EXPLANATORY NOTES

BULLEN

1:250 000 SHEET

WESTERN AUSTRALIA

SECOND EDITION

SHEET SG 51-1 INTERNATIONAL INDEX

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
DEPARTMENT OF MINERALS AND ENERGY

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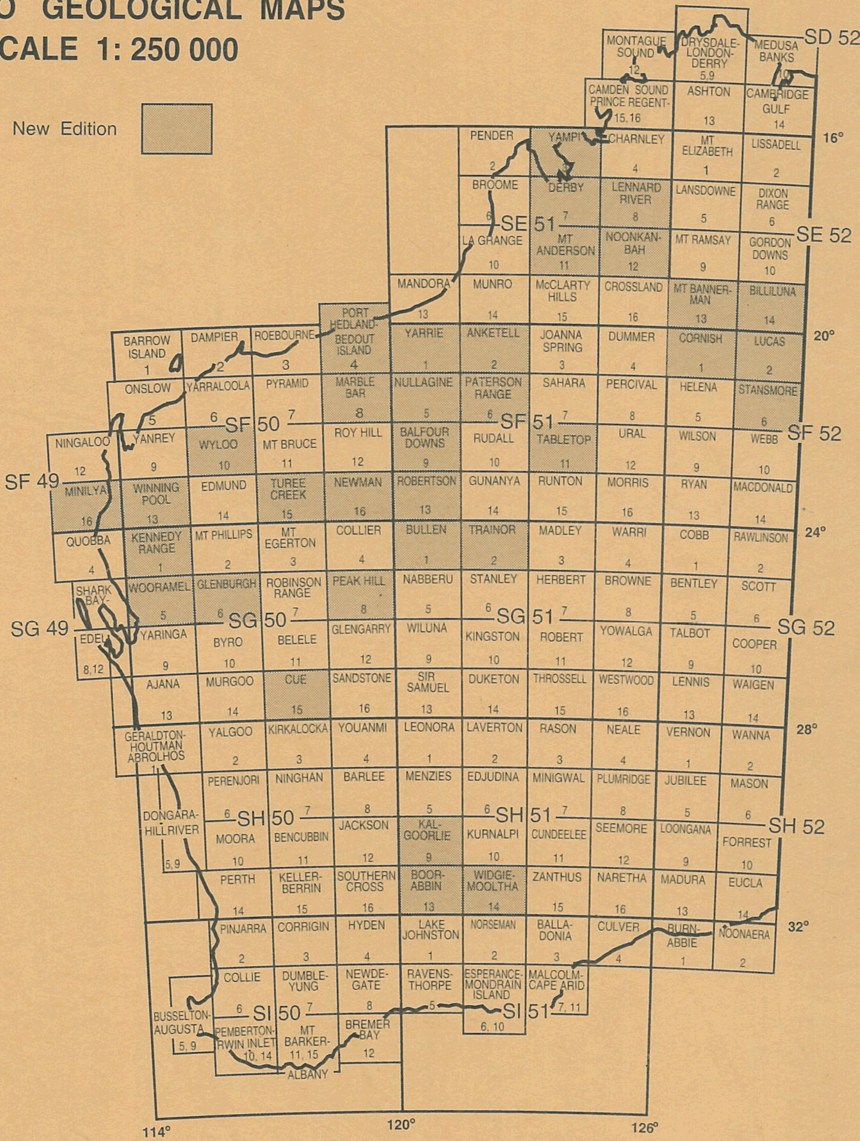

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

BULLEN

WESTERN AUSTRALIA

SECOND EDITION

SHEET SG51–1 INTERNATIONAL INDEX

by

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Perth, Western Australia 1995

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by I. R. Williams

INTRODUCTION

The BULLEN* 1:250 000 Sheet (SG51-1) is bounded by latitudes 24°00'S and 25°00'S and longitudes 120°00'E and 121°30'E. The sheet takes its name from Bullen Hill, latitude 24°53'20"S, longitude 120°36'50"E. At the time of remapping (1987–88) BULLEN was uninhabited, the only homestead in the area, Beyondie, had been recently abandoned. Adjoining cattle stations still maintain a small number of wells and bores along the western margin (Weelarrana, Kumarina and Marymia Stations) and in the southeastern corner (Glen-Ayle Station) of BULLEN.

