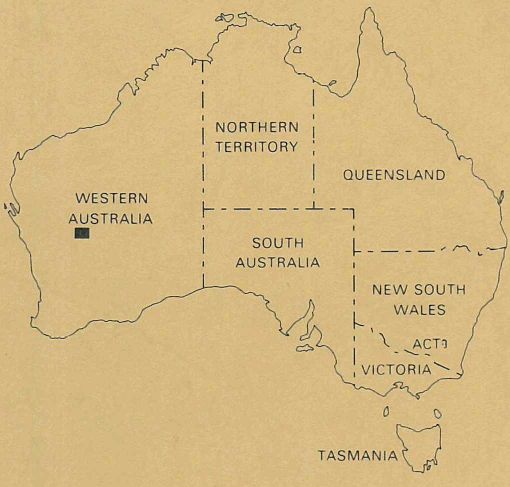
1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

SANDSTONE
WESTERN AUSTRALIA



SHEET SG/50-16, INTERNATIONAL INDEX

DEPARTMENT OF RESOURCES & ENERGY
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

DEPARTMENT OF MINES, WESTERN AUSTRALIA
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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COMPILED BY R. J. TINGEY

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Explanatory Notes on the Sandstone Geological Sheet

Compiled by R.J. Tingey

The Sandstone 1:250 000 Sheet area in the northern part of the Yilgarn Block, Western Australia, is bounded by latitudes 27° and 28°S and longitudes 118°30' and 120°E, and takes its name from a small trading township and Shire centre on the southern edge of the Sheet area. Sandstone was once a thriving gold-mining settlement serving the Black Range district of the East Murchison Goldfield. Most of the Black Range district's gold production came from the Sandstone greenstone belt which extends south from near the township into the Youanmi Sheet area; some gold was also produced from the Montague Range near Barrambie, and at Quinns in the northwest. Minor lode-mining was in progress in 1979 near Sandstone and Barrambie; past and present gold-mining centres are shown on the geological map. (The co-ordinates of places mentioned in the text are listed in Appendix 1.)

The spectacular rise in the gold price in 1979—81 spurred renewed interest in the search for gold in the Yilgarn Block, and in 1979 there was much activity around Sandstone township, most of it directed towards the discovery of gold nuggets using metal detectors. In recent years, larger scale gold-mining ventures have commenced, although the economic mainstay of the Sandstone Sheet area is still the pastoral industry, which comprises the running of sheep and cattle on the marginal grazing provided by the acacia scrub and spinifex grasslands. A major uranium deposit has been discovered near Yeelirrie in the northeast of the Sheet area, but assessment and development have been suspended following the Federal Government's withdrawal of permission to negotiate sales contracts.

Access is generally good with graded roads connecting Sandstone to Mount Magnet and Cue in the west, to Meekatharra in the northwest, to Wiluna and Yeelirrie in the northeast, and to Leonora in the east. An extensive network of station tracks provides access locally and there are airstrips at Sandstone and most pastoral stations.

The Sheet area has a semi-arid climate with hot summers, in which day temperatures above 40°C are normal, and cool winters with overnight frosts. Rainfall is irregular, and, although the mean annual precipitation is between 200 and 250 mm, there are years of almost complete drought, and others in which rainfall greatly exceeds the average.

The natural vegetation of the Sheet area is irregular in density and has probably been modified by grazing. The Sheet area is depicted as 'acacia shrubland' on Groves's (1981) map of Australia's natural vegetation, and is included in the Western Mulga Province (as shown by Doing, 1981, fig. 1). Speck (1963) quotes descriptions of the adjacent Wiluna-Meekatharra area as 'mulga scrub . . . mulga bush . . . and arid scrub', and notes that community types include woodlands, shrublands, and spinifex grasslands. He also gives descriptions of plant and tree species and habitats that generally apply to large parts of the Sandstone Sheet area, which lies mostly north of the region where mallee bush predominates. Saltbush and samphire characterise the areas around the various playa or salt-lakes. Probably the most authoritative account of the vegetation in the Sheet area is given by Beard (1976) who also discusses the regional physiography and the impact of grazing on the natural vegetation. He includes the Sandstone Sheet area in the 'Wiluna Sub-region' of the 'Austin Botanical District' in the 'Eremaean Botanical Province', and states (p.47): 'the Austin Botanical

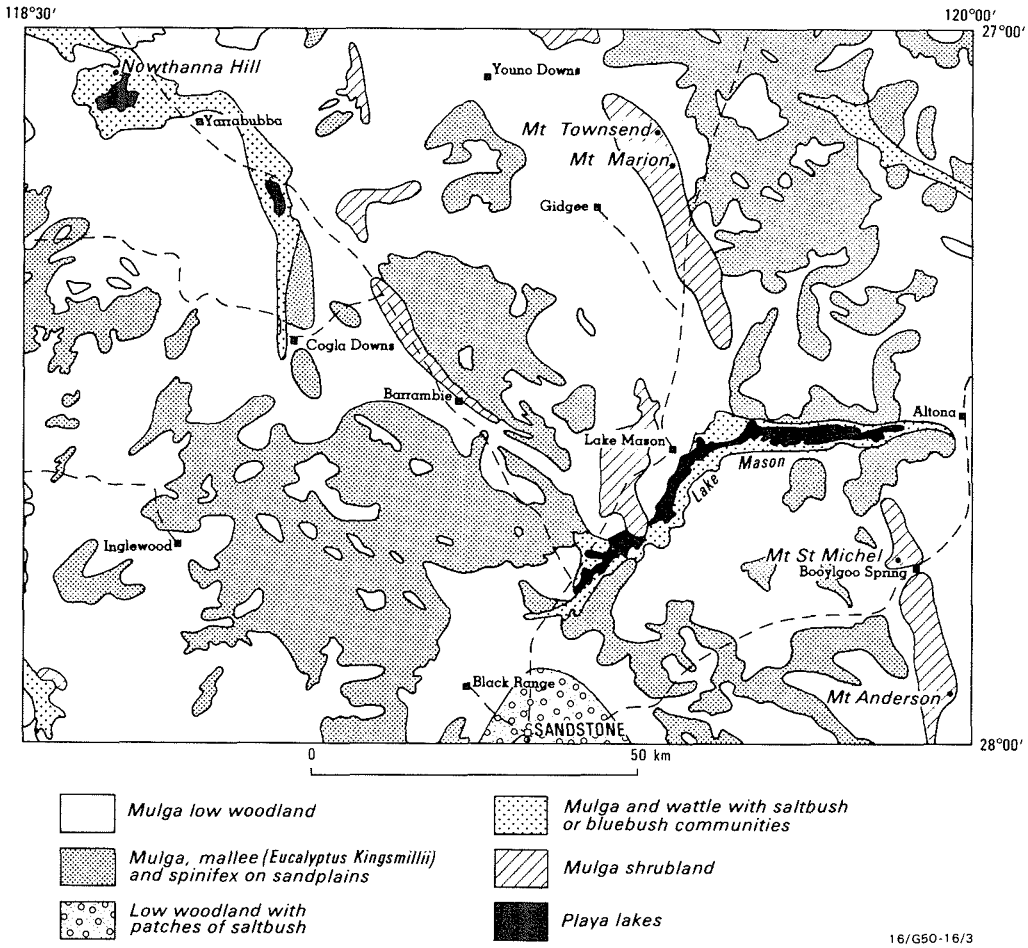


Fig. 1. Vegetation (after Beard, 1976).

District is essentially the mulga region of Western Australia. *Acacia aneura*—mulga—is dominant or contributes significantly to the biomass in the most extensive communities.' Figure 1 is based upon part of Beard's (1976) map, and shows that geological features of the area are reflected in the vegetation patterns. Vegetation cover in the Sandstone Sheet area is generally not thick enough to obscure surface geological features on aerial photographs, but, in combination with the flat terrain, is locally some hindrance to geological fieldwork, although virtually all outcrops are accessible by four-wheel-drive vehicles.

Fieldwork in the Sandstone Sheet area was carried out between June and September 1979 by L.A. Offe and R.J. Tingey (BMR) and S.J. Williams (GSWA). Offe covered the Montague Range area west to the line between Youno Downs and the Wyooda Thangoo Hills; Tingey, areas east of the Montague Range and southeast of Lake Mason; and Williams, the area around Sandstone, the Lake Mason zone of the Gum Creek greenstone belt, and the remaining western area of the sheet.

Rock nomenclature usage may not be completely consistent over the whole Sheet area since no one geologist has traversed the whole area.

The line-drawings in these Explanatory Notes (Figs. 1 and 2) were drawn by I. Hartig.

PREVIOUS INVESTIGATIONS

Exploration

The earliest European explorers to approach the Sheet area were Robert Austin (1855) who visited Poison Rocks (Youanmi Sheet area) and Mount Magnet (Cue Sheet area), and John Forrest (1875) who travelled along Lake Barlee on the southern border of the Youanmi Sheet area in a fruitless search for survivors of the Ludwig Leichhardt Trans-Australia expedition. Forrest (1875) assessed (p. 71) the country he explored as: 'worthless as a pastoral or agricultural district; and as to minerals I am not sufficiently conversant with the science to offer an opinion except that I should think it was worthwhile to send geologists to examine it thoroughly'.

The first recorded exploration of the Sandstone Sheet area was by a group from the 1891-92 Elder Scientific Exploring Expedition led by L.A. Wells; from Wells' account (Wells, 1893), it is evident that pastoralists and prospectors had already penetrated the area. Wells travelled east from Annean depot (Belele Sheet) through the northern half of the Sandstone Sheet area via Yarrabubba (see Appendix 1), Barlangi Rock ('a prominent granite rock') and Walga Gunya, the Montague Range ('prominent mountain composed of schistose rock banded with hematite, 2260 ft above sea level' [Mount Townsend]), and then southeast across desert and granite country to the Mann Range in the Sir Samuel Sheet area. Wells's geological observations and his report of possibly auriferous country to the east of the Montague Range doubtless encouraged the prospectors; gold was discovered at Black Range near the Sandstone township site in 1895.

Geoscientific investigations

Most geological investigations in the Sandstone Sheet area have been related to mining and prospecting, and detailed references to previous work at specific localities can be extracted from GSWA (1916) and Bridge (1970).

Apparently the earliest visit to the Sandstone Sheet area by a geologist was in 1892 when the Western Australian Government Geologist H.P. Woodward visited the Quinn's area (where gold had been found in 1891) to inspect mines and prospects (Woodward, 1893). The first recorded geological traverse across the Sheet area was undertaken in 1894 by Assistant Government Geologist S. Goczel who travelled along an established track from Lake Carey (east of the Leonora Sheet area) northwest to Cue. Goczel (1895) crossed four minor greenstone belts 'in a north by westerly direction' (p.30) and at least one of them is likely to have been in the Sandstone Sheet area. (The existence of the track demonstrates that it is likely that much of the earliest exploration of the Sheet area was unrecorded, since it was undertaken by prospectors, pastoralists, and others.) Some years later Blatchford (1899) crossed the northern part of the Sandstone Sheet area during a regional reconnaisance survey. He considered quartz reefs in the Montague Range to be unprospective for surface gold but suggested that quartz veins on the western side of the range might be prospective for lode gold.

The discovery of gold in 1895 near the site of the present Sandstone township led to the proclamation of the Black Range gold district which straddles the boundary between the Sandstone and Youanmi Sheet areas. Major mining activity did not occur at Black Range until 1903 when a gold rush (Montgomery, 1904) led to the establishment of a substantial if impermanent township. The first geological reports on the Black Range find were by Gibson (1904a, b) who noted that gold was being recovered from north-trending quartz reefs and alluvium, and described the country rock as altered and foliated amphibolite.

Subsequent reports on the Black Range area were compiled by Gibson (1980b) who described haematite-quartz 'jasper bars' that are in some cases gold bearing, and Clarke (1914) who showed that the jasper bars (not all of which contain jasper) pass at depth into sheared, locally pyritic, graphite schists, which in turn grade into chlorite schists at about 150 m depth. He considered that the iron in the jasper bars had been removed from leached rocks below the water table and redeposited in near-surface shear zones, but it is not clear what source he envisaged for the gold.

Gold production in the Yilgarn Block peaked in about 1903, but maximum production in the Black Range District was in 1912. Subsequent reports (Feldtmann, 1917, 1921) referred to gold mining in the Quinns area, but the gold-mining industry was soon eclipsed by pastoralism as the area's economic mainstay. From 1920 onwards, mining and prospecting activities in the Sandstone Sheet area gradually dwindled and were not revived until the exploration boom in the 1960s, although Berliat (1959a,b) and Connolly (1959) reported on iron ore deposits, and Jones (1965) and Baxter (1978) described vanadium deposits (see also Ward, 1975).

The 1960s mining boom resulted in intensive exploration in the Sandstone Sheet area, but no significant discoveries were made. Relevant company reports are held on open file at the Department of Mines in Perth although few appear to contain significant geological information. Exploration activity in the 1960s boom was largely aimed at the discovery of nickel sulphide and other base metal deposits, but related activity resulted in the detection of the Yeelirrie uranium deposit when company geologists investigated radiometric anomalies depicted on BMR geophysical maps (Gerdes & others, 1970; Haycraft, 1976). The Yeelirrie deposit is described by Western Mining Corporation (1978). Its discovery led to much company exploration as well as regional studies, particularly of valley calcretes (Butt & others 1977; Mann & Deutscher, 1978; Mann & Horwitz, 1979).

Groundwater

Morgan (1966) investigated parts of the Sandstone and Youanmi Sheet areas during a hydrogeological inspection of the East Murchison and North Coolgardie Goldfields and made general statements about the groundwater supplies likely to be encountered in particular rock types. Sanders (1969), following an earlier general study by Sofoulis (1963), examined the Sandstone, Youanmi, and other Sheet areas in the East Murchison district, but met with little success in an attempt to locate calcretes which could yield large quantities of good quality groundwater.

Geophysics

The results of an airborne magnetic and radiometric survey of the Sandstone Sheet area by BMR (Gerdes & others, 1970) aided base metal exploration and led directly to the discovery of the Yeelirrie uranium deposit. BMR also made a gravity survey of the Sandstone Sheet area in 1971; the results are available as a preliminary 1:250 000 map which can be purchased from the Copy Service, Australian Government Printer (Production), GPO Box 84, Canberra, ACT 2601. Exploration companies conducted localised geophysical surveys over the areas for which they held authorities to prospect, and employed a wide array of methods. Some indication of the work done can be gleaned from company reports submitted to the Western Australian Department of Mines, Perth. (Geophysical exploration in deeply weathered terrains like those of the Yilgarn Block poses particular problems and requires special methods; it is reviewed by contributors to the volume (which includes an extensive biliography) edited by Doyle & others (1981).)

Crustal structure

At the time of writing there is a poor understanding of the crustal structure of the Yilgarn Block although on-going programs promise some improvement in the next few years. Mathur (1974) postulated from seismic data that the crustal thickness increases from about 34 km in the east, where he proposed a two-layer structure, to about 44 km in the west where there appears to be an extra basal layer that thins eastwards. Glikson & Lambert (1976) interpret Mathur's geophysical evidence in terms of an eastward tilt of the Yilgarn Block that causes the exposure of successively shallower crustal levels from west to east. More recent accounts of Yilgarn crustal structure are given by Drummond (1979; 1981), Drummond & Shelley (1981), and Drummond & others (1981). Hallberg & Glikson (1981) review models for the Yilgarn Block's crustal structure in considering its evolution. Gee & others (1981) also discuss the structure of the Yilgarn Block and postulate that the 'gneiss terrain' in the western part of the Yilgarn Block (where the crust is thought to be thicker) represents the basement (see also De Laeter & others, 1981a) upon which the greenstones that characterise the rest of the block were originally deposited. The nature of the crust on which the greenstones were deposited is controversial in Precambrian geology, but the Yilgarn Block is unlikely to provide a definitive answer since it is composed of relatively young Archaean rocks. However, the 'Western Gneiss Terrain' (Gee & others, 1981) is somewhat older than the granite-greenstone complexes in the rest of the Yilgarn Block (see Geochronology). In the Pilbara Block, seismic studies apparently indicate a granitic crust beneath the greenstone-granite-gneiss surface exposures (Drummond, 1982).

PHYSIOGRAPHY

Although the physiography of the Sandstone Sheet area is partly described by Beard (1976) and Churchward (1977), studies of the Yilgarn Block's physiography, geomorphology, weathered profiles, and surficial deposits have been subordinate in recent years to investigations of Precambrian bedrock geology. This order of priority was applied in the mapping of the Sandstone Sheet area as described in these Explanatory Notes even though the most important mineral deposit in the Sandstone Sheet area, the Yeelirrie uranium deposit, is contained in recent valley calcretes that are a product of the current arid climate which dates from the mid-Tertiary.

The Sandstone Sheet area lies in the 'Salt Lake Division' or 'salinaland' of Jutson (1950; see also Pilgrim, 1979) and straddles the northeast-trending watershed between east and west-flowing drainage systems now occupied by strings of salt or playa lakes. The main physiographic features (Fig. 2) are: saline or playa lakes, lake deposits, and calcretes; bedrock outcrops; and breakaways and surficial deposits. The landscape comprises three main elements: a lower depositional surface of alluvial, colluvial, aeolian, and playa deposits; remnants of a higher undulating surface represented by mesas and tablelands of duricrust; and upstanding bedrock outcrops protruding through the upper surface (e.g. the higher peaks of the Montague Range and the Booylgoo Range). The best bedrock outcrops occur in these upstanding peaks and at the foot of breakaways where erosion has removed the weathering profile. Some breakaways or duricrust cliffs are as high as 25 m; they and nearby alluvial outwash deposits are portrayed in distinctive whitish tones on Landsat imagery and black-and-white aerial photographs.

