into the Aptian.

The Windalia Radiolarite (*Kw*) consists of varicoloured radiolarian siltstone, siltstone and chert and is commonly porcelaneous in outcrop. Casts, in places phosphatized, and imprints of ammonoids are locally present in outcrops in the Pleiades area, but not in the Giralia Range. Stratigraphic relationships with adjacent units, in particular the Birdrong Sandstone on AJANA (Hocking and others, 1980), and the Nanutarra Formation on YANREY - NINGALOO (van de Graaff and others, 1980), indicate that the Windalia Radiolarite formed on a marine shelf, rather than at bathyal to abyssal depths. The derivation of the dissolved silica necessary for deposition of the Windalia Radiolarite is uncertain. In the Carnarvon Basin, basalts being extruded on the mid-oceanic ridge a short distance to the northwest could have provided excess silica, but elsewhere, as in the Officer Basin where a correlative, the Bejah Claystone, is present (Jackson and van de Graaff, 1981), this mechanism is invalid. Deep weathering of onshore areas may have provided a source of dissolved silica (to feed radiolarian blooms) and also clay (to inhibit calcareous fauna) allowing siliceous rather than calcareous pelagic deposition, with negligible coarse-grained clastic input. This is broadly similar to a mechanism proposed by Folk (*in* McBride and Folk, 1979) to explain Italian Jurassic radiolarites. The unit is of Albian to Aptian age.

The Gearle Siltstone (*Kg*) consists of carbonaceous and pyritic siltstone and claystone with significant interbedded radiolarite. It was deposited under reducing conditions in a low-energy, offshore environment. Bentonitic claystone, barite nodules and secondary gypsum characterize the formation, which is rarely well exposed. It is Albian to Turonian in age (Belford, 1958; Playford and others, 1975).

The Nanutarra Formation (*Kn*) interfingers with the Birdrong Sandstone (and possibly the Muderong Shale and Windalia Radiolarite) in the Nyang and Towera areas. It rests on an irregular surface of Precambrian basement or Palaeozoic rocks, with deep channels locally developed. The formation consists predominantly of immature sandstone, and formed in fluviatile to subtidal environments with little re-sorting of sediment (Hocking and van de Graaff, 1978).

The Yarraloola Conglomerate consists of granule to cobble conglomerate, with minor sandstone, and is grouped with the Nanutarra Formation on the map face. It is a fluviatile deposit, possibly with minor marine intercalations, and is the onshore equivalent of the Nanutarra Formation.

The Toolonga Calcilutite (*Kt*) conformably overlies the Gearle Siltstone and is a chalky deposit characterized by a high content of foraminifers and calcareous nannoplankton. It formed on an open-marine shelf and is part of a world-wide event caused by changed oceanic circulation patterns following continental breakup. It is of Santonian to Campanian age (Belford, 1958), but locally extends into the Maastrichtian (McWhae and others, 1958).

The Korojon Calcarenite (*Kk*) both conformably overlies and is a lateral equivalent of part of the Toolonga Calcilutite. The formation differs from the Toolonga Calcilutite in the greater abundance of large fragments of a giant bivalve *Inoceramus* sp., and formed in a slightly shallower, slightly higher energy environment than the Toolonga Calcilutite.

The Miria Marl disconformably overlies the Korojon Calcarenite, and is a thin but persistent, condensed sequence with a rich, largely phosphatized macrofauna. Foraminifers indicate a Maastrichtian age (Edgell, 1957; Belford, 1958; McGowran, 1968).

Cainozoic

Cainozoic marine sedimentation in the Carnarvon Basin is characterized by carbonate shelf-deposition, and took place in four main episodes (Quilty, 1977, 1980):

1. Paleocene to Early Eocene (Cardabia Group);
2. Middle to Late Eocene (Giralia Calcarenite);
3. Late Oligocene to Middle Miocene (Cape Range Group); and
4. Late Miocene to Holocene.

The first three of these are preserved on WINNING POOL - MINILYA, but a continuous sequence from Late Miocene to Holocene has only been encountered in oil wells north of Barrow Island (Quilty, 1974).

Cardabia Group (TD): The Cardabia Group consists of, in ascending order, the Boongerooda Greensand, the Wadera Calcarenite (*Tw*), Pirie Calcarenite (*Tp*), Cashin Calcarenite (*Tc*) and Jubilee Calcarenite (*Tj*), and disconformably rests on the Miria Marl. The constituent formations are, to a large extent, mapped by differences in vegetation patterns, which reflect different trace-element balances in each formation. It is quite difficult to identify the formations on other than palaeontological grounds in the coastal anticlines south of the Lyndon River, and to a lesser extent in the Giralia Anticline. The group, which is richly fossiliferous, was deposited on a shallow-marine shelf.

Giralia Calcarenite (Tg): This is a greenish-brown, variably quartzose, bryozoan calcarenite characterized by large discoid foraminifers and limonite, goethite, and glauconite grains. Most glauconite is now altered to limonite and geothite. The unit formed in agitated waters on a shallow-marine shelf, with minor quartz introduced from onshore.

Merlinleigh Sandstone (Tm): This is a shorewards equivalent of the Giralia Calcarenite, and is only poorly exposed on WINNING POOL - MINILYA because of subsequent lateritization. Poorly preserved shells are present in an outcrop on Lyndon, indicating a marine depositional environment; but elsewhere such sedimentary structures as are preserved do not offer conclusive environmental evidence, and the unit may be of fluviatile origin. Cockbain (1981) confirmed an Eocene age for the unit, based on foraminifers.

Cape Range Group: Only the Trealla Limestone and Lamont Sandstone are present on WINNING POOL - MINILYA. The other units of the group were not deposited this far south in the Carnarvon Basin.