The region is poorly serviced with tracks. Most are restricted to the pastoral areas or extend only a short distance into the desert regions of BULLEN. The few tracks outside the pastoral areas are rough and sandy and negotiable only by four-wheel drive vehicles. Such a track follows the original north-northeast alignment of the abandoned Rabbit Proof Fence (No. 1 Vermin Fence) across the western part of BULLEN. There is also an old mineral exploration track extending 20 km north-northeast from Kulonski East Well, and a poorly defined track linking Snell Bore to Snell Soak which lies 35 km to the north-northwest of the Bore. Regional access to BULLEN is most easily gained via a poorly maintained graded road that links the abandoned Beyondie Homestead to Kumarina Roadhouse on the Great Northern Highway, 67 km to the west. Kumarina Roadhouse, in turn, lies 166 km south of the mining town of Newman, which is the nearest supply centre to the region, and 256 km north-northeast of Meekatharra. The southeastern part of BULLEN is accessible from the Canning Stock Route and Glen-Ayle Station tracks.

PREVIOUS AND CURRENT INVESTIGATIONS

A brief account of exploration and early geological investigations, prior to 1975, is given in the first edition explanatory notes (Leech and Brakel, 1980). The conceptual geological framework, outlined in the first edition explanatory notes, was included in the Bangemall Basin Bulletin (Muhling and Brakel, 1985).

In 1983 a regional mapping program was implemented to update and revise the 1:250 000 geological map sheets along the southeastern margin of the Pilbara Craton. The subsequent collation, reassessment and reinterpretation of data collected from BALFOUR DOWNS (Williams, 1989), and ROBERTSON (Williams and Tyler, 1991), led to the discovery of a Late Proterozoic basin, in an area previously mapped as the Middle Proterozoic East Bangemall Basin (Williams at al., 1976, Muhling and Brakel, 1985). This new basin was

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

subsequently named the Savory Basin (Williams, 1987). BULLEN was remapped in 1987–88 as part of the field survey conducted to outline the extent and nature of the newly discovered Savory Basin. This work is described in detail in the Savory Basin Bulletin (Williams, 1992). Field work for the second edition explanatory notes on BULLEN consisted of a number of detailed ground surveys, designed to investigate areas not visited during the earlier ground traverses and helicopter reconnaissance work carried out for the first edition map in 1975. The second edition of BULLEN incorporates the new Savory Basin stratigraphy which brings it into line with the Savory Basin Bulletin (Williams, 1992).

Preliminary geophysical data, collected by the Bureau of Mineral Resources, Canberra (now the Australian Geological Survey Organisation) has been published; BULLEN gravity data (Bouguer anomalies) were released in 1981 and total magnetic intensity data in 1986, both sheets are available at 1:250 000 scale. Recently (1991) the BULLEN Bouguer anomaly data were included in the Wiluna 1:1 000 000 gravity sheet (SG51).

The difficult desert terrain encountered on BULLEN has hindered systematic mineral prospecting and exploration. Although BULLEN has been subjected to broad reconnaissance geological, geochemical and geophysical surveys there has been little encouragement to date to indicate prospective mineralization. Open-file reports on base-metal and diamond searches are available from the Geological Survey Library.

CLIMATE, VEGETATION, PHYSIOGRAPHY

Although no meteorological stations exist on BULLEN the climate is regarded as arid (desert) with most rainfall in summer (Beard, 1975). However field observations over the last decade suggest that most rainfall has been in autumn and early winter during that period.

Potential evaporation for the area ranges from 3800 mm in the northwest to over 4000 mm in the southeast of BULLEN. The summers are hot with a mean maximum temperature for the summer months of 38.5°C and the winters mild to cool with a mean minimum temperature for the winter of 6.5°C. Frosts can occur in the mid-winter months.