Although the landscape of the Sandstone Sheet area appears very flat and monotonous, there is an overall relief of about 230 m between the lowest point at 425 m in the west of the Sheet area and the 660 m summit of Mount Townsend in

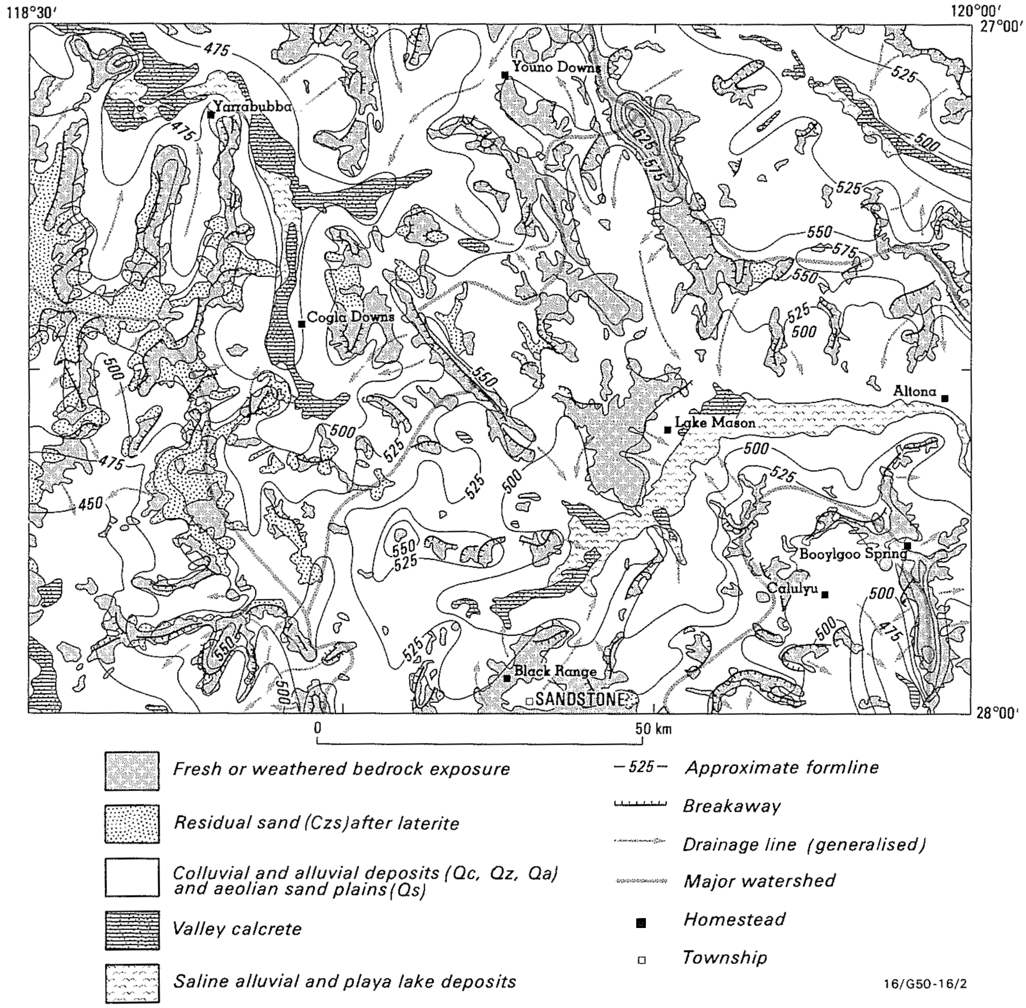


Fig. 2. Physiography.

the Montague Range. This is a somewhat greater relief than in the Youanmi Sheet area (Stewart & others, 1983).

Gee & others (1981) endorse earlier suggestions that the flat Yilgarn Block landscape is an exhumed Proterozoic peneplain, but contrary arguments and observations are presented by van de Graaff (1981) and van de Graaff & others (1977). The appearance of flatness in the Yilgarn Block is probably due to the absence of active externally draining river systems during late Cainozoic time. This led to extensive alluviation of river valleys and the formation of widespread superficial deposits and playa lakes. Van de Graaff (1981) notes that the valleys of an early Tertiary palaeodrainage system are preserved in the eastern Yilgarn Block and adjacent areas in a mainly duricrustal landscape of Eocene to Miocene age and suggests that subsequent denudation rates were low, probably of the order of only a few tens of centimetres per million years (Ma). He postulates that denudation rates in preceding more humid epochs were much higher (1.5-2 m.Ma^{-1}) in the Late Cretaceous-early Tertiary, and at least 4.5-5 m. Ma^{-1} during most of the Mesozoic.

The more humid conditions during the Mesozoic and early Tertiary also facilitated the formation of deep weathering profiles, remains of which are preserved in the Sandstone Sheet area as mesas and tablelands of duricrust bounded by breakaways (see discussion by Churchward, 1977 and, on a more regional scale, Mabbutt, 1980; Butt, 1981). The deep weathering or lateritic profiles constitute what Jutson (1950) termed the 'Old Plateau of Western Australia'. Mabbutt (1963) discusses this plateau and its dissection in describing the geomorphology of an area just to the north of the Sandstone Sheet area; similar relationships no doubt apply in the Sheet area. Mulcahy & Bettenay (1972) suggest that surficial deposits in some internal river systems in Western Australia overlie deep lateritic pallid zones, and deduce that the sediments infill river valleys of the original lateritised landscape rather than valleys incised into that landscape. This suggestion is consistent with the low late Cainozoic erosion rates inferred by van de Graaff (1981); it also implies that when the 'Old Plateau' formed and lateritisation occurred, erosion was very close to the present base level. This in turn implies that the reduced river activity in late Cainozoic time was only partly caused by increased aridity.

Weathered profiles similar to those in the Yilgarn Block and the Sandstone Sheet area have been studied in southwest Queensland and shown by palaeomagnetic methods to be the product of two pulses of deep weathering, one in Late Cretaceous–Eocene time and the other mid-Tertiary (Idnurm & Senior, 1978). It is likely that further research will reveal that several episodes of weathering were involved in the formation of the 'Old Plateau' in the Yilgarn Block.

SYNOPSIS OF GEOLOGY

Cainozoic sediments and duricrust cover much of the Sheet area. All bedrock outcrops consist of Precambrian rocks, the youngest being east-west dolerite dykes of probable Proterozoic age which intersect the Archaean rocks. Four main groups of Archaean rocks are recognised:

- —Orthogneiss and subordinate paragneiss metamorphosed under middle to upper amphibolite facies conditions.
- —Greenstone sequences comprising localised layered successions of greenschist or amphibolite facies metavolcanic or meta-igneous rocks of predominantly mafic composition with subordinate felsic or ultramafic types. These are accompanied by banded iron formation, minor pyritic shale, slate, and other metasediments.
- —Layered mafic intrusions.
- —Granitoid intrusions; some massive, others foliated.

ROCK NOMENCLATURE

The plutonic igneous nomenclature used follows Streckeisen (1976), except that the term 'adamellite' is retained for granitoids in which plagioclase comprises 35–65 percent of the total feldspar content.

REGIONAL SETTING

Gee & others (1981) propose that three greenstone provinces can be distinguished in the Yilgarn Block, each one 'apparently having a unified lithology, structural history, and perhaps even stratigraphy ' (p. 44). The Sandstone Sheet area lies in the Southern Cross (greenstone) Province of Gee & others (1981), which is apparently an equivalent of Williams's (1974) Southern Cross Subprovince of the Eastern Goldfields Province. Williams (1974) describes this subprovince as having an 'arcuate style and the northerly pre-granite trend of the greenstone belts' (p. 5). The major trends in the Sandstone

Sheet area are north-northwest, although the Sandstone greenstone belt also has north-northeast trends. Other accounts of Yilgarn Block geology are given by de la Hunty (1975), Gee (1979), Williams (1975a,b), Condie (1981), and Hallberg & Glikson (1981); a study by Hallberg (1976) is particularly relevant to the Sandstone Sheet area.

The controversy that exists among researchers in Archaean geology regarding the nature of the basement on which greenstone sequences were originally deposited has extended to studies in the Yilgarn block. Some workers, such as Gee & others (1981), regard the banded gneisses exposed in the Yilgarn Block's 'Western Gneiss Terrain' as representative of this basement, and apparently regard gneiss enclaves in the granite-greenstone provinces of the Yilgarn Block as basement relics. There is evidence that rocks in the 'Western Gneiss Terrain' are older than those in the granite-greenstone provinces (de Laeter & others, 1981b; Nieuwland & Compston, 1981; Froude & others, 1983). By contrast, authors such as Glikson (1978) regard at least some of the greenstone sequences as relics of a once-continuous volcanic crust. Condie (1981, p. 10) notes: 'evidence clearly indicates that some greenstone successions were erupted on older gneissic complexes. However, the fact that such complexes contain remnants of greenstones indicates that they, in turn, were preceded by an earlier episode (or episodes) of greenstone volcanism'. In the Sandstone Sheet area, exposures of gneiss are neither plentiful nor of good quality; most if not all contain remnants of earlier greenstone sequences in the form of banded iron formation and amphibolite inclusions. In addition, relationships between greenstone sequences and adjacent bedrock types are generally either poorly exposed or obscure. There is thus no clear evidence for the relative ages of the main greenstone sequences and gneisses; in the Diemals area (about 250 km south of Sandstone) Chapman & others (1981) were only able to define the age of gneiss precursors as being between about 2850 Ma and 2600 Ma, much the same time span as inferred for the greenstones. On a more regional basis de Laeter & others (1981a) identify 2700 Ma as the peak of the time of major generation of gneisses in the Yilgarn Block and note that there is little evidence for any wide spread about this peak.

GEOCHRONOLOGY

No geochronological studies have yet been made of rocks in the Sandstone Sheet area, but research by Chapman & others (1981) in the Diemals area 250 km to the south is probably pertinent. A general review of Yilgarn Block geochronology is given by De Laeter & others (1981a), following the pioneering studies of Arriens (1971). Chapman & others (1981) note that the ages of greenstones in the Yilgarn Block are as yet poorly constrained by the minimum Rb–Sr isochron ages of 2718 $\pm$ 50 Ma for the Kathleen Valley Gabbro in the Sir Samuel Sheet area (Cooper & others, 1978) and 2635 $\pm$ 80 Ma for the Marda Complex near Diemals (Hallberg & others, 1976). Greenstone sequences at Diemals were intruded by numerous granodiorite and adamellite plutons between 2650 Ma and 2500 Ma, during which interval the greenstones and earlier granitoids were deformed. Chapman & others (1981) also conclude that: 'the crust underwent a major metamorphic episode over the period 2650 Ma to 2550 Ma'. In the absence of better information, the geochronological framework presented by Chapman & others (1981) and De Laeter & others (1981a) is regarded as applicable to the Sandstone Sheet area.

ARCHAEAN

Gneisses

The largest exposure of gneiss is on the eastern flanks of the Sandstone greenstone belt (see inset map); there are other enclaves surrounded by either granitoid or weathered rock of indeterminate origin. Linear gneiss zones, as mapped in the Youanmi Sheet area by Stewart & others (1981, 1983), have not been found. Two gneissic rock types—*banded gneiss (Anb)* and *metaquartzite (Anq)*—are depicted on the map, but on outcrop scale further subdivisions are possible.

Continuous regular banding, mostly on the scale of centimetres, is the most striking feature of banded gneiss *(Anb)* of granodioritic to adamellitic composition and is exposed on the northeast flank of the Sandstone greenstone belt. It is defined by variations in biotite content, grainsize, and abundance of feldspar augen. The banded gneiss contains scattered microcline augen, and has a primary coarse-grained granoblastic texture upon which is imposed a streaky mylonite fabric defined by aligned, comminuted biotite (part altered to chlorite), and elongate polygonised quartz and feldspar. The primary granoblastic texture has no counterpart in nearby greenstone sequences, but the later dynamic fabric does. About 12 km north-northeast of Sandstone township a narrow band of coarse-grained, granoblastic quartzite *(Anq)* is intercalated with banded gneiss and a thin band of quartz-magnetite-grunerite rock. These metasediments may be remnants of a pre-gneiss greenstone sequence.

Poorly exposed banded gneiss near GR QQ1172 appears to consist almost entirely of rocks of granitoid composition but similar rocks near GR QQ3060 contain a lens of metamorphosed *banded iron formation (Aiw)*; there is also a quartzite band *(Anq)*, too small to show on the map. Other banded gneiss exposures (near GRs QR7808, QR8509, QR9503, QR7871, QQ7557, QR7743, QQ7436, QQ7430, QQ5011, QQ5340, and QP8399) range in composition from amphibolite to granitoid and not uncommonly contain enclaves of metamorphosed banded iron formation. They are generally surrounded by granitoid, and in some cases (e.g. at GR QQ7557) there is a gradation from amphibolite with *lit-par-lit* granitoid to banded gneiss; such gradations can be interpreted as evidence that the banded gneiss was formed by tectonic intermingling of granitoid and amphibolite or greenstone. Similar observations appear to have been made on the Shaw Batholith (which largely consists of gneissic rocks) in the Pilbara Block where Bettenay & others (1981) note (pp. 368–9): 'in the Emerald Mine area greenstone intercalations within the batholith can be traced into the greenstone envelope' which surrounds the batholith. These authors also note that Bickle & others (1980) 'present evidence that greenstones were interleaved with gneisses during an early period of subhorizontal tectonics'.

Contacts between banded gneiss and other rock types are either tectonic or intrusive, or obscure; for example, contacts between banded gneiss *(Anb)* and greenstone east of Sandstone township are not exposed, and banded gneiss in the extreme northeast corner of the Sheet area occurs as enclaves within unfoliated granitoids. There is thus no field evidence that banded gneiss formed a basement on which greenstones—even the younger greenstones—were deposited; on the other hand, the abundance of greenstone relics—for example, amphibolite and banded iron formation—in the banded gneisses indicates that the gneisses could have been formed by the intermingling of older greenstone sequences and granitoids. Compared to the Youanmi Sheet area (Stewart & others, 1983), only small amounts of banded gneiss are exposed; they provide no solution to the controversy that exists regarding the basement on which the greenstones were deposited.

Greenstone Sequences

This section encompasses descriptions of the rocks that crop out in the greenstone belts, namely metamorphosed basic volcanics, the associated banded iron formations and other metasediments, metavolcanics of felsic composition, and intrusive mafic and ultramafic rocks. Discussion of the various greenstone rock types is followed by descriptions of the sequences in the individual greenstone belts.

Greenstone sequences are clearly intruded by granitoids, but the nature of the substratum is not apparent. As noted previously, greenstone relics are quite common in banded gneiss, which suggests that there are at least two generations of greenstones: a younger one forming the greenstone belts, and an older one only represented by relics within banded gneiss.

Metamorphosed mafic extrusive rocks

These are by far the most abundant rocks in the greenstone belts. Three types are distinguished: *fine-grained metabasalt (Ab), schistose metabasalt (Aba)*, and *carbonate-bearing metabasalt (Abk)*. Pillow structures are locally preserved—for example at GR QQ9407 and GR QQ4535—and provide evidence of facing as well as of a probable subaqueous origin for the metabasalts (although the mimicking of pillow basalts by pahoehoe toes must be borne in mind).

Thick sequences of generally featureless, weakly foliated fine-grained metabasalt *(Ab)* crop out in the Sandstone, Gum Creek, and Meekatharra greenstone belts (see inset map), and include local variants such as amygdaloidal metabasalt (with quartz and/or carbonate-filled amygdales), and variolitic metabasalt which is distributed irregularly throughout the Gum Creek and Meekatharra greenstone belts; one example, at GR QR3838, 1.5 km north of Bob Well, apparently retains relicts of a primary spinifex texture. This is interpreted as evidence that the rock may belong to the komatiite (high-magnesium basalt) suite although it does not appear to be especially basic in composition.

Foliated or schistose metabasalt *(Aba)* occurs, commonly in association with fine-grained metabasalt *(Ab)*, in zones where deformation was abnormally intense; like the fine-grained metabasalt, these rocks also vary in composition and texture. Freshly broken surfaces of the schistose metabasalts characteristically sparkle because of aligned crystals of bladed amphibole (normally hornblende) and, in some cases, elongate plagioclase and quartz. Xenoliths of hornfelsic-textured amphibolite, some with hornblende porphyroblasts up to 2 cm long, occur within granitoid batholiths near contacts with greenstones, and are also mapped as schistose metabasalt *(Aba)*. Carbonate-bearing metabasalt *(Abk)* is a local minor component of most greenstone belts and has been mapped at GR QQ5462. The association of carbonate-bearing metabasalt with gold mineralisation is well known, although gold mineralisation is not known at this particular outcrop.

Banded iron formation

The three types of banded iron formation recognised are distinguished on the basis of degree of recrystallisation and metamorphism. Banded iron formation relics that are preserved among banded gneisses are generally more highly altered than those associated with greenstone sequences, and are generally mapped as *quartz-magnetite rock (Aiw)* or the higher metamorphic grade *quartz-magnetite-amphibole rock (Aim)*; these rock types also occur where greenstone successions are significantly deformed. The *banded ferruginous chert (Aic)*, the least altered of the banded iron formations, is granular and recrystallised, and is especially well displayed in the Booylgoo Range. The banded iron formations *(Aiw* and *Aim)* have a black and white appearance, whereas the ferruginous chert *(Aic)* is generally brown—local gradations between the various types are common but cannot be mapped at 1:250 000 scale. In the greenstone belts, the banded iron formation horizons tend to be more common towards the base of the succession, as for example in the Booylgoo Range. There is a strong spatial association between banded iron formation and gold mineralisation in greenstone belts throughout the Yilgarn Block; a general account of Yilgarn banded iron formations is given by Gole (1981).

Metasediments associated with the metamorphosed mafic extrusive rocks

Small lenses of metasediment are common in the greenstone belt sequences and indicate also that the sequences were deposited in a subaqueous environment. Four main types have been recognised—*schistose metasediment (As), quartzofelspathic metasediment (Asa), quartzite (Asq)*, and *black slate and phyllite (Ass)*—of which the last named has constituted an important exploration target in view of its association with base metals, particularly copper, especially in the vicinity of intrusions. This type of metasediment also contains small carbonate intercalations, as exposed on the west side of the Sandstone—Meekatharra main road and in the Montague Range (GR QQ5084). The metasedimentary units appear to be much more abundant in the Sandstone and Gum Creek greenstone belts than in, say, the Booylgoo Range greenstone belt. Other metasedimentary rocks of somewhat higher metamorphic grade occur in association with felsic volcanic rocks and are described elsewhere.

Metamorphosed ultramafic intrusions in the greenstone belts

These rocks intrude mafic igneous rocks, banded iron formation, and minor metasediments but apparently not the felsic volcanics which occur in some greenstone sequences. The ultramafic intrusives are also spatially associated with metamorphosed gabbro and dolerite, some at least of which intrude the felsic volcanics. The ultramafic intrusives are therefore also considered to be younger than the felsic volcanics although a direct field relationship has not been established.

The metamorphosed ultramafics are generally poorly exposed, although some larger bodies are marked by appreciable botanical anomalies. On weathering, they commonly yield magnesite and, in the case of olivine-rich types, chalcedony (variety, honey opal); local accumulations of these minerals in the weathered profile are good markers for ultramafic rocks or their metamorphosed equivalents, and magnesite in particular produces a distinctive white tone on aerial photographs.

The unspecified metamorphosed ultramafic *(Au)* at GR QQ4141 was mapped on the basis of a chalcedony accumulation and a poorly exposed schist outcrop; smaller bodies were noticed at several places in the Booylgoo Range and Gum Creek greenstone belts. *Tremolite-chlorite schist (Aur)* contains rare linear structures that possibly reflect an original spinifex texture, and may be dynamically metamorphosed komatiite; small bodies were mapped in the Gum Creek greenstone belt and at GR QR9009, and there is a larger north-trending body, about 17 km long, in the southern part of the Montague Range.

Medium to coarse *amphibole rock (Aux)* is considered to be a metapyroxenite; it now consists mostly of tremolite, actinolite, and minor plagioclase with relict clinopyroxene; an original clinopyroxene cumulus texture is discernible in some specimens. Examples of this rock are found in narrow bands in the Sandstone and Gum Creek greenstone belts and in a small enclave surrounded by deeply weathered banded gneiss in the extreme northeastern corner of the Sheet area (GR QQ9503).