The Lamont Sandstone (*Tl*) is a thin, highly silicified quartz sandstone in which all bedding structures have been obliterated. Portions of silicified tree trunks and branches are present as float on the Chargoo Anticline. As the sediment sorting, uniform thickness, and stratigraphic relationships of the Lamont Sandstone suggest a shallow-marine to littoral origin, this wood probably floated in and sank when waterlogged.

The Trealla Limestone (*Tt*) was deposited at the height of the Miocene transgression, and is in most places a white to cream, highly fossiliferous grainstone to boundstone, locally quartzose in the Giralia Anticline. The unit conformably overlies, and in places may grade into, the Lamont Sandstone. In the Giralia Anticline, the unit was deposited on a moderate-energy, shallow-marine shelf with little terrigenous contamination. To the east, near South Lyndon Well, silt and quartz-sand contamination increases, and deposition may have been partly in a lagoonal to coastal environment. At Cape Cuvier (to the south on QUOBBA), part of the Trealla Limestone was probably deposited in a lagoonal enviroment, with intermittent emergence (Denman and van de Graaff, 1978), and this facies appears to be present south of Gnaraloo homestead.

Bundera Calcarenite (Qb): Calcareous eolianite, coralgal reefs, coquina and shelly limestone, all of which are variably calcreted, crop out along the coast and around the margins of Lake MacLeod. These deposits are mapped as Bundera Calcarenite. Members within the unit, which are based primarily on recognition of wave-cut benches at different elevations (van de Graaff and others, 1976; Denman and van de Graaff, 1977) could not be mapped on WINNING POOL - MINILYA, because only one bench can be recognized at most localities. Therefore, subdivision of the Bundera Calcarenite is restricted to eolian sandstone (*Qbe*), shoreline conglomerate, coralgal reefs and possible beach sand (*Qbc*), and shallow-marine coralgal reefs, shelly limestone and sandstone (*Qbm*). Uranium-series dating of the unit on YANREY - NINGALOO and QUOBBA gives ages of 123 000 and 128 000 years (Veeh and others, 1979) for the younger part of the unit.

Superficial Cainozoic deposits

Mapping of superficial deposits on WINNING POOL - MINILYA is based primarily on photopatterns rather than differences visible on the ground. Units are mapped according to their inferred origin by eolian, alluvial and diluvial, lacustrine, residual or mixed processes.

Ferruginous and siliceous duricrust (*Czd*) includes laterite, silcrete, and some intensely ferruginized or silicified bedrock. On WINNING POOL - MINILYA the main phase of laterite and silcrete formation probably occurred in the Oligocene (van de Graaff and others, 1980), but some duricrust may be referred to a second Miocene phase which dominates in the southern Carnarvon Basin. There is preferential development of silcrete over Windalia Radiolarite and other clayey bedrock. These duricrusts indicate a more humid, possibly more strongly seasonal climate than at present, and predate dissection of the landscape.

Calcrete (*Czk*) is extensively developed both as a duricrust on the Korojon Calcarenite and some other calcareous units, and as valleyfill calcrete in Precambrian areas. Minor calcretization of most superficial deposits has also occurred. The calcrete indicates a dry climate with sluggish groundwater movement (Mann and Horwitz, 1979) and postdates silcrete and laterite. Duricrust calcrete probably formed in the Pliocene, whereas valley calcrete is probably younger.

Conglomeratic to sandy, loose to semi-indurated alluvium (*Qa*) is extensive along the major rivers and creeks. Where there is no well-defined drainage pattern and diluvial and/or colluvial processes dominate, wash (*Qw*) is mapped.

Consolidated hardpan (*Czc*) is only mapped in preference to other Quaternary units where distinctive dissection, often accompanied by low erosional terraces, can be seen. It is of mixed alluvial, colluvial and diluvial origins, and includes the Joolabroo Formation of Condon (1954).

Alluvium grades laterally into lacustrine and eolian deposits. Large claypans and playas (*Qp*) are mapped individually, but areas containing smaller claypans intermixed with dunes and sandplain are shown as a mixed eolian-lacustrine unit (*Qep*). This unit (*Qep*) passes transitionally into sandplain and dune deposits (*Qe*). These eolian quartz sands range from orange to deep red-brown and become partly calcareous near the coast. Much of the sand appears to be locally derived in the area of the Permian sandstone strike-ridges, as dune density and height increase significantly.

In some areas, a number of processes interacted to form the current landscape, and no one process appears to dominate, except possibly residual in-place weathering. These areas are grouped in a unit of mixed or uncertain origin (*Q*), which is partly equivalent to the unit *Czc* on YANREY - NINGALOO.

Both Lake MacLeod and a smaller salt lake near Cardabia were formed by barring of the coastline by eolian dunes. These lakes are underlain by sand, silt, clay and evaporite beds (mainly gypsum and halite) and are mapped as saline lake deposits (*Ql*). Bedded evaporite deposits (*Qg*) are present at the north end of Lake MacLeod, marking a previous extension of the lake. Gypsiferous loess (*Qlg*) flanks Lake MacLeod, and was derived by eolian reworking of the lake surface.

Beaches, beach ridges and coastal dunes (*Qs*), composed mostly of calcareous sand, are present along the coast except south of Gnaraloo where high coastal cliffs are present.

Living coragal reefs forming part of the Ningaloo Reef tract extend down the coastline and reach the shore near Gnaraloo. Extensive lagoonal deposits, with some sand and submerged Bundera Calcarenite (?) beach-ridges, occur behind the reef.