BULLEN lies almost entirely within the Keartland Botanical District of the Eremaean Botanical Province. The northwestern, southwestern and southeastern corners fall within the Ashburton Botanical District (Fig. 1) (Beard, 1975). On BULLEN the Keartland Botanical District is largely a mixed shrub steppe between sand dunes. The scattered rocky hills form islands with a grass steppe cover and a meagre scattering of low trees. Spinifex is ubiquitous although it thins southwards where it is largely replaced by ericoid shrubs such as *Thryptomene maisonneuvii* in the interdunal areas. *Eucalyptus* species generally have the mallee form (multiple stems). These, together with *Acacia, Eremophila* and *Grevillea* species make up the low scrub and shrub component. Desert oak (*Casuarina decaisneana*) occurs along broad palaeodrainage lines. Samphire communities and salt-tolerant shrubs occur along salt lakes margins.

Low mulga woodland (mainly *Acacia aneura*) with a distinctive striped air-photo pattern is typical of the Ashburton Botanical District on BULLEN. The mulga is interspersed with spinifex-covered sandplain with minor scattered *Acacia* and broad, pebble-veneered washes with little vegetation. Groves of coolabah (*Eucalyptus microtheca*) and *E. aspera* grow along river flats east of Beyondie Homestead. River gums, *E. camaldulensis*, line the larger creeks flowing towards the Little Sandy Desert.

The Keartland Botanical District corresponds exactly with the Little Sandy Desert Natural Region (Beard, 1970) which, in turn, is underlain by the Savory Basin (Williams, 1992).

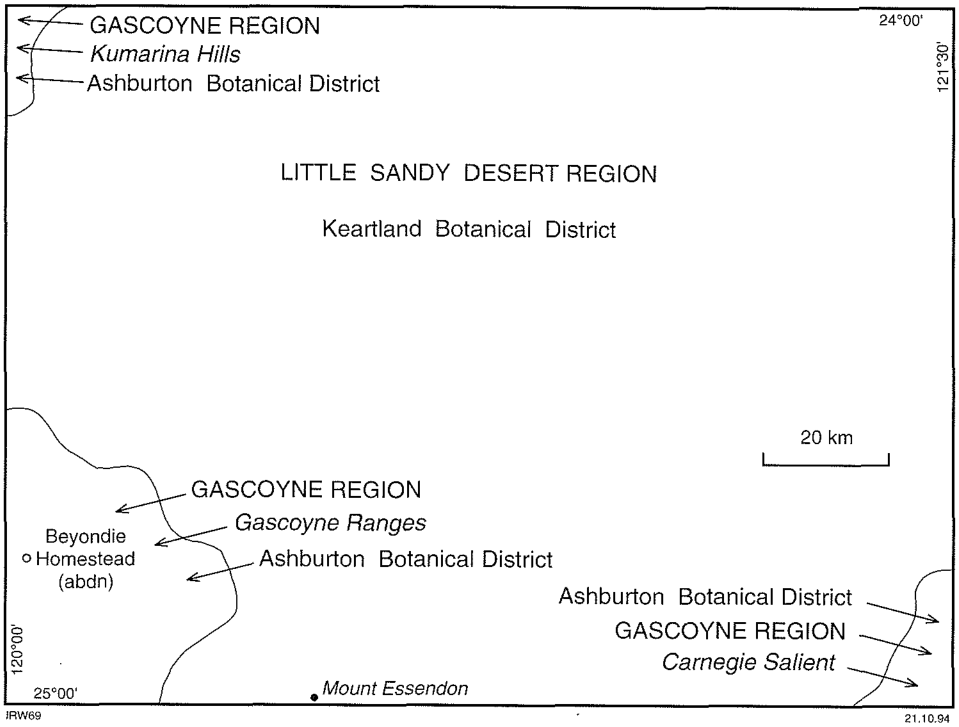

Figure 1. Natural regions, BULLEN

The Ashburton Botanical District corresponds to the Gascoyne Natural Region (Beard, 1975). Elements of the Gascoyne Region on BULLEN belong to three different physiographic units, the Kumarina Hills in the northwestern corner, the Gascoyne Ranges in the southwestern corner, and the Carnegie Salient in the southeastern corner (Beard, 1975) (Fig. 1).