Small podiform outcrops of *asbestiform minerals (Aus)* are not uncommon in the greenstone belts and are mapped at GR8713 on the western side of Booylgoo Range; another occurrence, at GR QQ8405, is too small to depict on the map. The asbestiform minerals are thought to have formed by metamorphism of olivine and pyroxene, and are interpreted as metaperidotite relicts.

Serpentinite or *tremolite-phlogopite-chlorite schist (Aup)* forms narrow concordant bodies near contacts between metabasalt and banded iron formation in the Gum Creek greenstone belt, and is also thought to be metamorphosed peridotite. Larger bodies of serpentinite crop out in the same greenstone belt at GRs QQ4629 and QQ4335, and in the Poison Hills at GR QR0207.

Layered amphibolite bodies *(Auj)* in the Booylgoo Range are considered to be metamorphosed, (multiple?) layered ultramafic intrusives. They consist mainly of amphibole and chlorite in various proportions, but metaperidotites, metapyroxenite, and metagabbro can be readily distinguished in the field. Most outcrops are in the central part of the Booylgoo Range but there is also one immediately beneath the banded iron formation sequences at the western margin of the Booylgoo Range, near the base of the succession, at GR QR8424. These layered bodies are commonly marked by conspicuous botanical anomalies and give rise to distinctive upstanding landforms and tonal patterns on aerial photographs. Outcrops of the layered meta-ultramafics define the synformal structure of the Booylgoo Range and indicate that the multiple intrusion was emplaced concordantly into the layered succession, although the timing of this event relative to the main deformation of the Booylgoo Range is unclear; it was not possible to assess whether or not the layered amphibolites are intersected by the axial plane fabric of the Booylgoo Range syncline. The metagabbros associated with metapyroxenites and metaperidotites in the layered amphibolites are but one of probably several generations of metagabbro in the Sandstone Sheet area.

Metamorphosed felsic volcanic rocks

These are found only in the Gum Creek greenstone belt and near Quinns in the northwestern corner of the Sheet area.

Poorly exposed, deeply weathered orange, purple, or white clay-rich rocks with scattered quartz grains and elongate quartz aggregates in the Gum Creek greenstone belt are mapped as *schistose felsic metavolcanics (Af)*. Similar deeply weathered felspathic rocks intercalated with slate and phyllite *(Ass)* in the Montague Range may also be lateritised metamorphosed felsic volcanics; a clear distinction is impossible in such poor outcrop. Some examples of schistose felsic metavolcanics are pale grey aphanitic rocks with white clay streaks, a texture interpreted as possibly reflecting rhyolitic flow banding.

Rocks interpreted as metamorphosed rhyolite and andesite are mapped as *Afl*, the metarhyolite now consisting of quartz, feldspar (locally almost totally sericitised), and accessory hornblende, biotite, and opaques. The meta-andesite comprises feldspar (very fine-grained in the matrix, and laths up to 4 mm long—both predominantly plagioclase and partly altered to epidote), quartz, hornblende, and opaques. The main difference between the two rock types is in the feldspar type, its degree, and product of alteration.

Near Quinns, metamorphosed and metasomatised rocks with an agglomeratic structure are mapped as *meta-agglomerate (Afv)*. They consist of chlorite, quartz, rutile, tourmaline, sericite, andalusite, and relict kyanite, and display textures ranging from schistose to highly irregular. Overall these agglomerates are more aluminous than normal felsic volcanics, possibly a result of the removal of other elements during metasomatism. The rocks are considered to be felsic volcanics mainly because of their agglomeratic texture. Compared to other greenstone belt volcanics in the Sandstone Sheet area and the Yilgarn Block generally, the meta-agglomerates near Quinns are unusual in that they have yielded evidence for two metamorphic episodes (see Metamorphism).

Deformed *schistose meta-agglomerate (Afx)* crops out at GR QQ5468. It consists of a fine-grained quartzofeldspathic matrix which contains feldspar grains about 1 mm wide and granitic clasts up to 170 mm long, both elongated parallel to the schistosity. This rock is compositionally quite distinct from the meta-agglomerate at Quinns; its classification as agglomerate is somewhat doubtful, being based on the felsic composition of the rock and its fragmental appearance. Poorly exposed sericite schist at two places in the Gum Creek greenstone belt is classified as metamorphosed quartz-feldspar porphyry *(Afp)*. At GR QQ2497 the metaporphyry is interlayered with metabasalt *(Ab)* and black slate and phyllite *(Ass)*, and consists of a fine-grained quartz-feldspar matrix which contains elongate aggregates of quartz and, less commonly, plagioclase, microcline, biotite, and opaque grains up to 4 mm long. Weathered examples of these rocks consist of clay with embedded quartz grains and feldspar aggregates. At the second locality (GR QR3710), the metaporphyry is strongly foliated with a lineation defined by quartz and feldspar aggregates; it is interlayered with black slate *(Ass)* along its eastern boundary although it is not clear if this relationship is tectonic or intrusive; it also contains two small gold prospects.

Metasedimentary rocks in the upper part of the layered succession

These poorly exposed and deeply weathered rocks are distinguished from the metasediments associated with metamorphosed mafic volcanic rocks in the lower parts of the greenstone sequence on the basis of their slightly higher metamorphic grade, coarser grain, and somewhat more aluminous composition. They also occur near metamorphosed rocks of possible felsic volcanic origin in the Quinns mining area. However, the difference between the two groups of metasediments is not great, and there may be gradations between them.

In the Barrambie belt and the Quinns area, medium and coarse-grained schist forms prominent outcrops, and is subdivided into *sericite-chlorite-quartz schist (Alm)* and *kyanite-sericite-andalusite-chlorite-quartz schist (Ala)*. These rocks are regarded as metamorphosed pelitic sediments, the metamorphic grade being somewhat higher than that of the small bodies of phyllite *(Ass)* found among metamorphosed mafic volcanic rocks lower in the sequence. At Nowthanna Hill in the Quinns area porphyroblasts of andalusite (now largely sericitised) up to 12 cm long dominate the schist *(Ala)* and are accompanied by a few crystals that are tentatively identified as kyanite. A discontinuous unit of *fuchsitic quartzite (Alq)* breccia contains rounded clasts up to 1 m in diameter of quartzite, schist, and altered felsic volcanic fragmental material. These rocks are interpreted on the basis of field observations as representative of volcanic breccias or necks within the meta-agglomerate sequence *(Afv)*. Because geological relationships at Nowthanna Hill and in the Quinns area in general are complex and difficult to interpret, further study is needed. The greenstone belt rock association at Barrambie also appears to be unusual: for example, metabasalt is confined to the extreme northwestern end.

Metamorphosed mafic intrusives in the layered succession

This group comprises metagabbro, metadolerite, and metamorphosed layered mafic complexes. Although some intrude, and therefore postdate, metamorphosed felsic volcanics near Quinns, they are found at various levels in the greenstone belts. There were probably several episodes of intrusive activity during the accumulation of the greenstone sequences, although some rocks mapped as metagabbro or metadolerite may be extrusive. Most rocks in the group now consist mainly of amphibole but retain relics of igneous mineral assemblages and textures; for example, *medium to coarse amphibolite (Ad)*, which is widespread as concordant bodies within mafic, sedimentary, and felsic layered sequences, retains some original gabbroic or doleritic textures. The most abundant mineral is amphibole—actinolite where the metamorphic grade was low, and hornblende where the grade was higher. Evidently the amphiboles have replaced clinopyroxene, which is preserved as relict cores; primary igneous plagioclase is also commonly preserved.

A more strongly foliated metagabbro—metadolerite is mapped as *foliated medium to coarse amphibolite (Ada)* in the Montague Range south of Mount Marion. It occupies a narrow north-northwest-trending zone on the eastern side of the medium to coarse amphibolite *(Ad)*, and appears to constitute a more intensely foliated equivalent. The rocks consist primarily of actinolite and plagioclase, the latter displaying possible traces of relict igneous textures.

Individual greenstone belts: stratigraphy and structure

In most belts metabasalt is by far the most abundant rock type. Banded iron formations are widespread, but individual units are thin, and generally discontinuous. Some belts also contain metamorphosed felsic volcanics, for example, agglomeratic rocks in the Meekatharra greenstone belt are interpreted as felsic volcanics, despite their aluminous composition.

Ultramafic bodies are found in all greenstone belts, and most appear concordant.A large multiple (or layered) ultramafic sill *(Auj)* is exposed in the Booylgoo Range. No relationship has been established between these localised ultramafic bodies and the large compound mafic complexes such as at Barrambie and Windimurra (see Mafic intrusive complexes, below).

In general, the greenstone belts are poorly exposed (Booylgoo Range is a notable exception), and their stratigraphy and structure are poorly known. The Sheet area straddles the narrow northern end of the Southern Cross Province of Gee & others (1981) and lies between their Eastern Goldfields Province in the east and Murchison Province in the west. The apparent scarcity of komatiitic basalt in the Sandstone Sheet area accords with comments by Gee & others (1981), and the lower orthoquartzite unit described by them as a feature of the Southern Cross Province greenstone sequence has not been found although Stewart & others (1981, 1983) report such rocks in the Youanmi Sheet area. The Sandstone Sheet greenstone belts display a mixture of features consistent with their position near the junction of the Southern Cross, Murchison, and Eastern Goldfields Provinces of Gee & others (1981). A sequence of mafic volcanics overlain by metasediments and felsic volcanics, as seen in the Gum Creek greenstone belt, is consistent with the succession identified by Gee & others (1981) for the Murchison Province. The presence of felsic volcanics is consistent with the Murchison Province and Eastern Goldfields Province successsions, although the latter area is characterised by a general scarcity of banded iron formation. In summary, it appears that the Sandstone Sheet greenstone sequences may have more in common with those of the Murchison Province than those of the Southern Cross Province, in which the Sheet area is placed by Gee & others (1981).

Booylgoo Range greenstone belt. The Booylgoo Range greenstone succession consists of metabasalt *(Ab, Aba)* and banded iron formation *(Aic, Aiw)* with minor metasediments *(Ass)* intruded by (metamorphosed) concordant ultramafic bodies *(Aus, Aup, Aux)* and a metamorphosed layered intrusive peridotite-pyroxenite-gabbro body *(Auj)*. Its facing is determined from pillows in metabasalt near Mount Anderson towards the southern end of the range. The overall structure of the greenstone belt is synclinal, the plunges at the northern and southern ends being towards the middle of the range, resulting in a boat-shaped structure. The syncline is intruded by granitoids *(Ag, Agb, Agt)* which are locally foliated near the intrusive contact, pegmatites *(Agx)*, and east-trending unmetamorphosed dolerite dykes *(d)* (at about 27°50′S) which also intrude the granitoids. A small patch of micaceous metaquartzite *(Asq)* 3 km southwest of Booylgoo Spring homestead might represent the basal quartzite described by Gee & others (1981) from other greenstone sequences in their Southern Cross Province. The Booylgoo Range is apparently breached by east- trending faults near Booylgoo Spring homestead, and at its southern end where the synclinal closure is repeated.

The Booylgoo Range also contains small patches of calcrete *(Czk)* where local streams cut through the ranges to disgorge onto the open plains, and local areas of pisolitic limonite *(Tl)*. In the middle of the range streams are eroding weathered rocks that may be related to the Wiluna Hardpan (Bettenay & Churchward, 1974). The upstanding nature of the Booylgoo Range contrasts with other greentone belt exposures in the Sheet area, and may indicate that local uplift has taken place in recent geological time.

Regional aeromagnetic data (Gerdes & others, 1970) suggest that the Booylgoo Range greenstone belt extends northwards beneath younger cover rocks to near the Red Handed Bore, where greenstone relics such as metabasalt *(Aba)* and banded iron formation *(Aiw)* are exposed. These rocks protrude from, and are intruded by, granitoids, and a contact sequence can be traced from metabasalt *(Aba)*, through metabasalt plus *lit-par-lit* granitoid, to banded gneiss *(Anb)*. It appears that, in this case at least, banded gneiss was formed tectonically by the smearing out of intrusive contacts between greenstones and granitoids; a similar relationship has been reported from the Pilbara region by Bettenay & others (1981). Aeromagnetic maps of the Youanmi and Leonora Sheet areas do not show anomaly patterns that could be interpreted as a southward continuation of the Booylgoo Range.

The Booylgoo Range greenstone sequence does not contain felsic volcanics, and thus differs from the Montague Range to the northwest. This might be a function of different levels of exposure of the same greenstone sequence, but a more obvious explanation is that the two greenstone belts have different successions. In addition, the Booylgoo Range sequence is intruded by muscovite- albite pegmatites not seen in the Montague Range.

Gum Creek greenstone belt. Elias & others (1979, 1982) mapped and named this greenstone belt in the southern part of the Glengarry Sheet area. It continues south and widens into the Sandstone Sheet area where three sub-zones (inset map)—the Lake Mason zone in the west, the central intermediate zone, and the eastern Montague Range zone—are recognised. The Lake Mason and Montague Range zones are characterised by outcrops of metabasalt *(Ab, Aba)* and banded iron formation *(Aic, Aiw)*, but the intermediate zone appears to be underlain by very poorly exposed and deeply weathered metamorphosed felsic volcanic rocks *(Af, Afp, Afl)* and metasediments *(Ass, Asq)*. An overall synclinal structure was deduced for the Gum Creek greenstone belt in the Glengarry Sheet area by Elias & others (1979, 1982), and this also appears to be the case in the Sandstone Sheet area. The intermediate zone of meta-felsic volcanics and metasediments therefore forms the upper part of the succession. The Gum Creek greenstone belt succession thus corresponds to the generalised model proposed by Gee & others (1981) for their Southern Cross Province.

The best exposures and main outcrops of the *Lake Mason Zone* are to the south and west of Lake Mason homestead, and in the Jasper Hills. Although metabasalts *(Ab, Aba)* are the most abundant rocks, possibly the most prominent geological feature is a large east-dipping body of banded iron formation *(Aiw)* which extends more than 15 km northwest from Schwartz Well. There are also minor bodies of metasediment *(Asa, Ass, Asq)* and small concordant bodies of metamorphosed ultramafic rock *(Aup)* (thought to be of intrusive origin; they attracted substantial exploration interest in the nickel boom of the 1960s and 1970s but no economic deposits were located), which occur mostly adjacent to banded iron formation. Concordant metadolerite bodies *(Ad)* are found throughout the greenstone succession and are generally thought to be intrusive.

Aeromagnetic data (Gerdes & others, 1970) show that banded iron formations in the Lake Mason zone are particularly prominent aeromagnetic marker horizons, and that the greenstone succession continues to the north-northwest beneath cover rocks to link up with isolated greenstone outcrops near Babba Meelah Rockhole, north and west of Bolger Well, southwest of Youno Downs homestead, and in the Glengarry Sheet area to the north (Elias & others, 1982). The outcrops near Babba Meelah Rockhole could be another example of the formation of banded gneiss by deformation of a granitoid-greenstone intrusive contact, and lie close to the western edge of the Lake Mason zone, which appears to consist of generally poorly exposed intrusive contacts between greenstone and granitoid.

The *Montague Range zone* includes some of the highest peaks in the Sheet area (e.g. Mount Townsend and Mount Marion). The main rock types are metabasalt *(Ab, Aba, Abk)* with numerous interbedded discontinuous layers of banded iron formation *(Aiw)*, minor metasediment lenses *(Ass, Asq)* and a few concordant lenticular bodies of metamorphosed ultramafic rock *(Au, Aup, Aur, Aux)*, some of which are intrusive. In addition, there are concordant metadolerites *(Ad, Ada)* which are also probably intrusive. The largest metadolerite sill in the southern Montague Range contains basal ultramafic layers, but it is not certain whether these represent distinct intrusive bodies, or were formed *in situ*. Banded iron formation layers are less common in the southern part of the Montague Range zone, and there is no counterpart of the large banded iron formation body that crops out in the Lake Mason zone. No clear facings have been observed in either metabasalts or metasediments in the Montague Range zone, but there is no reason to suspect that the sequence is overturned. Elias & others (1982) also conclude that the Gum Creek greenstone belt sequence is right-way-up.

In the Montague Range zone bedding in banded iron formation is commonly paralleled by a slaty cleavage (indicated on the map by a foliation symbol) in fine-grained metasediments. This cleavage is axial planar to both small and large-scale folds, and is also observed in the metabasalt. Both the metabasalt and the metasediments intercalated with it display a lineation which is thought to indicate the plunge of the Gum Creek greenstone belt structure. A younger crenulation cleavage (depicted on the map by a cleavage symbol) that intersects foliated metabasalt near Old Gidgee homestead is axial planar to closed late folds which are tentatively attributed to the intrusion of granitoids into the greenstone sequence. In the northern part of the Montague Range zone a mineral-elongation lineation in metabasalt, and small-scale folds in banded iron formation and metabasalt, generally plunge moderately southward: vergence of small-scale folds indicates fold closure to the north, as is evident in the map of Elias & others (1982).

The boundary between the Montague Range zone and the intermediate zone is gradational and is marked by an increasing abundance on the west side of the main Montague Range of rocks of possible felsic volcanic *(Af, Afl, Afp, Afx)* and sedimentary *(Asq, Ass)* origin. However, metaquartzite and other metasediments also occur close to the eastern flank of the Montague Range, especially near the boundary of the Sandstone and Glengarry Sheets at 119°24′E. The eastern margin of the Montague Range zone consists of poorly exposed greenstone-granitoid intrusive contacts. The granitoids *(Ag, Age, Agm)* are generally deeply weathered, and no signs of foliation have been found. Similar granitoids have been mapped in the Old Gidgee homestead area along with a large body of biotite-bearing adamellite *(Agf)*.

In the *intermediate zone* bedrock exposure is very poor and weathering deep. Scattered, very deeply weathered outcrops protruding through Cainozoic deposits are interpreted as relict felsic volcanic rocks *(Af)* and metasediments *(Ass, Asq)*. In addition, tremolite-actinolite-chlorite schist *(Aur)* in the Wyooda Thangoo Hills is interpreted as a metamorphosed ultramafic intrusion into metasediments *(Ass)*. Minor granitoids *(Ag, Agb)* have also been identified northwest of Gidgee. The intermediate-zone rocks are considered to be the upper part of the synclinal succession of the Gum Creek greenstone belt. Gold mineralisation at Gidgee (the former Jonesville mining centre) appears to be associated with deeply weathered metamorphosed felsic volcanic rocks. By contrast, most other gold deposits in the Sandstone Sheet area are associated with metabasalt, banded iron formation, and metasediment.

Meekatharra greenstone belt. The Meekatharra Greenstone belt is extensively exposed in the Glengarry (Elias & others, 1982), Belele, and Cue (de la Hunty, 1973) Sheet areas and only a small part, around the old Quinns mining centre, is in the Sandstone Sheet area. According to Elias & others (1982), the Meekatharra greenstone sequence consists of four volcanic units: two mafic ones alternating with two felsic. The Meekatharra greenstone belt is also described by Hallberg & others (1976), who identify five stratigraphic units. The exposures in the Sandstone Sheet area are within their lowermost 'lower sediment' unit and along strike from rocks described as metamorphosed komatiitic basalt and metasediment by Elias & others (1982).