STRUCTURE

The two major structural subdivisions on WINNING POOL - MINILYA in the Carnarvon Basin are the Gascoyne Sub-basin and the Merlinleigh Sub-basin, which grades northwards into the Peedamullah Shelf. The sub-basins are separated by the Wandagee Fault and Ridge (Figs 2 and 3). The Gascoyne Sub-basin is a platform of flat-lying to gently tilted rocks which is uplifted relative to the surrounding sub-basins. The sedimentary fill is primarily pre-Permian, with a cover of a westwards-thickening Cretaceous and Tertiary wedge. A horst block is present in the sub-basin beneath Lake MacLeod. The Merlinleigh Sub-basin is a west-dipping half-graben which onlaps Precambrian rocks to the east and has as its western boundary the Wandagee Fault system.

The sedimentary fill is mainly Devonian, Carboniferous, and Permian, with minor Cretaceous remnants. The Devonian and Carboniferous sequence was progressively removed by pre-Permian erosion northwards, and the Permian sequence was removed by pre-Cretaceous erosion. Silurian sediments are present near the Wandagee Fault, but are absent at the basin margin, because of either non-deposition or pre-Devonian erosion.

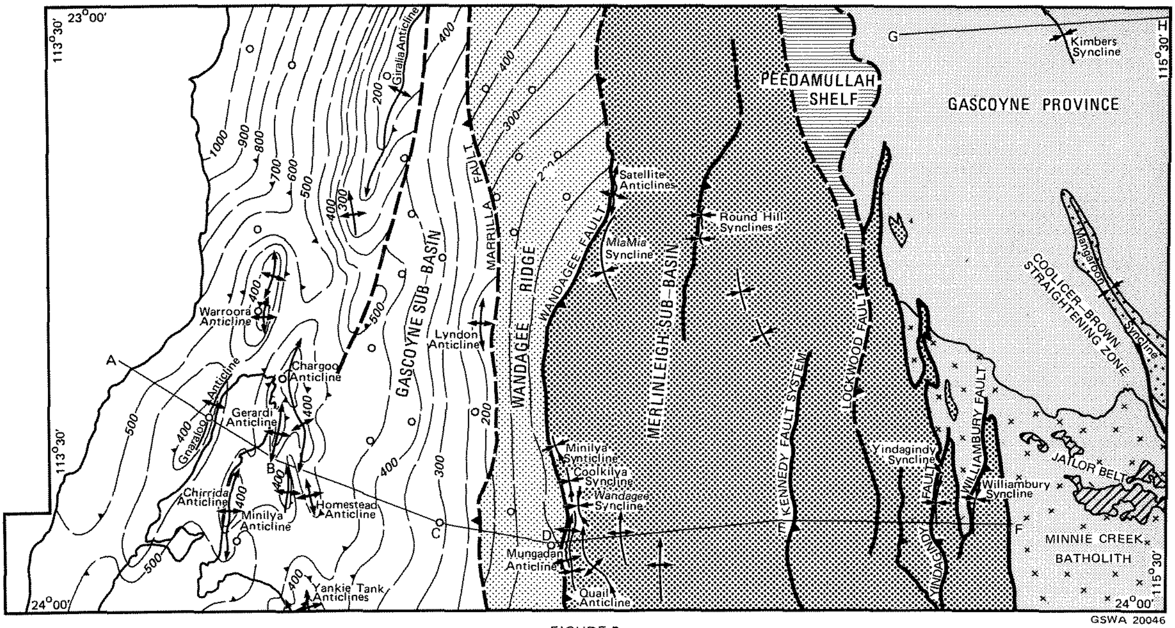

FIGURE 3

STRUCTURAL ELEMENTS

WINNING POOL–MINILYA, SHEETS SF 50–13 AND PART SF 49–16

0 10 20 30 km

REFERENCE

Carnarvon Basin:
- Peedamullah Shelf
- Gascoyne Sub-basin
- Wandagee Ridge
- Merlinleigh Sub-basin

Gascoyne Province

Fault

Syncline axis

Anticline axis

–100– Isopach : Lands surface to Top Birdrong Sandstone

o Borehole penetrating Birdrong Sandstone, west of Wandagee Fault

These basins attained their present form and attitude in the Jurassic and (possibly) Late Triassic as a result of major block faulting associated with continental rifting. Fault-plane exposures throughout the Carnarvon Basin indicate steep, normal faulting, with no evidence to suggest significant transcurrent movement. This, however, only reflects the final phase of movement, and earlier transcurrent movement may have occurred on some faults. Faulting in the Merlinleigh Sub-basin is predominantly down to the east (roughly normal to the regional tilt, thus resulting in repetition of section), and in the Gascoyne Sub-basin, down to the west.

Evidence for a similar, but earlier, phase of deformation in the Merlinleigh Sub-basin is present in the Williambury and Yindagindy Syncline, where steeply dipping Devonian and Lower Carboniferous rocks are unconformably onlapped by the more gently dipping Upper Carboniferous - Lower Permian rocks.

In the Late Miocene-Pliocene, reverse movement occurred on faults in the Gascoyne Sub-basin. This produced the series of anticlines near the coast, the structures of which are controlled by deep seated major faults. Warping of these anticlines continued into the quaternary (van de Graaff and others, 1976), and may still be continuing.

GEOLOGICAL HISTORY

Deformation of Proterozoic sediments on WINNING POOL - MINILYA occurred in the Late Proterozoic to Early Palaeozoic. Following this deformation, the fluviatile to marine Tumblagooda Sandstone and the overlying evaporitic Dirk Hartog Formation were deposited during the Silurian. The eastern limits of this phase of sedimentation are unknown, as are relationships between the uppermost Dirk Hartog Formation and the Devonian sequence. There is no evidence that deposition ceased, but a change of depositional style certainly occurred.