The Little Sandy Desert is characterized by the dense development of well-vegetated sand dunes rather than sand sheets. The dunes range from longitudinal (seif) dunes, through chain and braided forms, to net dunes. Single crest seif dunes are uncommon except along the northern margin. Anastomosing or braided sets of chain dunes are the commonest form. Dunes range up to 20 m high but average around 12–15 m in the east gradually decreasing to 8–10 m in the west of BULLEN. The net dunes are concentrated in depressions between rocky island hills or along the broad valleys occupied by the palaeodrainage lines. Such complexes indicate variable wind directions which, to some extent, may be due to interference from the surrounding topography. East of Mount Essendon and south of the Jilyili Hills extreme variations in wind direction have produced a series of large pyramidal or star dunes up to 20 m high. Overall the linear dunes trend between 270°–260° along the eastern margin but gradually swing to 210°–190° along the western and southern margins (Fig. 2). The dune trends indicate a prevailing east-northeast to northeast wind direction on BULLEN.

It has been observed that the sand dunes do not extend much past the edge of the Savory Basin. It is also evident that the Late Proterozoic sandstones of the Savory Basin are the main source of the sand in this region.

The topography on BULLEN is broadly rolling with the overall relief seldom more than 100 m between the rocky hills and the broad sand-choked valley floors. An exception is the southern margin of the sheet where several prominent ranges and hills rise over 350 m above the plains culminating in Mount Essendon, 910 m ASL* and the Yibbie Range, 711 m ASL. The margin of the Savory Basin coincides with a broad belt of rocky hills rising to over 650 m ASL. These form an arcuate belt trending northwest from Rowe Soak and Bullen Hill to the Glass Spring area. At this point the hills swing north-northeast, the high country extending to the northern margin of BULLEN. The whole of BULLEN slopes gently to the east, the lowest level, about 460 m ASL, has been recorded in Snell Lake on the eastern margin.

The east-flowing Ilgarari Palaeodrainage Basin occupies over 80% of the sheet. An east-trending divide separates it from the north-sloping Savory Palaeodrainage Basin (Fig. 2). On the western side of BULLEN three large ephemeral creeks flow towards the Little Sandy Desert region. All three terminate in salt lakes at the margin or a short distance into the sand dune country. These are the modern Ilgarari Creek which penetrates as far as Terminal Lake and the Nanyerinny and 477 Creeks which empty into the Beyondie–Ten Mile Lake system on the southwestern margin of the Little Sandy Desert. Gum Creek, in the southeastern corner of BULLEN, is similarly blocked by sand and terminates in small salt lakes north of Snell Bore. Strings of disconnected salt lakes and patches of valley calcrete now occupy the floor of the palaeodrainage system which once flowed east across BULLEN. The Ilgarari Palaeodrainage system continued east across the adjoining TRAINOR to join the north-flowing Disappointment Palaeoriver. This Tertiary sand-choked drainage system in the desert regions of Western Australia is described and discussed by van de Graaff et al. (1977). Further aspects of the physiography of BULLEN are given in Leech and Brakel (1980).

REGIONAL GEOLOGICAL SETTING

The distribution of tectonic units on BULLEN is shown in Figure 3 and the geological history is summarized in Table 1.

The oldest recognized units on BULLEN are confined to the southwestern corner. They consist of small, scattered outcrops of quartzose metasedimentary rocks and granitoid. The latter is known to intrude the metasedimentary rocks on the adjoining COLLIER (Brakel et al., 1982). These rocks form part of the Marymia Dome (Bunting et al., 1977). Gee, (1990) considered the Marymia Dome to be a northern extension of the Archaean Yilgarn Craton reworked to some extent during the Capricorn Orogeny. The Marymia Dome is unconformably overlain by sedimentary rocks of the Middle Proterozoic Bangemall Group of the Bangemall Basin.