The poorly exposed sequence at Quinns is dominated by rocks of aluminous composition—*meta-agglomerate (Afv)*—that are associated with banded iron formation *(Aiw)*, fuchsitic quartzite *(Alq)*, medium and coarse-grained schist *(Ala)*, and metabasalt *(Ab)*. The aluminous assemblages are considered to be of secondary, possibly metasomatic, origin, and the rocks that contain them are interpreted as volcanics. (According to Spitz & Darling (1975), it appears that the removal of alkalis from volcanic and pyroclastic rocks can result in peraluminous compositions; they relate this to hydrothermal alteration.) The Quinns area has been explored for possible stratiform massive sulphide deposits; minor copper and zinc occurrences are marked on the map.

Elias & others (1979, 1982) and Hallberg & others (1976) deduce an overall synclinal structure for the Meekatharra greenstone belt, but the local structure around Quinns consists of a doubly plunging antiform, although no evidence for the facing of the sequence was found in the 1979 survey. The antiform is a second-generation fold, and the form surface is a pre-existing schistosity. Minor first and second generation folds produce interference patterns in the antiform core.

Sandstone greenstone belt. The northern part of the Sandstone greenstone belt is indifferently exposed near Sandstone. Stewart & others (1983) show that the sequence in the Youanmi Sheet area comprises metamorphosed tholeiitic basalt, with lesser amounts of metadolerite (some, at least, intrusive), and banded iron formation.

In the Sandstone Sheet area metasedimentary rocks *(Ass)*—phyllite, slate, and dolomitic shale—are also exposed, together with thick accumulations of metamorphosed mafic volcanic rocks *(Ab, Aba)* containing bodies of coarse metapyroxenite *(Aux)*. The metapyroxenites display relict cumulus textures; clinopyroxene has been replaced by tremolite, actinolite, and minor plagioclase. The metavolcanics *(Ab, Aba)* are generally fine grained and moderately to strongly foliated (as defined by bladed amphibole crystals).

Stewart & others (1983) deduce that the belt is a north-plunging anticline; exposures in the Sandstone Sheet area therefore represent the upper part of the overall sequence. Neither facings nor evidence of inversion were observed in the Sandstone Sheet area, but Stewart & others (1983) demonstrate that the sequence is 'right-way-up'. To the extent that metasedimentary rocks are more common, and that the part of the section exposed in the Sandstone Sheet area is near the top of the sequence, it would appear that the Sandstone greenstone belt conforms with the generalised greenstone successions for the Southern Cross Province of Gee & others, (1981).

The eastern margin of the Sandstone greenstone belt is poorly exposed in the Sandstone Sheet area, but adjacent banded gneiss *(Anb)* is strongly foliated and contains small blocks of banded iron formation which may be either relics of even older greenstone sequences, or allochthonous blocks tectonically isolated from the Sandstone greenstone belt. Alternatively, the complete banded gneiss unit, including the banded iron formation blocks, may have been formed by tectonic reworking of the marginal zones of the Sandstone greenstone belt and adjacent granitoid intrusives. This model implies the existence of only one generation of greenstones, whereas the former model requires two or more.

The western margin of the Sandstone greenstone belt, northwest of Sandstone, is marked by a faulted contact (Youanmi Fault) between schistose metabasalt *(Aba)* and foliated granitoid *(Agt)*. Nearby fold hinges and lineations plunge south-southwest at moderate angles, and are thought to be related to rotational or drag effects along the fault.

The Sandstone greenstone belt was extensively worked for gold early this century and activity has revived recently. The old gold workings were mostly in metabasalt and metasediment south of Sandstone, and most, as described by Stewart & others (1983), were in the Youanmi Sheet area.

Poison Hills greenstone belt. This belt straddles the boundary between the Sandstone and Glengarry Sheet areas at 119°E, and outcrops consist of metabasalt *(Aba)* and banded iron formation *(Aim, Aiw)* with minor metasediment *(As)*; these are intruded by now-metamorphosed ultramafic rocks *(Aup)*, and muscovite-albite pegmatite *(Agx)*. The belt is flanked to the west by gneissic biotite granodiorite *(Agt)* but contacts are either poorly exposed or tectonic. Other granitoids *(Ag, Agb)* crop out on the east side of the belt, but show no sign of tectonism. (Foliated granitoids are common adjacent to greenstone belts and may have resulted from granitoid emplacement into a compressive tectonic environment.) In the Glengarry Sheet area Elias & others (1982) have identified metabasalt, banded iron formation, and metadolerite. The overall structure of the Poison Hills belt has not been determined, but north and south plunging fold axes have been mapped.

This deformation was followed by emplacement of a muscovite-albite pegmatite *(Agx)* characterised by euhedral albite megacrysts up to 50 mm long. Similar late-stage pegmatites are not known in the two nearest greenstone belts (Meekatharra and Gum Creek), but they do occur in the Booylgoo Range greenstone belt and near Agnew in the Sir Samuel Sheet area (the 'Perseverance Pegmatite' of Cooper & others, 1978).

Joyners Find greenstone belt. This belt is extensively exposed to the north in the Glengarry Sheet area, and extends a short distance into the Sandstone Sheet area. Elias & others (1979, p. 15) describe it as 'a relatively narrow north-trending belt with two subparallel banded iron formations' (see also Elias & others, 1982). They also suggest that it was formerly contiguous with the Booylgoo Range greenstone belt, but there is neither geological nor aeromagnetic nor other geophysical evidence for this.

The small outcrops of the belt in the Sandstone Sheet area consist of banded iron formation *(Aiw)*, and metabasalt *(Aba)*. Isolated outcrops of similar rocks in breakaway slopes close to, and northwest from, the proposed Yeelirrie townsite have the same trends and may be related. They occur within, or adjacent to, small patches of banded gneiss (Anb) and are generally set, probably as xenoliths, within large areas of granitoid *(Agb)*. A small patch of metamorphosed ultramafic rock *(Aux)* is exposed about 2 km north of the proposed Yeelirrie townsite.

Other greenstone relics. Minor greenstone relics occur on the margins of the Barrambie and Windimurra intrusions and are described with them in the next section.

Mafic Intrusive Complexes

Two large mafic igneous complexes crop out in the Sandstone Sheet area: the Barrambie Intrusion, in the central part, and the Windimurra Intrusion (gabbroid) in the southwestern corner. Stewart & others (1983) describe the Windimurra body and other mafic igneous complexes in the Youanmi Sheet area, and Williams & Hallberg (1973) give an account of other layered mafic intrusions in the Yilgarn Block. Korsch (1971) proposed that layered mafic intrusive bodies in the Sandstone-Youamni region of the Yilgarn Block were linked, but there is neither field nor geophysical evidence to support this.

Barrambie Intrusion

The Barrambie Intrusion makes up most of the Barrambie belt (see inset map) and consists largely of a layered mafic igneous complex *(Adj, Adjm)*. Metasediments *(Alm)* and minor greenstone relics, mainly in the form of banded iron formation *(Aiw, Aim)*, also occur in the belt, and there are minor metabasalt bodies *(Aba)* in peripheral areas; for example, north of the Errols gold mining centre, and northwest from Barrambie Bore. Banded gneiss *(Anb)* to the east of the belt (north of Fred Bore, and west of Corkscrew Well) apparently lacks greenstone relics and is largely granitoid in composition. It may therefore be a variant of the foliated granitoids *(Ag, Agt, Agu, Agb)* that also crop out in the area. Within the Barrambie belt the rocks mapped as quartz-chlorite-sericite schist *(Alm)* are thought to be metasediments, but their pre-metamorphic nature has not been definitely established and they might be metamorphosed felsic volcanics. The Barrambie mafic igneous body almost certainly intrudes the quartz-chlorite-sericite schists, though field evidence for this is not abundant. Possible contact metamorphism is indicated by the presence of albite porphyroblasts in schist at one locality near Barrambie homestead.

The Barrambie Intrusion consists of metagabbro with layers of metapyroxenite and meta-anorthosite *(Adj)*, and distinctive layers of magnetite rock *(Adjm)* formed presumably by cumulus processes. Rocks of anorthositic gabbro composition predominate in the core and contain three main zones of concentrated vanadium-bearing titaniferous magnetite *(Adjm)* (now martite) with an aggregate thickness of up to 25 m. Metagabbros on each side of the Barrambie belt meta-anorthosite also contain scattered magnetite-rich lenses. The magnetite cumulates occur between layers of metagabbro, pyroxenite, and anorthosite, but are too irregular to define the overall structure of the intrusion. However, most measured dips are westward, which is consistent with aeromagnetic anomaly patterns of Gerdes & others (1970) and with the overall outcrop pattern, particularly the occurrence of isolated rafts of magnetite rock in granitoids to the west of the main Barramble intrusion. The existence of these rafts of magnetite cumulate *(Adjm)* is interpreted as evidence that the mafic body was emplaced before the main phase of the granitoid intrusion in the Yilgarn Block; that is, before about 2550–2600 Ma. An intrusive relationship between the mafic body and the schists could be interpreted as implying that the mafic body postdated at least some stages of the formation of the greenstone sequences. It is possible that the Barrambie Intrusion was emplaced more or less contemporaneously with the extrusion of lavas in the greenstone succession, and that it was a manifestation of the same mafic igneous activity. Geochronological studies of the Barrambie Intrusion have not been made.

The Barambie belt is the site of a number of gold workings, some of which were still active in 1979; it has also been suggested that vanadium could be extracted from the magnetite-rich rocks (Ward, 1975; 1981). According to Gibson (1908b), the gold mineralisation, which is commonly accompanied by minor pyrite (only seen as pyritohedron casts in outcrops), appears to be associated with concordant quartz reefs within the schists. Ward (1981) records vanadium concentrations of between 1.9 and 3.6% in the magnetite-rich rocks. Minor copper mineralisation in the Barrambie area has attracted exploration studies, but no commercial deposits have been found (see Marston, 1979).

Windimurra Intrusion

This metamorphosed mafic-ultramafic anorthosite igneous complex crops out in the southwestern corner of the Sandstone Sheet area but is much more extensively exposed in the Youanmi (Stewart & others, 1983) and Kirkalocka (Baxter & others, 1980) Sheet areas; it also occurs in the Cue Sheet area (de la Hunty, 1973): slightly different names for the intrusion are used in these earlier publications. In the Sandstone Sheet area the relevant exposures consist of micaceous quartzite *(Asq)* and banded iron formation *(Aiw)*, intruded by coarse metagabbro *(Adj)*. The intrusion intersects felsic volcanic rocks in the Youanmi Sheet area and metasediments in the Cue Sheet area. In the Sandstone Sheet area it has *lit-par-lit* contacts with younger intrusive granitoids and is intersected by thin dolerite dykes. Stewart & others (1983) regarded equivalent dykes in the Youanmi Sheet area as co-magmatic with the main Windimurra Intrusion.

Ahmat & De Laeter (1982) cite a minimum age of 2669 ± 135 Ma for the Windimurra Intrusion (they use the synonymous term 'Gabbroid') based on Rb-Sr geochronological studies of cross-cutting granitoid rocks; this age is consistent with the observed field relationships. Ahmat (1983) postulates from preliminary Sm-Nd isotopic data that the Windimurra Intrusion might be as old as 3050 Ma and thus considerably older than the Yilgarn Block greenstone successions; however, this suggestion needs to be reconciled with field observations.

GRANITOIDS

As in most of the Yilgarn Block, granitoids are by far the most abundant rocks, but they are generally poorly exposed. Most of the best granitoid outcrops are to be found close to and below breakaway escarpments, but a few residual, weathering-resistant masses protrude above the general level of the laterite surface. The paucity of the outcrop effectively prevents delineation of individual batholiths and plutons, except in a few local areas where contacts can be traced out. Where outcrop is too deeply weathered for accurate distinction of specific granitoid types, the bedrock is mapped as undivided granitoid *(Ag)*. In general, observed field relationships do not define a sequence of granitoid intrusions. The Yilgarn Block granitoids are generally not regarded as economically significant and consequently they have not been studied in detail in the Sandstone Sheet area, although they are presumed to have been the source of the uranium in deposits such as Yeelirrie. Some analyses of Yilgarn Block granitoids are reported from localities close to the Sandstone Sheet area by Bunting & Williams (1979) and Stewart & others (1981; 1983). No geochronological studies have been made of granitoids in the Sheet area, but there is no reason to suspect that there is any great difference from sequences of granitoid intrusive events deduced in the Sir Samuel Sheet area by Cooper & others (1978) and in the Barlee Sheet area (south of Youanmi) by Chapman & others (1981).

The most common granitoid is a medium-to-coarse, generally seriate-textured, biotite-bearing rock *(Agb)* of adamellitic or granitic composition which locally has fine-grained, granular, pegmatitic, and granodioritic variants. Oligoclase is the dominant plagioclase and microcline generally the main potash feldspar; biotite is evenly distributed through the rock and is typically finer grained than quartz and feldspar. The typical seriate texture of these rocks is due to scattered larger crystals of microcline. There are also local foliated variants of the biotite granitoid *(Agb)*, the foliation being defined by aligned microcline megacrysts, elongate quartz and feldspar aggregates, and aligned biotite crystals. In places these granitoids have a more or less distinct wavy banding (defined by varied biotite abundance) which is thought to have formed before the magma had crystallised.

Most of the other granitoids can be described in terms of their relationship with the biotite granitoids *(Agb)*; for example, xenoliths of augen granite, porphyritic granitoid *(Agl)*, gneissic granitoid and biotite granodiorite *(Agt)*, and tonalite, as well as banded gneiss *(Anb)*, and amphibolite schlieren are found within larger bodies of *Agb*. The biotite granodiorite and tonalite xenoliths invite speculation that the biotite granitoid *(Agb)* was derived by partial melting of similarly more sodic and more primitive felsic igneous rocks. In most cases these xenoliths are too small to be mapped separately and the mixture of granitoids is mapped as *(Agm)*.

The rocks contained as xenoliths in the biotite granitoid *(Agb)* are clearly older than this granitoid, as are rocks intruded by it. Thus, biotite granitoid locally intrudes, and is younger than, foliated fine-grained biotite granite *(Age)* and foliated granitoid *(Agt)* that locally grades into banded gneiss *(Anb)*. Elsewhere, the biotite granitoid intrudes coarse, locally foliated, granitoid *(Agt)* that contains banded gneiss and amphibolite xenoliths. In addition, veins of biotite granitoid intersect foliated coarse porphyritic granitoid *(Agl)* (also containing amphibolite schlieren) and gneissic biotite granodiorite *(Agf)* near Barrambie. Biotite granitoid *(Agb)* is also predated by gneissic muscovite-biotite granite *(Agu)* of irregular grainsize which is partly intermingled near Barrambie with gneissic biotite granodiorite *(Agt)* which is bordered to the west by unfoliated biotite adamellite *(Agb)*. The gneissic musovite-biotite granite *(Agu)* contains rafts and xenoliths of magnetite rock and metagabbro which constitutes firm evidence that it postdates the Barrambie mafic intrusion.

Field relationships between various types of biotite granitoid *(Agb)* indicate a sequential development; for example, coarser biotite granitoid is intruded by finer grained varieties, and foliated biotite granitoid is intruded by unfoliated equivalents. This latter relationship might constitute evidence that foliation developed during intrusion rather than as a consequence of later tectonism. The biotite granitoid locally has a transitional relationship to biotite-poor *leucogranite* or *adamellite* of varied grainsize *(Agf)* that typically, but not exclusively, occurs near greenstone belt margins; these transition zones are characterised by numerous leucogranite veins. Field relationships also show that some granitoids intrude and thus postdate biotite granitoid *(Agb)*; for example, fine-grained biotite granite *(Age)* intrudes biotite granitoid and is itself intersected by pegmatite veins that are cross cut by aplite dykes. Locally however, biotite granitoid grades into its own pegmatitic phase rather than being intruded by a later pegmatite.

The remaining granitoids in the Sheet area are best considered in relation to rocks other than biotite granitoid *(Agb)*. Thus, southeast of Yarrabubba homestead an isolated mass of muscovite-albite granite *(Aga)* is intruded on its southeastern margin by two small plug-like bodies of hypabyssal *soda rhyolite granophyre (Agr)*, the eastern one, which forms the prominent Barlangi Rock, departing from typical granophyric texture in that silica mostly forms bladed crystals rather than cuneiform intergrowths with feldspar. Other bodies of granophyric tonalite *(Agr)* intrude leucogranite *(Agf)* near the southwestern corner of the Sheet area.

The *muscovite-albite granite (Aga)* displays features—such as bent plagioclase twin lamellae, inclusion trains in quartz crystals, and unusual parting in muscovites—that are interpreted as evidence of severe mechanical shock, possibly related to the emplacement of the soda rhyolite granophyre plugs; the absence of micro-ruptures is attributed to annealing when temperatures were raised probably during emplacement of the plugs. The muscovite-albite granite is borded to the south by biotite granitoid *(Agb)*, but the contact is poorly exposed. Although direct evidence is lacking, muscovite-albite granite *(Aga)* and soda rhyolite/granophyrric tonalite *(Agr)* are thought to be younger than the biotite granitoid *(Agb)*.

The youngest granitoid phase in the Sheet area appears to comprise locally zoned coarse grained *muscovite-albite granite* and *muscovite-albite pegmatite (Agx)* which typically contains prominent white albite phenocrysts up to 10 cm long and 2 cm wide. These rocks occur along the eastern margin of the Poison Hills (where they intrude biotite granitoid) and in the Booylgoo Range where they intrude the greenstone sequence. The muscovite-albite pegmatite appears to have much in common with the Perseverance granite/muscovite pegmatite of Cooper & others (1978). Although these authors note that the Perseverance pegmatite contains plagioclase of An 30 their chemical analyses are more compatible with albite being the main plagioclase feldspar, which would support correlation of the Perseverance pegmatite with the muscovite-albite pegmatites *(Agx)* in the Sandstone Sheet area. The Perseverance pegmatite intersects the Perseverance nickel orebody and is dated (Cooper & others, 1978) at 2588 ± 18 Ma with a high IR of 0.7624 ± 0.0068.

QUARTZ BLOWS

Narrow ridges composed almost entirely of quartz are common throughout the Sandstone Sheet area and are named quartz blows. The quartz appears to be a product of the last stages of granitoid emplacement and occupies fractures with two distinct orientation groupings: about north-south, and east-west. In some places the north-trending quartz blows offset the east-trending ones, but it is not clear that this is invariably the case. A green colouration, perhaps due to the chromium mica, fuchsite, appears to be more commonly associated with the apparently older east-trending blows. Some quartz blows intrude greenstone sequences and locally replace banded iron formation.