Deposition of the Devonian and Lower Carboniferous sequence probably extended over all of WINNING POOL - MINILYA except the easternmost quarter, and reflects a period of variable terrigenous input and changing sea levels. Environmental reconstructions by Lavaring (1979) and Moors (1981a) suggest that the eastern margin of the basin was near its present position. Moderate faulting and deformation of this sequence took place during a period of uplift and erosion in the Late Carboniferous. Following this, and probably contributing to much of the erosion, there was continental glaciation of the Precambrian areas, and glacigene sediments were deposited throughout the Perth and Carnarvon Basins, mostly in marine environments. A widespread marine transgression took place in the Late Sakmarian, possibly caused by a post-glacial, eustatic sea-level rise, during which the Callytharra Formation was deposited. There was a period of nondeposition and (probably) emergence in the early Artinskian, evidenced by a faunal break and, to the south on KENNEDY RANGE and GLENBURGH, the development of karst topography on the Callytharra Formation. This, and the subsequent regressive deposition, may reflect isostatic uplift following the melting of most of the ice sheet.

In the mid-Artinskian, the mixed fluviatile, deltaic and marine sedimentation of the Wooramel Group occurred along the margins of a developing marine shelf.

During the deposition of the Byro and Kennedy Groups, this shelf or shallow sea broadened and the coastline retreated to the east.

The Late Permian and Triassic were a period of erosion on WINNING POOL - MINILYA, and were followed in the Jurassic by a phase of major block faulting and subsequent erosion. Faulting may have commenced in the Late Triassic. This block faulting, associated with the breakup of Gondwanaland, resulted in the formation of the Ajana-Wandagee Ridge which separates the different structural styles of the Gascoyne and Merlinleigh Sub-basins.

By the late Neocomian, all fault movements had ceased and the resultant horst blocks had been planed down to base level. The continental margin foundered, sea levels rose in a major transgression, and a "post-breakup" transgressive sequence was deposited over the peneplained land surface, mostly in open-shelf environments and interfingering with continental and paralic deposits on eastern WINNING POOL - MINILYA. Pelagic marine-shelf sedimentation became dominant, and in the Late Cretaceous changed from siliceous to calcareous pelagic deposition.

On western WINNING POOL - MINILYA, calcareous shelf-deposition continued through the Tertiary, but areas in the east were intermittently or permanently emergent, and siliciclastic deposition and formation of duricrust took place. Events after laterization/silcretization are covered in the geomorphology section.

TABLE 2. WELLS DRILLED FOR PETROLEUM IN WINNING POOL - MINILYA

Name	*Type*	*Location*						*Elevation (m)*		*Total Depth (m)*	*Bottomed in*	*Drilled for*	*Year completed*	*Status*
		Lat.	*(S)*		*Long.*	*(E)*								
Airey Hill 1	NFW	23	04	02	113	52	20	GL	68	1 037	L. Permian	Monarch	1980	Dry, completed as water bore
Chargoo 1	NFW	23	35	57	113	55	56	GL	26	428	L. Permian	WAPET	1967	Dry, p & a
Gnaraloo 1	NFW	23	40	36	113	47	06	GL	46	502	Carboniferous	WAPET	1967	Very weak gas show, p & a
Pendock 1 (a)	NFW	23	17	02	113	20	10	WD	133	2 501	Silurian	Can. Sup.	1969	Very weak oil show, p & a
Quail 1	NFW	23	57	09	114	30	04	GL	115	3 580	Silurian	WAPET	1964	Dry, p & a
Wandagee 1	STR	23	53	20	114	23	57	GL	69	1 073	Silurian	WAPET	1962	Very weak gas show, completed as water well
Wandagee 2	STR	23	53	18	114	31	44	GL	103	309	L. Permian	WAPET	1962	Dry, abd
Wandagee 3	STR	23	49	48	114	20	10	GL	56	222	Devonian	WAPET	1962	Dry, abd
Warroora 1	NFW	23	30	35	113	52	55	GL	26	1 826	Carboniferous	WAPET	1955	Weak oil show, comp. as artesian bore

(a) west of sheet area.
GL=ground level.
WD=water depth.
NFW=new field well.
Monarch=Monarch Petroleum NL.
p & a=plugged and abandoned.
STR=stratigraphic test.
Can. Sup.=Canadian Superior Oil (Aust) Pty Ltd and associated companies.
abd=abandoned.
WAPET=West Australian Petroleum Pty Ltd.

ECONOMIC GEOLOGY

HYDROCARBONS

Petroleum

Most parts of the Phanerozoic sequence have been explored for hydrocarbons on WINNING POOL - MINILYA, but poor exposure and poor seismic exploration has resulted in limited knowledge and understanding of the deeper structure of the area. Consequently, only a few hydrocarbon plays have been generated. Two have been tested, one Mesozoic and one Palaeozoic.

The Mesozoic play, tested by Chargoo 1, Gnaraloo 1 and Warroora 1, is an analog of the Rough Range discovery, with the Birdrong Sandstone as the primary objective in anticlinal structures visible at the surface. Drops of oil were obtained in a water flow from the Birdrong Sandstone in Warroora 1, but no shows were encountered in the other wells. The Palaeozoic sequence tested by Quail 1 and Wandagee 1 lacks clearly defined structural closure, and the objective was largely stratigraphic, to locate attractive source rocks and reservoir targets. Although source rocks were encountered, all the Palaeozoic reservoirs were tight.

The Birdrong Sandstone is a good, areally extensive reservoir. Unfortunately, the only source rock with access to the reservoir appears to be insufficiently mature to have generated hydrocarbons. In the Palaeozoic section numerous reservoirs have been located, but because of the poor-quality, gas-prone source of low maturation, there have been no petroleum accumulations. Though electric-log evaluation has indicated that some of the sands could be suitable reservoirs, laboratory tests on core have shown porosity to be low and permeability negligible. For example, the Tumblagooda Sandstone in Wandagee 1 had a log porosity of 13-22% but core porosities of only 2-3%, and no permeability.