Two subgroups of the Bangemall Group, the shallow marine shelf Collier Subgroup and the deltaic, fluvial Kahrban Subgroup, occur on BULLEN. The Collier Subgroup is exposed in the northwestern and southwestern corner of the sheet. In the latter area the Collier Subgroup rests unconformably on the Marymia Dome. The Kahrban Subgroup occupies the southeastern corner of BULLEN (Muhling and Brakel, 1985). On ROBERTSON to the north of BULLEN a stratigraphic equivalent of the Collier Subgroup called the Manganese Subgroup, has yielded a Rb–Sr isotopic glauconite age range of 1330–1260 Ma (de Laeter, unpublished data 1991). This would suggest that the Bangemall Group is marginally older than previously published (Muhling and Brakel, 1985; Williams, 1990).

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*Above see level.

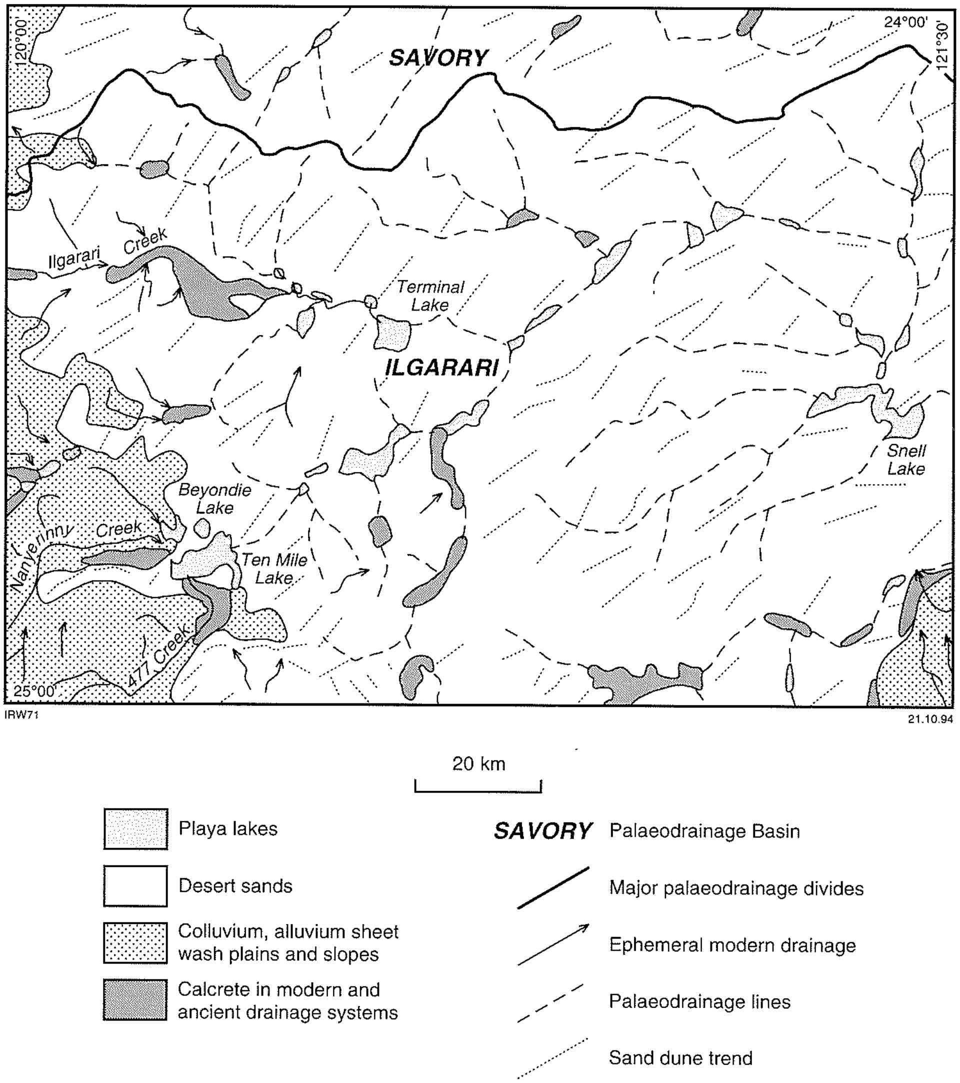


Figure 2. Palaeodrainage sketch map, Bullen

The sedimentary sequence of the Bangemall Group and intercalated mafic sills points to an extensional environment at the time of deposition. The initial distribution of the sedimentary rocks was controlled by basement block faulting. This was gradually replaced by a compressive regime that formed the southeast- to east-trending Edmund Fold Belt. This has been attributed to northward movement of the Gascoyne Complex towards the Pilbara Craton (Muhling and Brakel, 1985). However more recent studies of the Ashburton Basin and its relationship to the Capricorn Orogen (Thorne, 1990; Thorne and Seymour, 1991) have suggested that the folding in the Bangemall Basin is more likely to be connected with spatial re-adjustments between the Pilbara and Yilgarn Cratons, following the initial collision between the two cratons as interpreted from the Capricorn Orogen (2.0–1.6 Ma) (Myers, 1990a). The Bangemall Basin deformation was followed by uplift and erosion.

Table 1. Summary of Precambrian geological history

Tectonic unit		*Geological event*	*Age*
Marymia Dome (Yilgarn Craton)	1.	Deposition of clastic and chemical sedimentary rocks (?greenstone belt)	c. 2700 Ma