PROTEROZOIC

The only known Proterozoic rocks in the Sheet area are east-trending mafic dykes which have been found in three places: in the Booylgoo Range; 7 km west of Calulyu homestead; and in the southwestern corner of the Sheet area at GR PQ6822. At the first locality the dykes cut across the Booylgoo Range greenstone sequence, but at the other two the country rock is granitoid. The Booylgoo Range mafic dykes stand up from the greenstone sequence, and the dense brown- black olivine dolerite of which they are composed rings distinctively when struck by a hammer. The dolerite is essentially unaltered and consists of plagioclase An_{55}, clinopyroxene, opaques, and olivine. The dyke rocks near Calulyu homestead are similar. In all of the dykes olivine is slightly altered but there is no sign of the greenschist-facies regional metamorphism that affected the greenstone sequences. The dykes are tentatively correlated with the Widgiemooltha Dyke Suite (Sofoulis, 1966), of which some dykes have been isotopically dated by the Rb-Sr method at 2420 ± 30 Ma (Turek, 1966). This constitutes circumstantial evidence that the greenschist facies metamorphism of the greenstone sequences occurred prior to 2420 Ma.

CAINOZOIC

The Precambrian bedrock is largely obscured by extensive surficial deposits of Cainozoic age; neither Palaeozoic nor Mesozoic rocks have been found. Butt (1981a) suggests that Precambrian cratonic areas in Western Australia have been emergent at least since the Permian, and that Permian glaciation and erosion during the Jurassic and Cretaceous (with concomitant deposition in marginal basins—see van de Graaff, 1981) had led to extensive planation by the mid-Cretaceous. Deep weathering in a probably humid, temperate to warm climate followed, with possibly even tropical conditions developing in Oligocene–Miocene times. Since then an arid climatic regime has been established, possibly as a consequence of the continental-scale glaciation of Antarctica. Products of the deep weathering regime now mantle the Precambrian bedrock and are overlain by mostly unconsolidated deposits produced in the arid climatic regime of more recent times. Relationships between the various Cainozoic rocks in the Youanmi Sheet area are illustrated by Stewart & others (1983), and a similar scheme applies in the Sandstone Sheet area (see inset cross-section).

The Cainozoic rocks are subdivided into Tertiary weathering profile deposits *(Tb, Tl, Tj)*, Cainozoic deposits *(Czk, Czs)*, and Quaternary cover deposits *(Qa, Qz, Qc, Qs, Ql, Qg, Qgd, Qsc)*.

Tertiary weathering-profile deposits

These constitute a prominent component of the Sandstone Sheet area and are characteristically exposed in flat-topped 'breakaways' (see Physiography). Their age of formation is poorly constrained and the processes probably lasted for many millions of years; profile development appears to have started in the Mesozoic and continued into the Tertiary. Although several pulses of deep weathering probably occurred, it has not been possible to recognise multiple profiles—as in Queensland (Idnurm & Senior, 1978)—and no direct age determinations have been made of profiles in the Yilgarn Block.

Three types of Tertiary weathering-profile rocks are recognised, although differences between them are not always distinct.

Duricrust (Tb) generally refers to rocks that make up the 'breakaways' and are mostly derived from bedrock of granitoid or other felsic composition; it includes laterite, minor silcrete, and the upper part of the underlying, pallid, saprolite zone.

Ferricrete or *laterite (Tl)* refers to more ferruginous and generally less resistant weathering profiles developed over greenstone; minor 'breakaways' exist near Sandstone, notably at London Bridge about 5 km southeast of the town (just within the Youanmi Sheet area). The symbol *Tl* is also used to refer to the topographically more subdued parts of the weathering-profiles over granitoids — mainly pallid saprolite—from which the resistant duricrust capping *(Tb)* has been removed.

Jasperoidal chalcedony and siliceous limonite (Tj) are very limited in extent since they are closely associated with ultramafic rocks, but they constitute a valuable aid in prospecting for ultramafic rocks and possibly associated nickel sulphides.

Cainozoic surficial deposits

These comprise limonitic sandplains *(Czs)* and valley calcrete *(Czk)*. The *limonitic sands (Czs)* are typically reddish brown in colour and overlie the Tertiary weathering-profile deposits exposed at 'breakaways'. They are thought to be relics of the surface horizon of the Tertiary weathering-profile, and thus date from the deep-weathering climatic regime. They are also thought to have formed by reworking of hydrous iron oxides in the upper part of the weathering profile, and consist of quartz and resistant accessory minerals such as zircon, ilmenite, anatase, magnetite, and chromite (Butt, 1981a) as well as fragments of pisolite, and laterite. These limonitic sandplains appear to be more widespread in the west of the Sheet area than in the east. This may be an artefact of the mapping, but could reflect the less-ferruginous trend in near-surface zones towards the northeast noted by Butt (1981a).

Valley calcrete (Czk) occupies the central channels of former main drainage lines, and also occurs where drainage systems enter saline lakes such as Lake Mason. It is thought to have formed as a result of groundwater circulation and desiccation (Mann & Deutscher, 1978; Mann & Horwitz, 1979, who also discuss calcrete genesis and lithology in some detail). It is generally mounded at least 2 to 3 m above the surrounding unconsolidated deposits in the wide flat drainage basins. As a result, drainage now generally occurs in twin streams along the edges of the calcrete mounds.

The calcrete, which is up to 15 m thick, is generally white, crumbly to hard, and includes some dolomitic varieties (Mann & Horwitz, 1979), some darker-coloured sections, and patches of cemented country-rock fragments. The calcrete is fissured, perhaps as a result of differing responses of the various constituent rock types to desiccation. The fissures provide a suitable location for the precipitation of carnotite, a uranium- and vanadium-bearing mineral that occurs in large quantities in the Yeelirrie uraniferous calcrete prospect (Mann, 1974; Western Mining Corporation, 1975, 1978; Cameron & others, 1980).

The age of the valley calcrete is uncertain, and it appears that its formation or modification is continuing. The calcrete is a product of the current arid climate that began in Miocene times.

Quaternary cover deposits

These deposits cover most of the Sheet area. They range from sand-plain deposits overlying Tertiary weathering profiles to deposits in saline lakes. The *sandplains (Qs)* consist of aeolian sands derived from the weathering products of granitoid rocks, and differ from the older Cainozoic sandplains *(Czs)* in being characterised by north-to-northwest-aligned linear dune systems. They are typically covered by spinifex grass.

The other Quaternary deposits are found within the wide, flat drainage basins that are rimmed by breakaways. *Colluvium (Qc)* consisting of broken rock debris is found immediately downslope from the breakaways and associated bedrock exposures, and grades downhill into *mixed alluvium and colluvium (Qz)* which in turn grades into *active alluvium (Qa)*. Areas of mixed alluvium and colluvium are typically thickly vegetated and have few stream channels: water flows, in sheet-flow mode, across them. Stream channels, albeit impermanent ones, are much more common in the alluvium *(Qa)* areas, and are likely to be considerably modified when water flows, especially after storms. Areas of *Qa* and *Qz* can generally be expected to yield reasonable-quality groundwater from bores and wells because recharge conditions are relatively favourable.

The alluvial deposits *(Qa* and local *Qz)* mark drainage courses that lead into saline playa lake systems that are remnants of large-scale Cainozoic drainage systems in Western Australia (van de Graaff & others, 1977). The lake systems are characterised by four types of Quaternary deposits: *lake deposits (Ql)* that have no vegetation cover and are deposited or modified when the lakes fill with water; *marginal lake deposits (Qg)* that are only flooded under exceptional circumstances and are commonly vegetated with stunted grasses and trees; *gypsum dunes (Qgd)* that have accumulated by aeolian reworking of gypsum crystals from the saline playa lakes, together with small amounts of windblown red sand. These dunes locally have hard gypsiferous encrustations and red sand cover. The fourth Quaternary unit is photo-interpreted, and comprises *aeolian sand cover on karst surfaces of buried valley calcretes (Qsc)*; it has only been mapped in the Yeelirrie drainage basin.

The saline lakes may have some economic significance in that they may possibly provide the groundwater recharge that permits redistribution and deposition of carnotite in valley calcretes. There are two small such playa lakes on top of the valley calcrete which contains the Yeelirrie uranium deposit.

METAMORPHISM

The mineral assemblages of metamorphic rocks described previously, mainly reflect low-grade (greenschist facies) metamorphism, especially in the greenstone belts. In the neighbouring Youanmi Sheet area banded gneiss is exposed more extensively than in the Sandstone Sheet area and Stewart & others (1983) deduce that the gneiss has been affected by two metamorphisms, whereas the greenstone successions show evidence of only one. These conclusions support the idea proposed by several authors that banded gneiss in the Yilgarn Block represents a metamorphic basement on which greenstones were deposited.

By contrast, evidence for two metamorphisms in the Sandstone Sheet area comes from the Meekatharra greenstone belt where early-formed andalusite and kyanite crystals (some relics remain) appear to have been replaced by chlorite and sericite; and from the banded-gneiss/greenstone-belt contact on the eastern side of the Sandstone greenstone belt where the gneiss has a streaky mylonitic fabric superimposed on a coarse granoblastic fabric, the younger fabric being of similar style to fabrics in metabasalt in the adjacent greenstone belt.

Metamorphic effects are varied both within and between greenstone belts, with some rocks containing hornblende and actinolite, and others the lower-grade assemblage, chlorite and sericite. These variations might be interpreted as evidence of discrete metamorphic episodes, but a more plausible explanation is that low-grade metamorphism had varied effects from place to place depending largely on the availability of water. Similarly, low-grade metamorphic effects are evident but patchy in granitoids and banded gneisses.

The main metamorphism appears to have been a low-grade greenschist-facies episode that was of patchy intensity; it postdates the emplacement of granitoids but predates the dolerite intrusions (the dolerites are unaltered). The low-grade metamorphism thus appears to have been more or less coeval with the major deformaton of the area and probably occurred during, perhaps in the later stages of, the granitoid intrusive activity.

STRUCTURE AND LINEAMENTS

The general structure of the Archaean rocks is illustrated in the inset map (interpreted Precambrian geology), mainly by the disposition of the various rock units. Most of the Sandstone Sheet area is underlain by unfoliated granitoid rocks, and it is difficult to compile a comprehensive account of the area's structural geology. Foliated rocks are mostly found in the greenstone belts, which are separated by wide areas of granitoid rocks or surficial deposits and define a dominant north to northwesterly structural grain; a subordinate northeast trend appears in the Meekatharra and Sandstone greenstone belts.

Stewart & others (1983) mapped two major faults—the Youanmi and Edale faults—in the Youanmi Sheet area and described them as first-order wrench faults; they converge at the Sandstone greenstone belt and form its western and eastern boundaries. Evidence for the continuation of the Edale fault into the Sandstone Sheet area is less convincing than that for the Youanmi fault, although it is perhaps significant that the Barrambie belt lies along the same trend as the Edale fault which may mark a fundamental lineament active in Archaean time. These relationships accord with the deduction of Stewart & others (1983) that wrench faulting in the Youanmi Sheet area occurred before Proterozoic dolerite dykes were emplaced (i.e. probably before 2420 ± 30 Ma ago); these authors estimated the amount of lateral movement along the Youanmi and Edale faults, but this has not been possible in the Sandstone Sheet area.

The structures of the individual greenstone belts have been discussed previously and no consistent pattern (apart from the trends already mentioned) is discernible. However, deformation clearly predates intrusion of dolerite dykes and appears to have been closely coincident with widespread granite plutonism, as would be expected. Deformation probably also occurred in conjunction with the wrench faulting described by Stewart & others (1983).

A preliminary analysis of Landsat imagery of the Sandstone Sheet area shows that the northwest and northeast trends of the greenstone belts and other structural features are also reflected in Landsat lineaments. It was not possible to make a comprehensive analysis which would have involved examination of a number of sets of imagery, each acquired at different seasons. The significance of Landsat and other lineaments is unclear, but interesting coincidences have been pointed out by various authors, notably O'Driscoll (1981, 1982).

ECONOMIC GEOLOGY

MINERAL OCCURRENCES

Gold

Table 1 summarises GSWA gold production statistics for the Sandstone Sheet area, although figures for Sandstone include production from some mines and workings in the Youanmi Sheet area. It is evident that production in the vicinity of Sandstone was an order of magnitude greater than that in the other centres. Gold-mining activity in the Sheet area has revived in recent years in response to increased gold prices but statistics were not available when these Notes were compiled. Although alluvial and dollied gold were important in the discovery and establishment of the various gold mines, their contribution to total gold production has been very small.

Gold is found in various rock types in the Sandstone Sheet area. The association in the vicinity of Sandstone township is with basalt, dolerite, and banded iron formation. Maitland (1919) states that the most important orebody in this vicinity was the Sandstone Reef composed of crumbly and friable quartz; the Sandstone reef abuts against a 'jasper bar' (banded iron formation) and is closely followed by a fine-grained dolerite dyke, but neither of these rocks appears to have 'exerted any appreciable influence on the gold values' (Maitland, 1919, p. 44). Another important ore horizon near Sandstone township was the Black Range Reef, which also consists of quartz and has a spatial association with a 'jasper bar'.

Other gold production centres are at Barrambie (where Dougherty's gold mine was still operational in 1979) and Errols in the Barrambie greenstone belt; Quinns in the Meekatharra greenstone belt; and Jonesville and Birrigrin in the Gum Creek greenstone belt. Maitland (1919) notes that quartz reefs infilling shear zones aligned parallel to the foliation of the schistose country rocks are the main gold source-rocks in the Errols–Barrambie area. He refers to the Gum Creek greenstone belt mining centres (as the Montague gold belt) and states that ore deposits appear to occur in

TABLE 1. GOLD PRODUCTION DATA—SANDSTONE SHEET AREA

Goldfield	*District*	*Locality*	*Alluvial gold (kg)*	*Dollied gold (kg)*	*Ore treated (t)*	*Gold recovered (kg)*	*Average grade (g/t)*	*Total gold recovered (kg)*
East Murchison	Black Range	Errols	0.644	17.150	15 407.59	308.896	20.04	326.690
		Barrambie (incl. Sugarstone)	0.159	5.995	21 987.69	622.012	28.29	628.166
		Montague (incl. Jonesville)	—	5.327	86 189.11	829.291	9.621	834.618
		Birrigrin	—	31.122	14 763.65	507.743	34.391	538.865
		Sandstone	1.612	194.526	731 781.93	14 381.503	19.652	14 577.641
Murchison	Meekatharra	Quinns	0.696	77.017	37 795.50	503.338	13.317	581.051
		Total	3.111	331.137	907 925.47	17 152.783	18.89	17 487.031

Figures provided by Geological Survey of Western Australia.

quartz reefs and in nearby country rock schists; as in other mining areas, gold is closely associated with the quartz reefs. This is also the case at Quinns where there are, however, some large barren quartz reefs. The gold-bearing reefs at Quinns are described as 'laminated', and consist of white and bluish jointed quartz. The gold is somewhat erratically distributed (Maitland, 1919).

A final source of gold is in the weathering-profile rocks; test crushings of these were being made at the Sandstone State Battery in 1979, but no results are known.

Silver

Maitland (1919) notes that silver is found in most gold occurrences in Western Australia, but its only economic significance is as a mining by-product. These comments presumably apply to the Sandstone Sheet area.

Copper (and locally zinc)

A comprehensive account of copper mineralisation in Western Australia is given by Marston (1979) who mentions minor copper mineralisation at Barrambie and Quinns.

The Barrambie mineralisation was mined in 1944, and between 1956 and 1961; it occurs in an open flat 200 m west of the (abandoned) Barrambie homestead on the western side of a narrow northwest-trending greenstone belt too small to be shown on the map. The country rock in the abandoned open cut appears to be very weathered chlorite-quartz schist, and the copper mineralisation (malachite and chrysocolla) occurs in a north-northwest-striking laminated quartz vein. Marston (1979) assigns this mineralisation to his 'Type C' (cupriferous quartz veins and shears). Explorationists have examined the Barrambie area for copper prospects, but no economic deposits have been found.

Marston (1979) designates the copper-zinc mineralisation near Quinns as 'Type A—stratabound mineralisation in supracrustal rocks'. He describes it under 'deposits in medium-to-high-grade metamorphic rocks' although, in view of the nearby occurrence of apparently felsic volcanic rocks at Nowthanna Hill, a more apt subgrouping might be 'deposits in felsic metavolcanic and volcaniclastic rocks'. The mineralisation, which is about 1.5 km west of Nowthanna Hill, consists mostly of pyrite and pyrrhotite in gossanous zones in banded iron formation. Exploration in the Quinns area apparently has not resulted in the discovery of any orebodies.

Other minor patches of copper mineralisation have been found in the Booylgoo Range, two being on the contact between metasediments *(Ass)* and an ultramafic intrusive *(Auj)*, and another in a metasediment lens within metabasalt *(Aba)*. These examples are however only mineral occurrences, and no potentially commercial deposits are known.

Nickel

During the nickel boom of the late 1960s and early 1970s, the Sandstone Sheet area was explored by company geologists seeking nickel sulphide deposits associated with ultramafic bodies, especially komatiites; other base metals were also sought. No commercial deposits were found, probably because of the lack of komatiitic rocks. Gee & others (1981) note that the Yilgarn Block komatiites are rare in the Murchison Province and the northern part of the Southern Cross Province. Accounts of the company exploration were submitted to the Western Australia Mines Department, Perth, where they are available for inspection. Western Australian nickel deposits are described in detail in 26 papers in *Economic Geology*, 76 (1981),6 and it is evident that mineralisation is concentrated in the Yilgarn Block's Eastern Goldfields Province. Marston & others (1981) give a thorough review of nickel mineralisation in the Yilgarn Block.

Iron

Low-grade iron ore in banded iron formation is widespread and accounts of deposits in the Booylgoo Range, Montague Range, and Black Range District are given by Connolly (1959) who quotes assay results ranging from 30 to 52% Fe. In view of these low grades and the remoteness of the deposits, it is clear that economic exploitation of iron ore in the Sandstone Sheet area is unlikely to take place in the foreseeable future. Gole (1981) gives a general account of banded iron formations in the Yilgarn Block.

Uranium

The major uranium deposit at Yeelirrie was discovered by Western Mining Corporation in 1972. The company has evaluated the deposit, but assessment and development were suspended in 1983 when the Federal Government withdrew permission to negotiate sales contracts. The uranium ore mineral is carnotite ($K_2O.2U_3O_8.V_2O_5.nH_2O$—a potassium uranyl vanadate) which fills fractures and voids, and forms coatings on mineral grains in calcrete and kaolinitic clay-quartz rocks in a valley calcrete body. The source of the uranium was probably the granitoid rocks that comprise most of the area's Precambrian bedrock. However, the calcrete and its contained carnotite are presumably both products of the arid climate. The orebody, resources, and possible mining options are described by Western Mining Corporation (1979).

The orebody comprises a central core of 'prime ore' and a halo of lower-grade material. The prime ore amounts to 13 000 000 t grading 0.24% U_3O_8, and lower-grade, 'intermediate', ore 22 000 000 t at 0.09% U_3O_8. Total contained U_3O_8 in these zones amounts to 52 500 t.

The Yeelirrie orebody was discovered by Western Mining Corporation geologists while investigating geophysical anomalies on 1:250 000 maps produced as a result of regional airborne radiometric surveys conducted by BMR (Gerdes & others, 1970). The Yeelirrie radiometric anomaly relates to a small outcrop (about 30 m^2) of the uranium orebody just north of Twelve Mile Bore. In the nearby No. 2 costean it is possible to trace the top of the ore zone to the surface; this may be an artefact of the local groundwater circulation and is perhaps related to recharge from a nearby saline lake. Other radiometric anomalies on the map of Gerdes & others (1970) were investigated, but commercial deposits were not located.