Undoubtedly, reservoirs and some mature source rocks exist in this part of the Carnarvon Basin. It remains to locate suitable structures to develop effective plays.

Oilshale

On WINNING POOL - MINILYA several units were deposited, at least partially, in offshore, restricted circulation, anoxic environments, which leave a high residual of kerogen. This type of environment is prospective for the development of oil shale. The formations are the Callytharra Formation, Coyrie Formation, Bulgadoo Shale, Wandagee Formation, Baker Formation and Gearle Siltstone. Exposure of the fine-grained parts of these formations is poor except in dams. Exploration and evaluation of the Permian sequence with regard to oil shale is currently (1981) in progress.

Coal

A thin (<1 m) seam of coal in the Billidee Formation was intersected by Quail 1, and The Broken Hill Proprietary Company Ltd subsequently drilled five holes to evaluate the seam (1976). The coal is parabituminous and at a depth of approximately 170 m. Further carbonaceous material was encountered at greater depths in the Moogooloo Sandstone. The Wooramel Group may therefore be prospective for coal in areas nearer outcrop, although deposition was largely in shallow-marine environments on WINNING POOL - MINILYA.

In the Eastern Goldfields, major palaeodrainage channels have been investigated for brown coal, but major drainages and palaeodrainages on WINNING POOL - MINILYA are too young and at too low an elevation to be prospective.

URANIUM

Uranium exploration on WINNING POOL - MINILYA has had four targets: the metamorphic terrain of the Gascoyne Province; valley calcrete both in the Gascoyne Province and Carnarvon Basin; the Palaeozoic sequence of the Carnarvon Basin; and the Mesozoic sequence near the Carnarvon Basin margin. Targets in the Palaeozoic sequence are the Moogooloo Sandstone (in areas south of WINNING POOL - MINILYA) and, to a lesser extent, the Gneudna Formation. Mesozoic targets are primarily the lower parts of the Winning Group where they interfinger with the Nanutarra Formation/Yarraloola Conglomerate. Substantial carnotite mineralization within calcrete at Jailor Bore has been established. Virtually all publically available information on uranium exploration and mineralization was collated by Carter (1981).

BASE METALS

Blockley (1971) recorded assays for lead samples from Lyndon and Towera stations. The nearest mines for which details are available are in the Uaroo Range group on adjacent YANREY and EDMUND.

Marston (1979) documents known copper mineralization from adjacent areas on YANREY and EDMUND. Copper mineralization is visible in samples from old mine workings north of Lyndon.

Within the Carnarvon Basin, the Gneudna Formation and Moogooree Limestone have been investigated for possible base-metal mineralization, but with only minor results. Exploration is continuing.

DIAMONDS

The area to the east of the Wandagee Fault contains kimberlitic pipes, and has been under investigation since 1978. To date, no economic concentrations have been reported. Alluvial deposits appear unlikely, as drainage in the area is primarily sheet flood, and there are no obvious palaeodrainages.

EVAPORITE MINERALS

To the south on YARINGA, the Dirk Hartog Formation contains a significant salt-bearing sequence, but this facies does not appear to extend on to WINNING POOL - MINILYA.

Texada Mines Pty Ltd operates evaporite pans in Lake MacLeod on adjacent QUOBBA. The operation was designed for potash production, but to date only halite has been sold (Denman and van de Graaff, 1978). Carter (1976) and Low (1976a) give further details of these operations. It is probable that the thickness of the evaporite sequence is much less on WINNING POOL - MINILYA, and thus is uneconomic.

Bedded gypsum covers an extensive area north of Lake MacLeod, but details of the size and purity of the reserves are not available (Low, 1976b) and their economic potential is thus unknown. The cost of extraction and distance from potential markets reduces their viability. Caldwell (1977) investigated gypsum deposits in the region.

CONSTRUCTION MATERIALS

The Trealla Limestone, Windalia Radiolarite and calcrete are used locally for road construction. The Trealla Limestone in particular is commonly the only good source of aggregate in coastal areas, although pisolitic calcrete is used locally. Flaggy Callytharra Formation and Moogooloo Sandstone have been used in other areas as paving stones and building stones.

WATER SUPPLIES

Shallow supplies with salinities ranging from about 200 to 2 000 mg/L are obtained from major drainages, but these sometimes fail during prolonged drought. The widespread superficial deposits commonly contain stock-quality water at shallow depths also.

East of the Wandagee Fault, the Moogooloo Sandstone and Munabia Sandstone generally provide good-quality water when at shallow to moderate depths. Both supply and quality of water from other Palaeozoic sediments are highly variable.

West of the Wandagee Fault, subartesian and artesian water is obtained from the Birdrong Sandstone and, to a lesser extent, the Windalia Radiolarite. Quality ranges from about 2 000 mg/L to 10 000 mg/L. In coastal regions however this groundwater is at depth (Fig. 3) and is therefore quite expensive to test. Shallower but less reliable aquifers are the Trealla Limestone, Giralia Calcarenite, Boongerooda Greensand and Korojon Calcarenite.

Large supplies of fresh water are unlikely in coastal areas. Sizeable areas of coastal dunes in some cases support wells, but supplies are small and in the form of a freshwater lens floating on saline water.

In Precambrian terrain, weathered and fractured rocks locally form good aquifers with, locally, low-salinity water suitable for domestic use. Valley calcretes and deeper, infilled drainage valleys are also used.