The Yeelirrie discovery encouraged extensive company exploration of other valley calcretes in the Sandstone Sheet area and other parts of the various relict drainage systems that cross the Yilgarn Block (van de Graaff & others, 1977). A comprehensive account of uranium occurrence in the Yilgarn Block, and exploration for them, is given by Butt & others (1977; see also Carter, 1979). The only substantial deposit known, apart from Yeelirrie, is at Lake Way near Wiluna in the Wiluna Sheet area. Butt & others (1977) report other minor occurrences of uraniferous calcrete in the Sandstone Sheet area near Nowthanna Hill (27°05′S, 118°41′E), Bedan Well (27°06′S, 118°51′E), Scottie Well (27°19′S, 118°54′E), Cogla Downs homestead (27°26′S, 118°55′E), Rocky Dump Well (27°49′S, 118°32′E), Nulyer Camyer Well (27°57′S, 118°32′E), and Anketell (28°00′S, 118°42′E).

Vanadium

Prospecting for vanadium in magnetite-rich layers associated with the Barrambie Intrusion has revealed an indicated ore reserve of 27 million tonnes containing an average of 0.7% $V_2 0_5$ according to Ward (1975), who also described some metallurgical studies. The Barrambie deposit is also described by Baxter (1978, 89–91). The vanadium is mostly contained in martite although some is in ilmenite. Ward (1981) describes how deep weathering has enriched the vanadium concentration.

It was planned also that vanadium would be a by-product of the Yeelirrie ore treatment; this, if Yeelirrie were allowed to proceed, would presumably not enhance the commercial prospects of the Barrambie deposit.

Other commodities

Gypsum is abundant in the playa lakes but deposits in such a remote area have virtually no foreseeable economic significance. *Asbestiform minerals* (some of them silicified) are present over weathered ultramafic rocks in some greenstone belts but these also do not indicate any economic potential. *Beryl* was apparently mined at Mining Claim 2163 near Sandstone township, but it is not a commodity that would be likely to have substantial economic potential at this remote locality.

ECONOMIC POTENTIAL

The most prospective minerals appear to be uranium and gold, although further exploration for uranium seems unlikely until obstacles in the way of development of the Yeelirrie project are resolved. Gold prospecting is continuing, and a substantial exploration effort is in progress near Sandstone township, with activity focussed on the reprocessing of old mine dumps and the rejuvenation of old mines. All greenstone belts still appear to have some potential for gold although there is no record of any being either sought or found in the Booylgoo greenstone belt. There appears to be no geological reason why this greenstone belt should be more or less prospective for gold than others in the Sheet area. However, it is most unlikely that early prospectors would not have examined it and there is no doubt that they were very proficient at finding surface gold deposits.

The potential of the Sheet area for copper and nickel must be rated as low, in view of the effort already expended on the search for these metals.

WATER RESOURCES

As the Sandstone Sheet area has a low average rainfall which has an erratic seasonal distribution, groundwater is the main source of water for pastoral and domestic use. The salinity of the water in most wells and bores in the Sheet area was measured during the 1979 field season (Appendix 2). As would be expected, the most saline groundwater occurs near saline lakes and in valley calcretes, and the least saline occurs in shallow aquifers in colluvium and alluvium over weathered granitoid bedrock on or near watersheds, and well away from the saline relict main draingage courses. Water from bores in or near greenstone is commonly more saline than that from bores in granitic areas, although relatively few bores in the granitic areas exploit the weathered bedrock to any significant extent as most of them are drilled only into the overlying unconsolidated Cainozoic deposits.

REFERENCES

AHMAT, A. L., 1983—Structure, stratigraphy, and mineralisation potential of the anorthositic Windimurra Gabbroid, Yilgarn Block, Western Australia. *Geological Society of Australia, Sixth Australian Geological Convention, Abstracts*, 265-66.

AHMAT, A. L., & DE LAETER, J. R., 1982—Rb-Sr isotopic evidence for Archaean-Proterozoic crustal evolution of part of the central Yilgarn Block, Western Australia: constraints on the age and source of the anorthositic Windimurra Gabbroid. *Journal of the Geological Society of Australia*, 29, 177-90.

ARRIENS, P. A., 1971—The Archaean geochronology of Australia. *Geological Society of Australia, Special Publication 3*, 11-23.

AUSTIN, R., 1855—Report by Assistant Surveyor Robert Austin of an expedition to explore the interior of Western Australia. *Government Printer, Perth.*

BAXTER, J. L., 1978—Molybdenum, tungsten, vanadium, and chromium in Western Australia. *Geological Survey of Western Australia, Mineral Resource Bulletin* 11.

BAXTER, J. L., LIPPLE, S. L., & MARSTON, R. J., 1980—Explanatory notes on the Kirkalocka 1:250 000 Geological Sheet, Western Australia. *Geological Survey of Western Australia, Record* 1980/3.

BEARD, J. S., 1976—The vegetation of the Murchison Region—Explanatory notes Sheet 6, 1:1 000 000 Vegetation Series, vegetation survey of Western Australia. *University of Western Australia Press, Perth.*

BERLIAT, K., 1959a—Booylgoo Range. *In* CONNOLLY, R. R. (Editor)—IRON ORES IN WESTERN AUSTRALIA. *Geological Survey of Western Australia, Mineral Resources Bulletin* 7, 45-6.

BERLIAT, K., 1959b—Black Range District. *In* CONNOLLY, R. R. (Editor)—IRON ORES IN WESTERN AUSTRALIA. *Geological Survey of Western Australia, Mineral Resources Bulletin* 7, 50-1.

BETTENAY, E., & CHURCHWARD, H. M., 1974—Morphology and stratigraphic relationships of the Wiluna Hardpan in arid Western Australia. *Journal of the Geological Society of Australia*, 21(1), 73-80.

BETTENAY, L. F., BICKLE, M. J., BOULTER, C. A., GROVES, D. I., MORANT, P., BLAKE, T. S., & JAMES, B. A., 1981—Evolution of the Shaw Batholith—an Archaean granitoid gneiss dome in the eastern Pilbara, Western Australia. *In* GLOVER, J. E., & GROVES, D. I. (Editors)—ARCHAEAN GEOLOGY. *Geological Society of Australia, Special Publication 7*, 361-72.

BICKLE, M. J., BETTENAY, L. F., BOULTER, C. A., GROVES, D. I., & MORANT, P., 1980—Horizontal tectonic interaction of an Archean gneiss belt and greenstones, Pilbara Block, Western Australia. *Geology*, 8, 525-9.

BLATCHFORD, T., 1899—A geological reconnaissance of the country at the heads of the Murchison and Sandford rivers, in the Murchison, East Murchison, and Peak Hill Goldfields. *Geological Survey of Western Australia, Annual Progress Report for 1898*, 36-51.

BRIDGE, P. J., 1970—Combined index to the publications of the Geological Survey of Western Australia, 1910-69 (copyright—*Peter J. Bridge, 248 Rutland Avenue, Carlisle, WA 6101*).

BUNTING, J. A., & WILLIAMS, S. J., 1979—Sir Samuel, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SG/51-13.

BUTT, C. R. M., 1981a—The nature and origin of the lateritic weathering mantle with particular reference to Western Australia. *In* DOYLE, H. A., GLOVER, J. E., & GROVES, D. I. (Editors)—GEOPHYSICAL PROSPECTING IN DEEPLY WEATHERED TERRAINS. *University of Western Australia, Perth*, 11-29.

BUTT, C. R. M., 1981b—History and characteristics of weathering in Australia. *In* SMITH, R. E. (Editor)—GEOCHEMICAL EXPLORATION IN DEEPLY WEATHERED TERRAIN. *CSIRO Institute of Energy and Earth Resources, Floreat Park, Western Australia*, 9-18.

BUTT, C. R. M., HORWITZ, R. C., & MANN, A. W., 1977—Uranium occurrences in calcrete and associated sediments in Western Australia. *CSIRO, Australia, Minerals Research Laboratories, Division of Mineralogy, Report FP-16.*

CAMERON, E., 1984—The Yeelirrie calcrete uranium deposit, Western Australia. *In* SURFICIAL URANIUM DEPOSITS. *International Atomic Energy Agency, Technical Document* 322, 157-64.

CAMERON, E., MAZZUCCHELLI, R. H., & ROBBINS, T. W., 1980—Yeelirrie calcrete uranium deposit, Murchison Region, Western Australia. *In* BUTT, C. R. M., & SMITH, R. E. (Editors)—CONCEPTUAL MODELS IN EXPLORATION GEOCHEMISTRY. *Journal of Geochemical Exploration*, 12 (2/3), 350-53.

CARTER, J. D., 1979—Mineral fuels—Uranium. *In* PRIDER, R. T. (Editor)—MINING IN WESTERN AUSTRALIA. *University of Western Australia Press, Perth*, 160-66.

CHAPMAN, H. J., BICKLE, M. J., DE LAETER, J. R., BETTENAY, L. F., GROVES, D. I., ANDERSEN, L. S., BINNS, R. A., & GORTON, M., 1981—Rb-Sr geochronology of granitic rocks from the Diemals area, central Yilgarn Block, Western Australia. *In* GLOVER, J. E., & GROVES, D. I. (Editors)—ARCHAEAN GEOLOGY. *Geological Society of Australia, Special Publication 7*, 173-86.

CHURCHWARD, H. M., 1977—Landforms, regoliths and soils of the Sandstone-Mount Keith area, Western Australia. *CSIRO, Australia, Division of Land Resource Management, Land Resources Management Series* 2.

CLARKE, E. de C., 1914—Notes on the geology and mining at Sandstone and Hancocks, East Murchison Goldfield. *Geological Survey of Western Australia, Bulletin* 62, 11-66.

CONDIE, K. C., 1981—ARCHAEAN GREENSTONE BELTS. *Elsevier, Amsterdam.*

CONNOLLY, R. R., 1959—Montague Range. *In* CONNOLLY, R. R. (Editor)—IRON ORES IN WESTERN AUSTRALIA. *Geological Survey of Western Australia, Mineral Resources Bulletin* 7, 46-52.

COOPER, J. A., NESBITT, R. W., PLATT, J. P., & MORTIMER, G. E., 1978—Crustal development in the Agnew region, Western Australia, as shown by Rb/Sr isotopic and geochemical studies. *Precambrian Research,* 7, 31-59.

DE LA HUNTY, L. E., 1973—Cue, Western Australia, 1:250 000 Geological Series. *Geological Survey of Western Australia, Explanatory Notes* SG/50-15.

DE LA HUNTY, L. E., 1975—Yilgarn Block—Murchison Province. *Geological Survey of Western Australia, Memoir* 2, 54-64.

DE LAETER, J. R., FLETCHER, I. R., ROSMAN, K. J. R., WILLIAMS, I. R., GEE, R. D., & LIBBY, W. G., 1981a—Early Archaean gneisses from the Yilgarn Block, Western Australia. *Nature,* 292, 322-24.

DE LAETER, J. R., LIBBY, W. G., & TRENDALL, A. F., 1981b—The older Precambrian geochronology of Western Australia. *In* GLOVER, J. E., & GROVES, D. I. (Editors)—ARCHAEAN GEOLOGY. *Geological Society of Australia, Special Publication* No. 7, 145-57.

DEUTSCHER, R. L., MANN, A. W., & BUTT, C. R. M., 1980—Models for calcrete uranium mineralization. *In* BUTT, C. R. M., & SMITH, R. E. (Editors)—CONCEPTUAL MODELS IN EXPLORATION GEOCHEMISTRY. *Journal of Geochemical Exploration,* 12 (2/3), 158-61.

DOING, H., 1981—Phytogeography of the Australian floristic kingdom. *In* GROVES, R. H. (Editor)—AUSTRALIAN VEGETATION. *Cambridge University Press,* 3-25.

DOYLE, H. A., GLOVER, J. E., & GROVES, D. I. (Editors), 1981—GEOPHYSICAL PROSPECTING IN DEEPLY WEATHERED TERRAINS. *University of Western Australia,* Perth.

DRUMMOND, B. J., 1979—A crustal profile across the Archaean Pilbara and northern Yilgarn cratons, northwest Australia. *BMR Journal of Australian Geology & Geophysics,* 4(3), 171-80.

DRUMMOND, B. J., 1981—Crustal structure of the Precambrian terrains of northwest Australia from seismic refraction data. *BMR Journal of Australian Geology & Geophysics,* 6, 123-5.

DRUMMOND, B. J., 1982—Seismic constraints on the chemical composition of the Pilbara craton, northwest Australia. *Revista Brasileira de Geosciencas,* 12, 113-20.

DRUMMOND, B. J., & SHELLEY, H. M., 1981—Isostasy and structure of the lower crust and upper mantle in the Precambrian terrains of northwest Australia, from regional gravity studies. *BMR Journal of Australian Geology & Geophysics,* 6, 137-43.

DRUMMOND, B. J., SMITH, R. E., & HORWITZ, R. C., 1981—Crustal structure in the Pilbara and northern Yilgarn Blocks from deep seismic sounding. *In* GLOVER, J. E., & GROVES, D. I. (Editors)—ARCHAEAN GEOLOGY. *Geological Society of Australia, Special Publication 7,* 33-41.

ELIAS, M., BUNTING, J. A., & WHARTON, P. H., 1979—Explanatory notes on the Glengarry 1:250 000 Sheet, Western Australia. *Geological Survey of Western Australia, Record* 1979/3.

ELIAS, M., BUNTING, J. A., & WHARTON, P. H., 1982—Glengarry, Western Australia—1:250 000 Geological Series. *Geological Survey of Western Australia, Explanatory Notes* SG/50-12.

FELDTMANN, F. R., 1917—Quinns, Murchison Goldfield. *Geological Survey of Western Australia, Annual Progress Report for the year 1916,* 22-23.

FELDTMANN, F. R., 1921—The mining centres of Quinns and Jasper Hill. *Geological Survey of Western Australia, Bulletin* 80.

FORREST, J., 1875—EXPLORATIONS IN AUSTRALIA. *Low, Marston, Low & Searle, London.*

FROUDE, D. O., IRELAND, T. R., KINNY, P. D., WILLIAMS, I. S., COMPSTON, W., WILLIAMS, I. R., & MYERS, J. S., 1983—Ion microprobe identification of 4100-4200 Myr-old terrestrial zircons. *Nature,* 304, 616.

GEE, R. D., 1979—Structure and tectonic style of the Western Australian shield. *Tectonophysics,* 58, 327-69.

GEE, R. D., BAXTER, J. L., WILDE, S. A., & WILLIAMS, I. R., 1981—Crustal development in the Archaean Yilgarn Block, Western Australia. *In* GLOVER, J. E., & GROVES, D. I. (Editors)—ARCHAEAN GEOLOGY. *Geological Society of Australia, Special Publication 7,* 43-56.

GERDES, R. A., YOUNG, G. A., CAMERON, B. F., & BEATTIE, R. D., 1970—Sandstone and Youanmi airborne magnetic and radiometric survey, Western Australia, 1968. *Bureau of Mineral Resources, Australia, Record* 1970/2.

GIBSON, C. G., 1904a—Black Range find. *Geological Survey of Western Australia, Annual Progress Report for the year 1903,* 14-16.

GIBSON, C. G., 1904b—Black Range find. *Western Australia, Report of the year 1903, Division 4,* 130-2.

GIBSON, C. G., 1904c—The geology and mineral resources of a part of the Murchison Goldfield. *Geological Survey of Western Australia, Bulletin* 14.

GIBSON, C. G., 1908a—The Black Range District, East Murchison Goldfield. *Geological Survey of Western Australia, Bulletin* 31.

GIBSON, C. G., 1908b—Report upon the auriferous deposits of Barrambie and Errols (Cue District) and Gum Creek (Nannine District) in the Murchison Goldfield; also Wiluna (Lawlers District) in the East Murchison Goldfield. *Geological Survey of Western Australia, Bulletin* 34, 7-43.

GLIKSON, A. Y., 1978—Archaean granite series and the early crust, Kalgoorlie, Western Australia. *In* WINDLEY, B. F., & NAQVI, S. M. (Editors)—ARCHAEAN GEOCHEMISTRY. *Elsevier, Amsterdam, 151*-73.

GLIKSON, A. Y., & LAMBERT, I. B., 1976—Vertical zonation and petrogenesis of the early Precambrian crust in Western Australia. *Tectonophysics*, 30, 55-89.

GOCZEL, S., 1894—The interior gold region of Western Australia. *Western Australia, Annual Report of the Department of Mines for the year 1894.*

GOLE, M. J., 1981—Archaean banded iron formations, Yilgarn Block, Western Australia. *Economic Geology*, 76, 1954-74.

GROVES, R. H., 1981 (Editor)—AUSTRALIAN VEGETATION. *Cambridge University Press.*

GSWA, 1916—General index to reports 1870-1910. *Geological Survey of Western Australia, Bulletin* 60.

HALLBERG, J. A., 1976—A petrochemical study of a portion of the western Yilgarn Block. *CSIRO, Minerals Research Laboratories, Division of Mineralogy, Report* FP-13, 1-35.

HALLBERG, J. A., & GLIKSON, A. Y., 1981—Archaean granite-greenstone terranes of Western Australia. *In* HUNTER, D. R. (Editor)—PRECAMBRIAN OF THE SOUTHERN HEMISPHERE—DEVELOPMENTS IN PRECAMBRIAN GEOLOGY, 2. *Elsevier, Amsterdam*, 33-103.

HALLBERG, J. A., CARTER, D. N., & WEST, K. N., 1976—Archaean volcanism and sedimentation near Meekatharra, Western Australia. *Precambrian Research,*, 3, 577-95.

HAYCRAFT, J. A., 1976—Sampling of the Yeelirrie uranium deposit, Western Australia. *Australasian Institute of Mining & Metallurgy (Melbourne Branch), Sampling Symposium*, 51-62.

IDNURM, M., & SENIOR, B. R., 1978—Palaeomagnetic ages of Late Cretaceous and Tertiary weathered profiles in the Eromanga Basin, Queensland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 24(4), 263-77.

JONES, W. R., 1965—Vanadium deposits of Western Australia. *Eighth Commonwealth Mining and Metallurgical Congress*, 1, 154-5.

JUTSON, J. T., 1950—The physiography (geomorphology) of Western Australia. *Geological Survey of Western Australia, Bulletin* 95 (reprint of volume first published in 1934).

KORSCH, R. J., 1971—The occurrence of a stratiform basic intrusion in the Barrambie area, Western Australia. *Search*, 2, 289-90.

MABBUTT, J. A., 1963—Introduction and summary description of the Wiluna-Meekatharra area. *In* Lands of the Wiluna-Meekatharra area, Western Australia, 1958. *CSIRO, Land Research Series* 7 (1), 9-23.

MABBUTT, J. A., 1980—Weathering history and landform development. *In* BUTT, C. R. M., & SMITH, R. E. (Editors)—CONCEPTUAL MODELS IN EXPLORATION GEOCHEMISTRY. *Journal of Geochemical Exploration*, 12 (2/3), 96-116.

MAITLAND, A. G. 1919—The gold deposits of Western Australia. *In* MAITLAND, A. G. (Editor)—THE MINING HANDBOOK, Chapter II (Economic Geology), Part III, Section 1. *Geological Survey of Western Australia, Memoir* 1 (reprinted, 1979, as GOLD DEPOSITS. *Hesperian Press, Perth*).

MANN, A. W., 1974—Chemical ore genesis models for the precipitation of carnotite in calcrete. *CSIRO, Minerals Research Laboratories, Division of Mineralogy, Report* FP-7.

MANN, A. W., & DEUTSCHER, R. L., 1978—Hydrogeochemistry of a calcrete-containing aquifer near Lake Way, Western Australia. *Journal of Hydrology*, 38, 357-77.

MANN, A. W., & HORWITZ, R. C., 1979—Groundwater calcrete deposits in Australia: some observations from Western Australia. *Journal of the Geological Society of Australia*, 26 (6), 293-304.

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

MARSTON, R. J., GROVES, D. I., HUDSON, D. R., & ROSS, J. R., 1981—Nickel sulfide deposits in Western Australia : a review. *Economic Geology*, 76 (5), 1330-63.

MATHUR, S. P., 1974—Crustal structure in southwestern Australia from seismic and gravity data. *Tectonophysics*, 24, 151-82.

MONTGOMERY, A., 1904—Report of the State Mining Engineer for the year 1903. *Western Australia, Report of the Department of Mines for the year 1903, Division* 2, 42-102.

MORGAN, K. H., 1966—Hydrogeology of the East Murchison and North Coolgardie Goldfields. *Geological Survey of Western Australia, Annual Report for the year 1965,* 14-19.

MULCAHY, M. J., & BETTENAY, E., 1972—Soil and landscape studies in Western Australia: I)—The major drainage divisions. *Journal of the Geological Society of Australia*, 18 (4), 349-57.

NIEUWLAND, D. A., & COMPSTON, W., 1981—Crustal evolution in the Yilgarn Block near Perth, Western Australia. *In* GLOVER, J. E., & GROVES, D. I. (Editors)—ARCHAEAN GEOLOGY. *Geological Society of Australia, Special Publication* 7, 159-71.

O'DRISCOLL, E. S. T., 1981—A broad-scale structural characteristic of major nickel sulfide deposits of Western Australia. *Economic Geology*, 76, 1364-72.

O'DRISCOLL, E. S. T., 1982—Patterns of discovery—the challenge for innovative thinking (1981 PESA Australian distinguished lecture). *Journal of the Petroleum Exploration Society of Australia*, 1, 11-31.

PILGRIM, A. T., 1979—Landforms. *In* GENTILLI, J. (Editor)—WESTERN LANDSCAPES. *University of Western Australia Press, Perth*, 49-87.
SANDERS, C. C., 1969—Hydrogeological reconnaissance of calcrete areas in the East Murchison and Mount Margaret Goldfields. *Department of Mines, Western Australia, Annual Report for 1968*, 54-67.
SANDERS, C. C. 1974—Calcrete in Western Australia. *Geological Survey of Western Australia, Annual Report for 1973*, 12-14.
SOFOULIS, J., 1963—The occurrence and hydrological significance of calcrete deposits in Western Australia. *Geological Survey of Western Australia, Annual Report for the year 1962*, 38-42.
SOFOULIS, J., 1966—Widgiemooltha, Western Australia—1:250 000 Geological Series. *Geological Survey of Western Australia, Explanatory Notes* SH/51-14.
SPECK, N. H., 1963—Vegetation of the Wiluna-Meekatharra area: Part VII of General Report on Lands of the Wiluna-Meekatharra Area, Western Australia, 1958. *CSIRO Australia Land Research Series* 7, 143-61.
SPITZ, E., & DARLING, R., 1975—The petrochemistry of altered volcanic rocks surrounding the Louvern copper deposit, Val d'or, Quebec. *Canadian Journal of Earth Science*, 12, 1820-49.
STEWART, A. J., WILLIAMS, I. R., & ELIAS, M., 1981—Notes on the preliminary Youanmi 1:250 000 Geological Series map, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1981/23.
STEWART, A. J., WILLIAMS, I. R., & ELIAS, M. J., 1983—Youanmi, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SH/50-4.
STRECKEISEN, A., 1976—To each plutonic rock its proper name. *Earth Science Reviews*, 12, 1-33.
TUREK, A., 1966—Geochronology of the Kalgoorlie area. *Ph.D. Thesis, Australian National University* (unpublished).
VAN DE GRAAFF, W. J. E., 1981—Palaeogeographic evolution of a rifted cratonic margin: S.W. Australia—discussion. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 34 (1/2), 163-72.
VAN DE GRAAFF, W. J. E., CROWE, R. W. A., BUNTING, J. A., & JACKSON, M. J., 1977—Relict early Cainozoic drainages in arid Western Australia. *Zeitschrift fur Geomorphologie, N.F.*, 21, 379-400.
WARD, H. J., 1975—Barrambie iron-titanium-vanadium deposit. *In* KNIGHT, C.L. (Editor)—ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA. 1. METALS. *Australasian Institute of Mining & Metallurgy, Monograph Series* 5, 207-11.
WARD, H. J., 1981—The effects of lateritisation at Barrambie, Western Australia. *In* LATERITISATION PROCESSES. *A.A. Balkema, Rotterdam*, 24-33.
WELLS, L. A., 1893—Mr Wells' Journal. *In* JOURNAL OF THE ELDER SCIENTITIC EXPLORING EXPEDITION, 1891/92, UNDER COMMAND OF D. LINDSAY. *Government Printer, Adelaide*, 161-92.
WESTERN MINING CORPORATION LTD, 1975—A general account of the Yeelirrie uranium deposit (unpublished).
WESTERN MINING CORPORATION LTD, 1979—Yeelirrie Uranium Project, WA. Environmental impact statement, and environmental review and management program.
WILLIAMS, D. A. C., & HALLBERG, J. A., 1973—Archaean layered intrusions of the Eastern Goldfields region, Western Australia. *Contributions to Mineralogy & Petrology*, 38, 45-70.
WILLIAMS, I. R., 1974—Structural subdivision of the Eastern Goldfields province, Yilgarn Block. *Geological Survey of Western Australia, Annual Report for 1973*, 53-9.
WILLIAMS, I. R., 1975a—Yilgarn Block—Eastern Goldfields province. *Geological Survey of Western Australia, Memoir* 2, 33-52.
WILLIAMS, I. R., 1975b—Yilgarn Block—Southwestern province. *Geological Survey of Western Australia, Memoir* 2, 65-71.
WOODWARD, H. P., 1893—The Murchison Goldfield. *Perth* (by Authority).
WOODWARD, H. P., 1907—Barrambie and Errols. *Geological Survey of Western Australia, Annual Progress Report for the year 1906*, 15-17.

APPENDIX 1: CO-ORDINATES OF LOCALITIES MENTIONED IN TEXT

	Lat(S)	Long(E)		Lat(S)	Long(E)
Babba Meelah Rockhole	27°28′	119°18′	Mount Marion	27°11′	119°31′
Barlangi Rock	27 11	118 50	Mount Townsend	27 09	119 30
Barrambie belt		*	Nowthanna Hill	27 04	118 40
Barrambie Bore	27 27	119 07	Nulyer Camyer Well	27 56	118 31
Barrambie homestead	27 31	119 11	Old Gidgee homestead	27 30	119 31
Bedan Well	27 08	118 52	Poison Hills	27 05	119 02
Birrigrin	27 30	119 31	Poison Hills greenstone belt		*
Bob Well	27 41	119 25	Quinns	27 04	118 38
Bolger Well	27 21	119 23	Red Handed Bore	27 26	119 48
Booylgoo Range	27 43	119 54	Rocky Dump Well	27 59	118 32
Booylgoo Spring homestead	27 45	119 54	Sandstone township	27 59	119 18
Calulyu homestead	27 50	119 44	Schwartz Well	27 42	119 29
Christmas Bore	27 19	119 17	Scotties Well	27 19	118 54
Cogla Downs homestead	27 26	118 56	Scotty Well	27 12	119 21
Coronation Well	27 08	119 23	Sugarstone	27 22	119 04
Errols	27 18	119 01	Twelve Mile Bore	27 11	119 55
Fred Bore	27 24	119 08	Walga Gunya	27 04	119 15
Gidgee	27 15	119 24	Wyooda Thangoo Hills	27 24	119 26
Gum Creek greenstone belt		*	Yarrabubba	27 08	118 47
Jasper Hills	27 44	119 30	Yeelirrie	27 11	119 55
Jonesville	27 15	119 25	Yeelirrie townsite	27 05	120 00
Lake Mason homestead	27 35	119 31	Youno Downs homestead	27 04	119 15
Lake Mason zone		*			
Milgoo Well	27 55	118 35			
Montague Range	27 13	119 32			
Montague Range Zone		*			

Latitudes and longitudes extracted from *Australia 1:250 000 Series Map Gazetteer*, Division of National Mapping, Canberra, 1979.

*See 'Interpreted Precambrian geology' marginal sketch map.

APPENDIX 2: GROUNDWATER SALINITY MEASUREMENTS, JUNE-SEPTEMBER 1979

Bore or well	*Observer*	*Pastoral lease*	*Salinity (mg.L⁻¹)*
Alpha Bore	W	Hillview	2592
Altona Bore	T	Altona	1664
Anniversary Bore	W	Black Range	2136
Avonong Well	W	Hillview	1548
Baird Well	W	Black Range	3150
Barlanga Well	W	Yarrabubba	2790
Bedan Well	W	Yarrabubba	6000+
Billeroo Well	W	Yarrabubba	1326
Bellview Bore	T	Booylgoo Spring	1058
Bills Bore	W	Yarrabubba	2976
Binga Well	O	Gidgee	760
Birrigrin (S) Well	O	Gidgee	800
Bo Peep Well	O	Gidgee	430
Bob Well	W	Lake Mason	444
Bolger Well	O	Gidgee	2100
Bolithos South Bore	T	Lake Mason	6104
Bolithos Well	T	Lake Mason	4590
Boomerang Well	W	Black Range	978
Boundary Well	W	Cogla Downs	1062
Bradley	W	Yarrabubba	1374
Breakaway Bore	O	Gidgee	510
Brealya Well	W	Yarrabubba	630
Buxs Bore	T	Yeelirrie	1184
Calulyu Bore	T	Calulyu	832
Calulyu Well	T	Calulyu	1037
Carbines	W	Lake Mason	1170
Carlson Well	W	Yarrabubba	1230
Cemens Well	W	Yarrabubba	1956
Cement Bore	W	Yarraquin	882
Charlton Well	W	Windsor	2112
Christmas Bore	W	Black Range	6000+
Christmas Bore	O	Gidgee	1000
Christmas Well	W	Yarraquin	6000
Cootharra Bore	W	Yarraquin	Dry
Cootia Bore	W	Yarraquin	1086
Creamies Bore	W	Yarrabubba	942
Creek Bore	T		3000
Deep Bore	T	Booylgoo Spring	476
Deep Water Bore	T	Calulyu	637
Dooley Well	W	Hillview	972
Dowden Well	W	Cogla Downs	1686
Dummy Well	W	Yarrabubba	1788
East Mill Well	W	Yarrabubba	1692
East Well	W	Yarraquin	4122
Easter Mile Bore	T	Yeelirrie	1510
Eds Bore	T	Gidgee	1110
Eleven Mile Well	T	Gidgee	450
Erroll Bore	W	Hillview	3708
Erroll Well	W	Yarrabubba	5922
Five Mile Well	W	Hillview	2778
Forty Mile Well	W	Lake Mason	4272
Foster Well	W	Cogla Downs	3342
Freds Bore	W	Lake Mason	1770
Garden Well	T	Booylgoo Spring	305
Granites Bore	T	Lake Mason	6954
Gum Patch Bore	T	Booylgoo Spring	2082
Homestead Well	W	Yarrabubba	2058
Hutt Well	W	Windsor	1482
Independence Bore	T	Yeelirrie	630
Inglewood Bore	W	Yarraquin	318
Inglewood Well	W	Yarraquin	312
Jasper Well	T	Lake Mason	2290
Jasper Well	W	Lake Mason	2370
Jericho Bore	T	Lake Mason	416
Johnson Bore	W	Yarraquin	1338
Kelly Bore	W	Yarrabubba	6000
Kellys Bore	O	Altona	4488
Kennedys Bore	O	Gidgee	800
Kurrajong Well	O	Gidgee	1000
Lake Mason (E)	W	Lake Mason	3288
Lake Mason (Homestead)	T	Lake Mason	350
Lake Mason (Shearers)	T	Lake Mason	3100
Lake Mason (South)	W	Lake Mason	222
Limestone Well	W	Yarrabubba	2238
Little Mill Well	O		900
Mallers Bore	W	Cogla Downs	1668
Middle Well	T	Booylgoo Spring	535
Miller Bore	W	Yarraquin	1524
Minchin Bore	W	Yarraquin	1162
Minga Bore	W	Cogla Downs	1512
Minga Well	W	Hillview	1116
Mogul Bore	W	Yarrabubba	1386
Mogul Well	W	Yarrabubba	2922
Montague Well	T	Gidgee	1500
Morphies Bore	T	Booylgoo Spring	1378
Nalganadgo Bore	W	Yarrabubba	2328
Nalline Well	W	Yarrabubba	3252
Nanadie Well	W	Yarrabubba	3120
Nedney Well	W	Windsor	2700
Neils Well	W	Windsor	2274
Nelsons Well	W	Cogla Downs	2244
New Mill Well	W	Yarrabubba	3060
New Well	W	Yarrabubba	6000
Nine Mile Well	W	Black Range	2190
Noel Bore	W	Yarrabubba	1890
Noels Well	W	Windsor	2190
North Bore	W	Yarrabubba	1050
Nugget Bore	W	Yarrabubba	5532
Nullor Well	W	Yarrabubba	2922
Nulyer Camyer Bore	W	Windsor	1908
Nulyer Camyer Well	W	Windsor	1758
Number One Bore	T	Booylgoo Spring	480
Number 1 Bore	W	Cogla Downs	5052
Number One Bore	W	Windsor	1488
Number Three Bore	W	Cogla Downs	1776
Number Four Bore	W	Windsor	306
Number Six Bore	T	Booylgoo Spring	627
Number Six Bore	T	Depot Springs	800
Number Eight Well	O		1400
Number 17 Bore	W	Colga Downs	3672
Number 24 Well	W	Windsor	2640
Number 28 Bore	W	Cogla Downs	2214
Nundy Well	W	Windsor	1866
Nyuing Well	W	Windsor	2364
Old Barrambie Bore	W	Barrambie	3018
Old Shed Bore	W	Lake Mason	2706
Outcamp Well	W	Hillview	3180
O'Connors Bore	T	Lake Mason	572
Payne Well	O	Gidgee	4250
Peggy Bore	W	Yarrabubba	3612
Peggy Well	W	Yarrabubba	3810
Pera Well	W	Yarrabubba	2652
Peregrine	W	Cogla Downs	954
Phils Bore	T	Booylgoo Spring	390
Picnic Well	W	Black Range	3996
Pioneer Well	W	Windsor	2928

Bore or well	*Observer*	*Pastoral lease*	*Salinity ($mg.L^{-1}$)*
Progress Bore	O	Gidgee	800
Quartz Blow Bore	T	Kaluwirri	1017
Quartz Bore	W	Yarrabubba	8330
Rainbow Bore	T	Calulyu	1728
Rabbit Well	W	Windsor	2682
Reads Well	W	Yarraquin	2016
Red Well	W	Lake Mason	3684
Red Castle Well	W	Lake Mason	3276
Reid Well	W	Yarrabubba	3618
Reids Well	W	Hillview	3270
Robbies Well	O	Gidgee	980
Rocky Dump Well	W	Wondinong	4884
Rocky Dump Well (N)	W	Windsor	4056
Salty Bore	T	Lake Mason	6760
Samaria Bore	T	Lake Mason	2052
Sardine Well	O	Gidgee	2538
Sawyers Well	T	Altona	986
Schwartz Well	W	Lake Mason	2736
Scotties Well	W	Yarrabubba	5496
Scotty Well	O	Gidgee	800
Scour well	W	Yarrabubba	1560
Seven Mile Well	W	Gidgee	1944
Shaws Bore	T	Altona	2082
Snake Bore	W	Cogla Downs	Dry
Snake Well	T	Lake Mason	2312
South Mill Well	W	Yarrabubba	6000
Spexter Bore	W	Cogla Downs	2598
Star Well	W	Cogla Downs	1770
Star Well	W	Windsor	1392
Swan Bitter Well	O	Gidgee	2200
Taffs Bore	T	Booylgoo Spring	773
Tango Well	O	Gidgee	1500
Terra Cotta Bore	T	Kaluwirri	406
Three Mile Well	O	Lake Mason	750
Trailer Bore	T	Lake Mason	1323
Twenty-eight mile Well	W	Cogla Downs	1902
Two Mile Well	T	Gidgee	2400
Victory Bore	O	Gidgee	900
Wandarrie	W		Dry
Waukenjerrie (W)	W	Lake Mason	1302
White Well	W	Cogla Downs	2070
White Well	W	Windsor	384
Willow bore	W	Hillview	726
Willow Well	T	Kaluwirri	509
Winding Well	W	Yarrabubba	5682
Winnie Creek Well	W	Hillview	702
Wizards Bore	W	Lake Mason	5574
Woiner Well	W	Cogla Downs	1086
Woodstock Well	W	Windsor	2064
Woolgoo Bore	W	Hillview	2358
Woolshed Bore	W	Cogla Downs	5658
Woolshed Well	W	Yarrabubba	4854
Worral Well	W	Yarrabubba	4626
Wotun Bore	W	Cogla Downs	4476
Wyatt Well	W	Yarraquin	6000
Yallahbiddy Well	W	Lake Mason	Dry
Yandayarrah Well	W	Yarraquin	1164
Yanyeen Well	W	Windsor	1500
Yarra Well	W	Yarrabubba	3660
Yo-Yo Bore	W	Cogla Downs	1032
Youno Downs homestead	O	Youno Downs	650
Unnamed bores and wells allocated letters on map			
A.	O	Youno Downs	1250
B.	O	Youno Downs	1500
C.	W	Yarraquin	1224
D.	W	Windsor	4056
E.	W	Yarraquin	1146
F.	W	Windsor	5760
G.	W	Windsor	750
H.	W	Windsor	1188
I.	T	Altona	1332
J.	T	Depot Springs (12/6)	1094
	T	Depot Springs (12/7)	890

Notes

—Observer column: O = Offe; T = Tingey; W = Williams.

—Salinities listed against Offe's name are uncorrected for temperature.

—All readings were taken between June and September 1979. Each observer used a different salinity meter. They were not calibrated against one another. Salinity figures should be regarded as only order-of-magnitude estimates.

—For salinities and full analyses of Yeelirrie Station bores and wells see Yeelirrie Project Environmental Impact Statement (Western Mining Corporation Ltd, 1979).