APPENDIX

LOCALITIES MENTIONED IN TEXT
WINNING POOL - MINILYA GAZETTEER

Locality	Latitude			Longitude		
	°	′	″	°	′	″
Baltic Bore	23	34	40	115	10	50
Bangoona Pool	23	16	10	115	20	40
Boundary Well	23	47	40	115	28	30
Brown Bore	23	35	00	115	20	40
Bulga Well	23	02	50	115	22	20
Burnerburnung Hill	23	39	20	114	32	40
Cardabia homestead	23	06	20	113	47	50
Coolicer Bore	23	30	50	115	21	00
Coolkilya Pool	23	44	00	114	25	10
Coral Bay	23	08	40	113	45	40
Coyango Well	23	47	30	114	58	20
Emu Creek Bore	23	01	50	115	15	00
Giralia Range	23	04	00	114	03	00
Gnaraloo homestead	23	49	30	113	31	10
Gneudna Well	23	55	30	115	12	50
Gooch Range	23	41	00	114	47	00
Harris Bore	23	51	20	115	04	40
Hongs Corner Bore	23	58	30	115	23	10
Jailor Bore	23	45	00	115	19	10
Kelly Corner Bore	23	37	10	115	22	50
Kimbers Well	23	06	10	115	17	50
Lake MacLeod	23	50	00	113	45	00
Lyndon homestead	23	38	10	115	15	30
Marbia Well	23	23	30	115	23	00
Minilya Roadhouse	23	48	50	114	00	20
Mount Hamlet	23	14	10	115	22	00
Munabia Bore	23	48	30	115	16	10
Nyang homestead	23	01	50	115	02	10
Pleiades Hills	23	28	40	114	54	40
Round Hill	23	21	00	114	39	40
South Lyndon Wells	23	28	40	114	15	40
Strossel Well	23	54	10	115	27	00
Sugarloaf Hill	23	22	40	114	54	20
Towera homestead	23	10	30	115	06	50
12 Mile Bore	23	10	00	115	23	00
Wandagee Hill	23	50	10	114	27	00
Wandagee homestead	23	46	00	114	33	00
Williambury homestead	23	52	00	115	08	40
Winning Well	23	28	50	115	22	10

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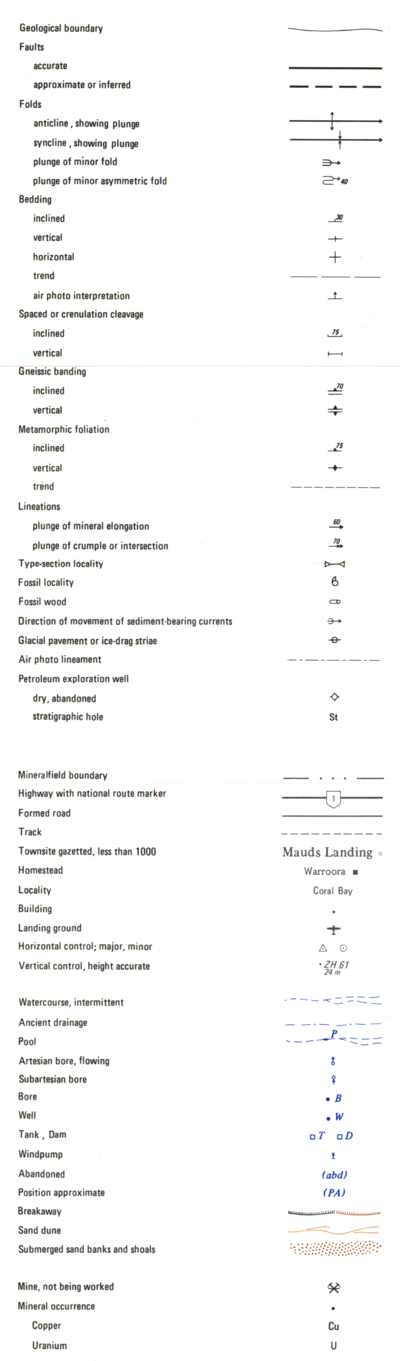
AUSTRALIA 1:250 000 GEOLOGICAL SERIES

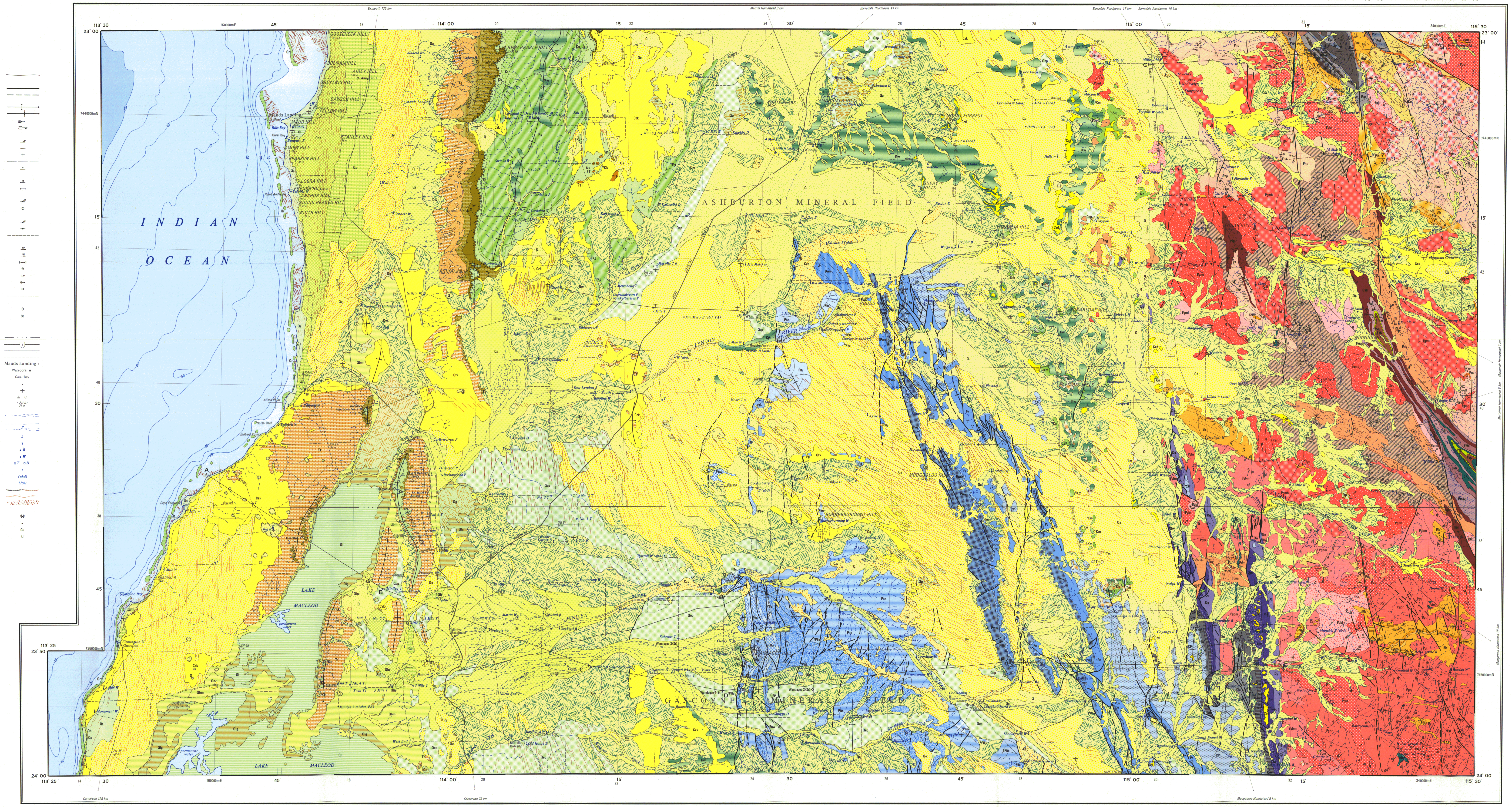
WINNING POOL - MINILYA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SF 50-13 AND PART OF SHEET SF 49-16