—$mg.L^{-1}$ is equivalent to parts per million (ppm).

SANDSTONE

WESTERN AUSTRALIA

Geological boundary, approximate
Anticline, Precambrian Geology diagram only
Syncline
Fault; q-quartz filled

Where location of folds and faults is approximate line is broken; where inferred, queried; where concealed, folds are dotted, faults are shown by short dashes

Shear zone
Minor anticline
Minor syncline
Drag-fold
Fold axis
Strike and dip of strata
Strike and dip of strata, facing not known
Vertical strata

Arrow indicates trend, and value indicates plunge of fold axis

Trend-line, Lineament — airphoto interpretation

Facing of pillow lava top
Strike and dip of joint
Vertical joint
Strike and dip of foliation
Vertical foliation
Strike of foliation
Strike and dip of metamorphic banding
Vertical metamorphic banding
Strike and dip of cleavage
Vertical cleavage
Trend and plunge of mineral elongation

Some structural elements observed at a single locality may be combined on the map

· Cu — Minor mineral occurrence
Prospect or mine with little production
Mine

Gold unless otherwise indicated
Cu-Copper; U-Uranium; Zn-Zinc
May or may not be abandoned

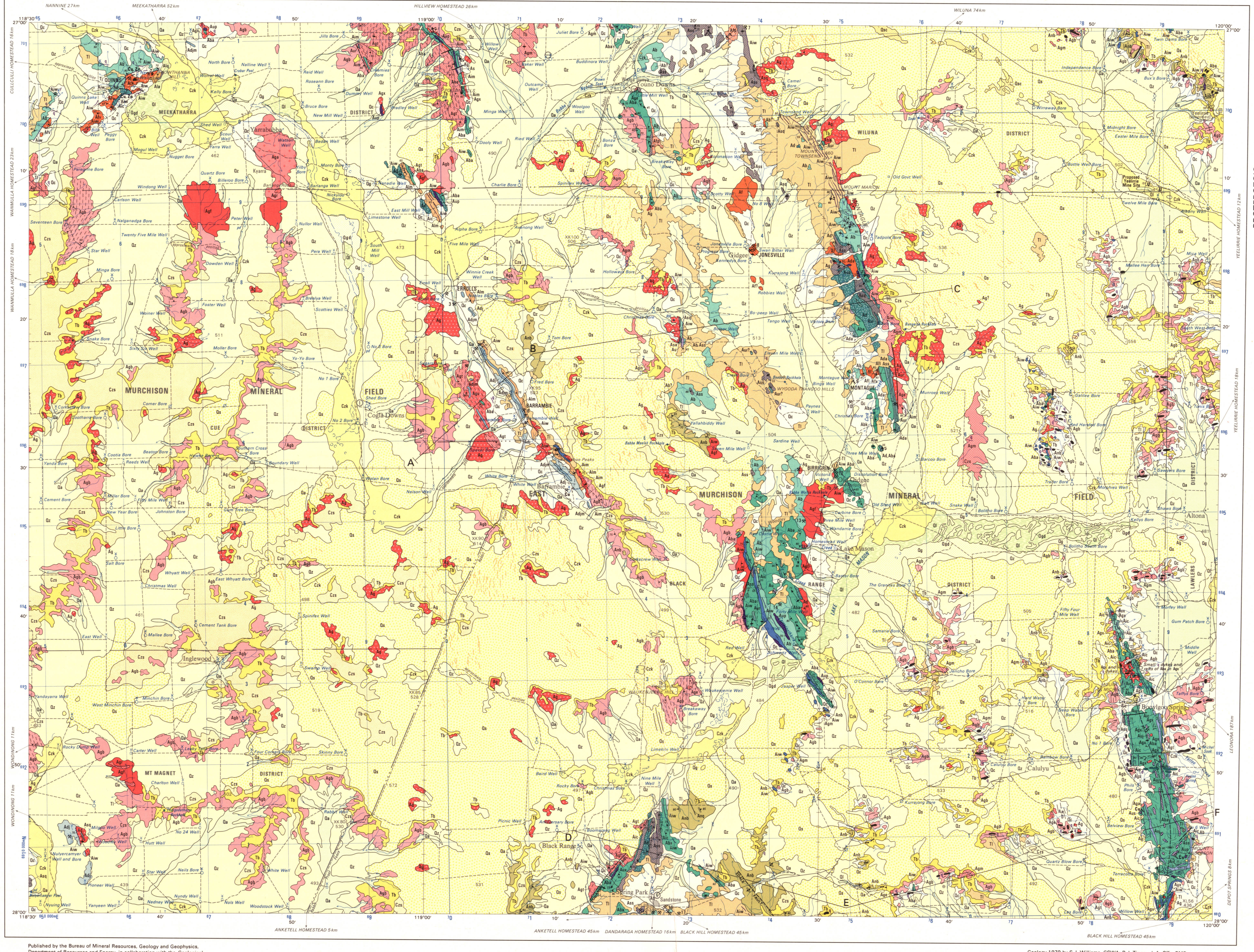
Battery, abandoned
Limit of intensive exploration at Yeelirrie uranium prospect
Costean, showing depth in metres
QUINNS — Mining locality

MINE INDEX

1	Commonwealth
2	Nowathanna
3	Legacy
4	Mystery
5	Sugarstone
6	Barrambie Ranges
7	Alma May
8	Swan Bitter
9	Montague Boulder
10	Caledonian
11	Hawthorne
12	Pelerin
13	Grace Darling
14	Sebastopol
15	Wanderie
16	Oroya Black Range
17	Oroya East

Intermittent lake
Spring
RH — Rockhole
Bore
Abandoned bore
Well
Abandoned well
Windpump
E — Earth dam

Formed road
Vehicle track
Landing ground
Townsite, gazetted
· Gidgee — Homestead
Building
Yard
Mineral Field boundary
Mineral Field District boundary
Sand dune
Astronomical station
XK80 530 — Benchmark; elevation in metres, accurate
pd — Position doubtful



Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of Resources and Energy, in collaboration with the Geological Survey of Western Australia: Issued under the joint authority of the Minister for Resources and Energy, and the Minister for Mines, Western Australia
Base map supplied by the Division of National Mapping, topographic information shown on this map is correct to 1966, with additions in 1979 by BMR and GSWA

UNIVERSAL GRID REFERENCE

GRID ZONE DESIGNATION: 50J
100,000 METRE SQUARE IDENTIFICATION
PR QR PQ QQ QP
IGNORE the SMALLER figures of any grid number; these are for finding the full co-ordinates. Use ONLY the LARGER figures of the grid number; example: 850 000mE

TO GIVE A STANDARD REFERENCE ON THIS SHEET TO NEAREST 1000 METRES
SAMPLE POINT: · Gidgee
1 Read letters identifying 100 000 metre square in which the point lies: QQ
2 Locate first VERTICAL grid line to LEFT of point and read LARGE figure labelling the line either in the top or bottom margin, or on the line itself: 3
3 Estimate tenths from grid line to point: 8
4 Locate first HORIZONTAL grid line BELOW point and read LARGE figure labelling the line in either the left or right margin, or on the line itself: 8
5 Estimate tenths from grid line to point: 3
SAMPLE REFERENCE: QQ3883
If reporting beyond 18° in any direction, prefix Grid Zone Designation, as: 50JQQ3883

INDEX TO ADJOINING SHEETS

Showing Magnetic Declination 1980

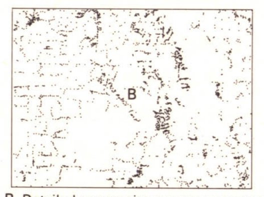
BELELE SG50-11	GLENGARRY SG50-12	WILUNA SG51-9
CUE SG50-15	SANDSTONE SG50-16	SIR SAMUEL SG51-13
KIRKALOCKA SH50-3	YOUANMI SH50-4	LEONORA SH51-1

SCALE 1:250 000

5 0 5 10 15 20 25 Kilometres

BLUE NUMBERED LINES ARE 10 000 METRE INTERVALS OF THE AUSTRALIAN MAP GRID, ZONE 50
TRANSVERSE MERCATOR PROJECTION

RELIABILITY DIAGRAM



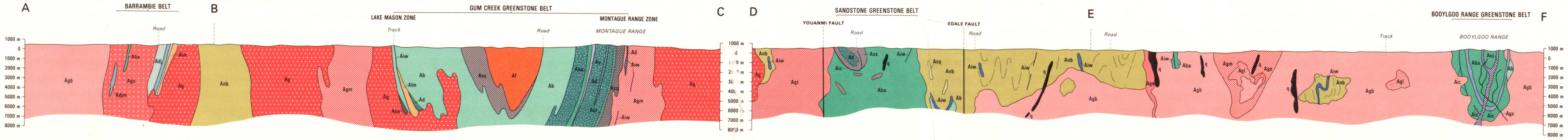
Geology B Detailed reconnaissance: numerous traverses, and airphoto interpretation
Dots indicate field observation localities

Geology 1979 by S.J. Williams, GSWA; R.J. Tingey, L.A. Offe, BMR
Compiled 1980-81 by R.J. Tingey, L.A. Offe, P.J. Corbett, BMR; S.J. Williams
Edited 1983 by G.W. D'Addario, J.F. Stirzaker, BMR
Cartography by J.A. Gallagher, A.J. Maxwell, R.A. Swoboda, J.N. Mason, BMR
Drawn by P. Moffat, A.J. Maxwell, BMR
Printed by Mercury-Walch, Hobart, Australia

SCHEMATIC SECTIONS

Cainozoic units omitted

Scale $\frac{V}{H} = 1$



CAINOZOIC

QUATERNARY

Qa	Qz	Qc	Qs	Ql	Qg	Qgd	Qsc

Qa — Poorly sorted clay to gravel deposits along drainage lines; grades to Qz: alluvium
Qz — Red-brown silt to sand sheet-wash over pebbly clay hardpan; grades to Qa, Qc and Qs: mixed alluvium and colluvium
Qc — Poorly sorted sand to gravel, rock fragments; hill-wash and scree adjacent to bedrock exposures; grades to Qz: colluvium
Qs — Red or red-brown quartz sand in sheets and dunes; grades to Qz
Ql — Saline and gypsiferous alluvium, clay, and silt in playa lakes: lake deposits
Qg — Saline and gypsiferous mixed alluvium and aeolian deposits marginal to playas; red-brown to white sand in sheets and dunes; clay, silt, and gravel in claypans
Qgd — Gypsum dunes in playas; local hard encrustations and red sand cover
Qsc — Aeolian sand overlying valley calcrete

Czs	Czk

Czs — Predominantly brown sand, silt, and clay, with limonite pisolites; sheets and dunes overlying ferruginous and siliceous duricrust: sandplain
Czk — Massive nodular and sheet carbonate with minor chalcedony; locally dark-coloured and in places carnotite-bearing: valley calcrete

TERTIARY

Tb	Tl	Tj

Tb — Ferruginous and siliceous duricrust including some silcrete, and nodular and pisolitic ferricrete; deep weathering profile pallid zone; developed over granitoid or gneiss; commonly forms breakaways, upstanding flat-topped features
Tl — Ferruginised deep weathering profile, ferruginous duricrust, massive pisolitic limonite; developed over greenstone and locally over granitoid where Tb capping removed; subdued and broken topography (lower levels than Tb)
Tj — Jasperoidal chalcedony and siliceous limonite; developed over ultramafic rocks

PROTEROZOIC OR ARCHAEAN

q	d

q — Quartz dyke, (quartz blow)
d — Dolerite dyke

ARCHAEAN

GRANITOIDS

Ag	Agb	Agf	Agl	Agt	Agu	Age	Agm	Aga	Agr	Agx

Strongly foliated variants

Ag — Undivided granitoid; deeply weathered
Agb — Biotite-bearing, commonly seriate granite, adamellite, or granodiorite
Agf — Leucogranite or adamellite; varied grain size
Agl — Porphyritic adamellite with crudely aligned microcline phenocrysts; inclusions of gneissic granitoid and banded gneiss
Agt — Gneissic, fine to coarse-grained biotite granodiorite
Agu — Gneissic muscovite-biotite granite
Age — Fine-grained biotite adamellite and granite
Agm — Mixed granitoids; mainly Agb with Age or Agl
Aga — Muscovite-albite granite
Agr — Biotite-amphibole granodiorite or granophyric tonalite; soda rhyolite granophyre at Barlangi Rock
Agx — Muscovite-albite pegmatite and coarse-grained granite; locally zoned

MAFIC INTRUSIVE COMPLEXES

Ad	Ada	Adj	Adjm

Ad — Medium to coarse-grained amphibolite; metamorphosed dolerite or gabbro
Ada — Foliated medium to coarse-grained amphibolite; metamorphosed dolerite or gabbro
Adj — Layered mafic complex; metagabbro with pyroxenitic and anorthositic layers
Adjm — Magnetite rock; cumulus textured, forms segregated layers in Adj

GREENSTONE SEQUENCES AND ASSOCIATED INTRUSIVE ROCKS

Alm	Ala	Alq

Alm — Sericite-chlorite-quartz schist
Ala — Kyanite-sericite-andalusite-chlorite-quartz schist
Alq — Fuchsitic quartzite; contains large clasts of quartzite, schist, and altered felsic volcanics

Af	Afl	Afv	Afx	Afp

Af — Schistose felsic metavolcanics
Afl — Fine-grained to aphanitic metamorphosed felsic lava
Afv — Meta-agglomerate with abundant prominent chloritised andalusite metacrysts; locally schistose; grades into Ala; contains fuchsite-bearing quartz-rich zones (Alq) which may be remnants of vents
Afx — Schistose meta-agglomerate
Afp — Metamorphosed quartz-feldspar porphyry in sills and dykes

Au	Aur	Aux	Aus	Aup	Auj

Au — Talc-anthophyllite schist; metamorphosed ultramafic rock
Aur — Tremolite-chlorite schist; includes metamorphosed komatiitic basalt
Aux — Medium and coarse-grained amphibole rock: metapyroxenite
Aus — Fine to medium-grained beds of serpentine or asbestiform minerals: metaperidotite
Aup — Medium and coarse-grained serpentinite or phlogopite-tremolite-chlorite schist; metaperidotite?
Auj — Layered amphibolite: discrete metaperidotite, metapyroxenite and metagabbro layers: metamorphosed layered ultramafic intrusives

As	Asa	Asq	Ass

As — Schistose metasediment; commonly in very small lenses
Asa — Quartzofeldspathic metasediment
Asq — Quartzite, micaceous quartzite, and well-parted feldspathic quartzite
Ass — Black slate and phyllite with carbonate (dolomite?) and thin chert intercalations

Aic	Aiw	Aim

Aic — Banded ferruginous chert; granular recrystallised rock
Aiw — Quartz-magnetite rock; metamorphosed banded iron formation
Aim — Quartz-magnetite-amphibole (grunerite?) rock; banded iron formation, higher metamorphic grade than Aiw

Ab	Aba	Abk

Ab — Fine-grained metabasalt, pillow structures locally preserved; minor intercalated coarse-grained metagabbro, possible komatiitic basalt
Aba — Schistose metabasalt; fine to medium-grained amphibole-plagioclase rock or amphibolite, more strongly deformed than Ab
Abk — Carbonate-bearing metabasalt

GNEISSES

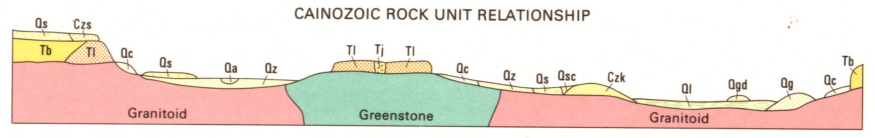
Anb	Anq

Anb — Banded gneiss, adamellite to granodiorite composition; minor inclusions of amphibole rock and banded iron formation
Anq — Coarse-grained granoblastic quartzite and quartz-magnetite-grunerite rock

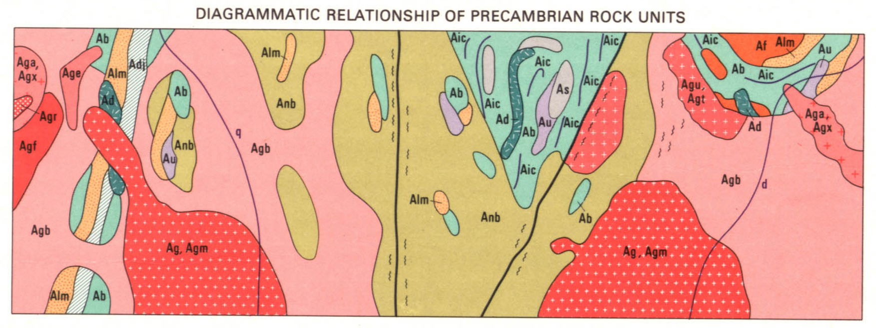
Aa

Aa — Hornblende-plagioclase amphibolite

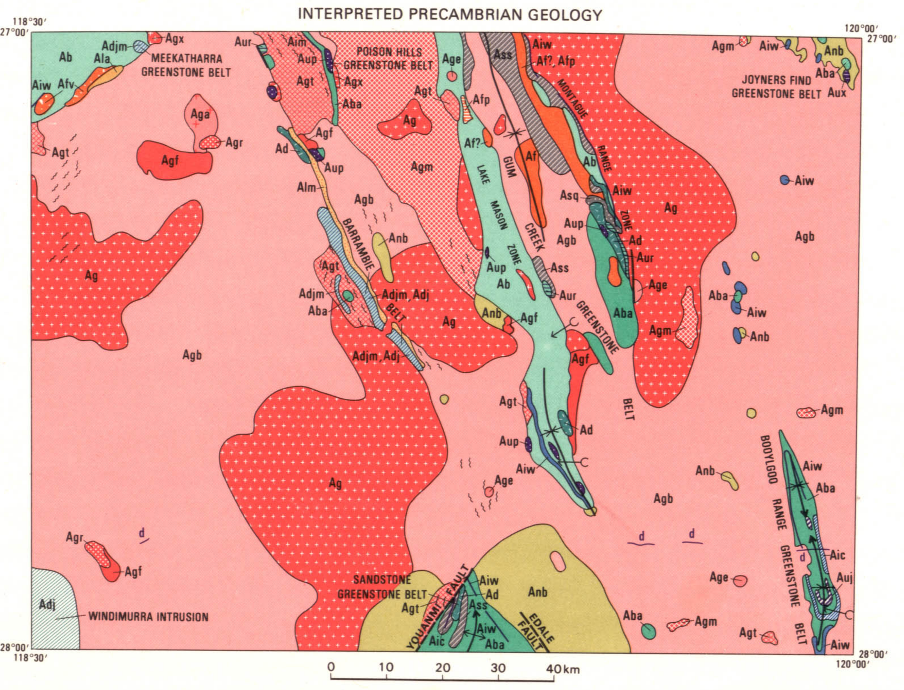
CAINOZOIC ROCK UNIT RELATIONSHIP



DIAGRAMMATIC RELATIONSHIP OF PRECAMBRIAN ROCK UNITS



INTERPRETED PRECAMBRIAN GEOLOGY



SANDSTONE
SHEET SG 50-16
FIRST EDITION 1984