SYMBOLS





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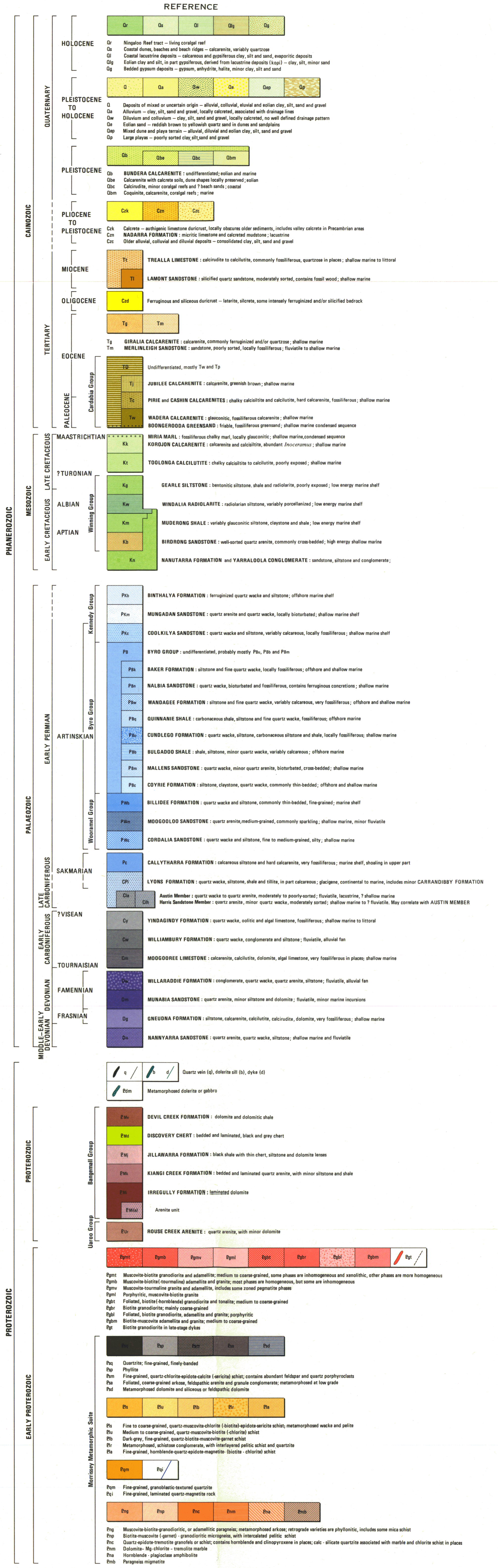
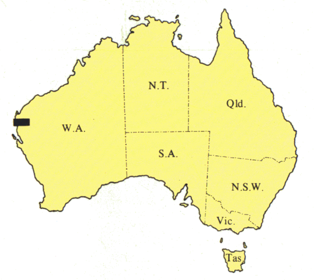
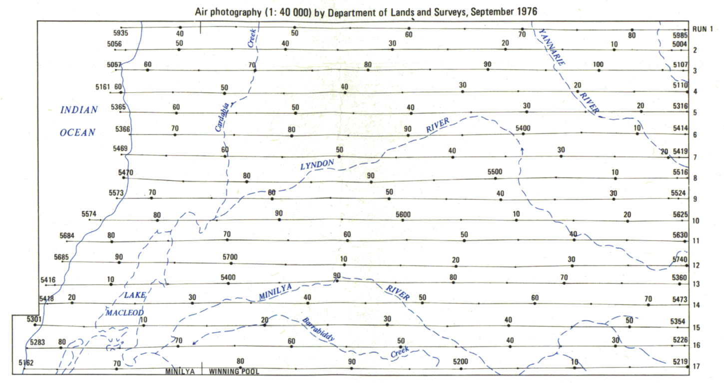


Compiled and published by the Geological Survey of Western Australia. Cartography by the Geological Mapping Section, Department of Mines. Topographic base from compilations by the National Mapping, Canberra. A.C.T.
Copies of this map may be obtained from the Geological Survey of Western Australia, 66 Adelaide Tce., Perth.

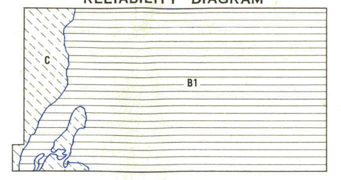


FLIGHT DIAGRAM

Air photography (1: 40 000) by Department of Lands and Surveys, September 1976



RELIABILITY DIAGRAM



B1 Numerous traverses with air photo interpretation
C Air photo interpretation

HON. DAVID PARKER, M.L.A.
MINISTER FOR MINERALS AND ENERGY
A. F. TRENDALL, DIRECTOR, GEOLOGICAL SURVEY DIVISION

SCALE 1:250 000

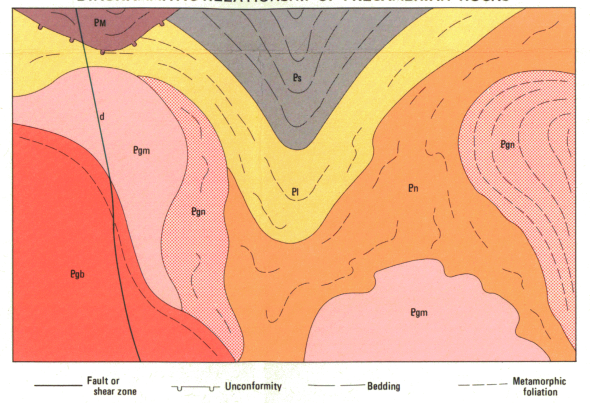
5 0 5 10 15 20 25 30 Kilometres

TRANSVERSE MERCATOR PROJECTION
ZONE 50 AUSTRALIAN MAP GRID

INDEX TO ADJOINING SHEETS

	YANREY – NINGALOO SF 50-9, 49-12	WYLOO SF 50-10
	WINNING POOL – MINILYA SF 50-13, 49-16	EDMUND SF 50-14
QUOBBA SG 49-4	KENNEDY RANGE SG 50-1	MT. PHILLIPS SG 50-2

DIAGRAMMATIC RELATIONSHIP OF PRECAMBRIAN ROCKS

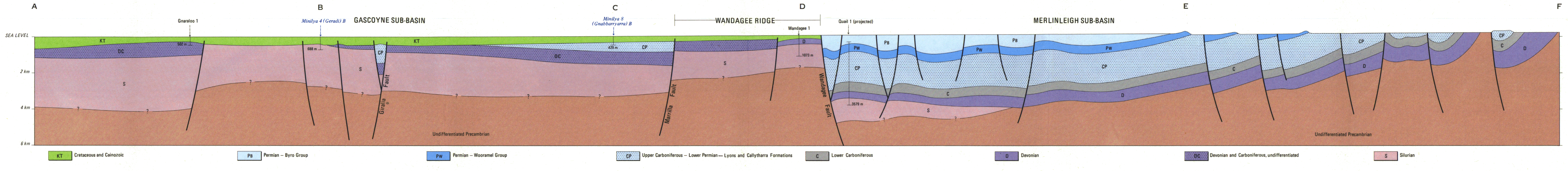


Geology: Phanerozoic – R.M. Hocking, I.H. Lavaring 1978, 79
Precambrian – S.J. Williams 1978

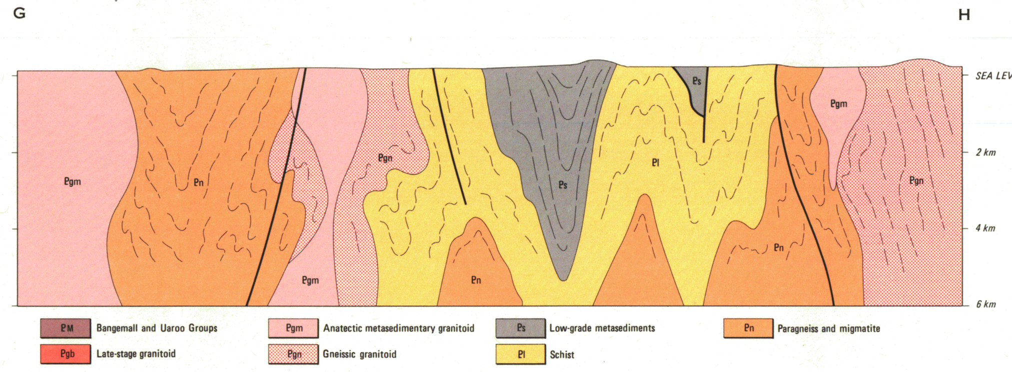
DECLINATION DIAGRAM

DIAGRAMMATIC SECTIONS

SECTION A-B-C-D-E-F



SECTION G-H



Ɛqm Fine-grained, granoblastic-textured quartzite
Ɛqi Fine-grained, laminated quartz-magnetite rock

Ɛng Muscovite-biotite-granodioritic, or adamellitic paragneiss; metamorphosed arkose; retrograde varieties are phyllonitic, includes some mica schist
Ɛnp Biotite-muscovite (-garnet) - granodioritic microgneiss, with intercalated pelitic schist
Ɛnc Quartz-epidote-tremotite granofels or schist; contains hornblende and clinopyroxene in places; calc - silicate quartzite associated with marble and chlorite schist in places
Ɛnm Dolomite- Mg-chlorite - tremolite marble
Ɛna Hornblende - plagioclase amphibolite
Ɛmb Paragneiss migmatite

WINNING POOL - MINILYA

SHEET SF 50-13 AND PART OF SHEET SF 49-16

SECOND EDITION 1984