	2.	Deformation, low-grade regional metamorphism of sedimentary sequence; accompanied and followed by granitic intrusion	c. 2600 Ma
	3.	Renewed deformation, including faulting and recrystallization of granitic rocks during the Capricorn Orogeny	c. 2600–1600 Ma
	4.	Uplift, erosion and block faulting	c. 1600 Ma
Bangemall Basin	5.	Deposition of the Bangemall Group (Collier and Kahrban Subgroups)	c. 1400–1300 Ma
	6.	Intrusion of mafic sills	
	7.	Folding and faulting, Edmund Fold Belt	c. 1200 Ma
	8.	Uplift and erosion	
Savory Basin	9.	Deposition of Savory Group	c. <810 Ma
	10.	Intrusion of basalt, amygdaloidal basalt sills and dykes	
	11.	Brittle faulting, gentle folding, basin inversion along northwestern margin, Blake Movement	c. 750 Ma
	12.	Intrusion of dolerite	
	13.	Intrusion of north-northeast-trending dolerite dyke swarm	c. 640 Ma

The Late Proterozoic Savory Group of the Savory Basin unconformably overlies the Bangemall Group of the Bangemall Basin. The initiation of the Savory Basin, which is nestled within the Bangemall Basin, is attributed to further adjustments between the Yilgarn and Pilbara Cratons (Williams, 1992). Consequently the Savory Basin may have resembled a faulted interior fracture basin which rapidly widened and opened to the east. The oldest exposed rocks in the Savory Basin, the Glass Spring Formation, indicate a marine transgression from the east and southeast. These shallow marine-shelf deposits were progressively encroached upon by an outbuilding lobate delta system (Jilyili Formation) from the southeast. The distribution of sediments at this time was controlled by the wedge-shaped Blake Sub-basin, the initial depocentre for the Savory Basin (Williams, 1992). The Glass Spring and Jilyili Formations were subsequently intruded by high-level mafic sills and dykes which are probably related to the initial extensional phase of the Basin. Strong uplift to the west of the Savory Basin, recorded in biotite ages from the Gascoyne Complex at around 800 Ma (Myers, 1990b), coincided with a change in the provenance contributing to the Savory Basin. This event is recorded in the Savory

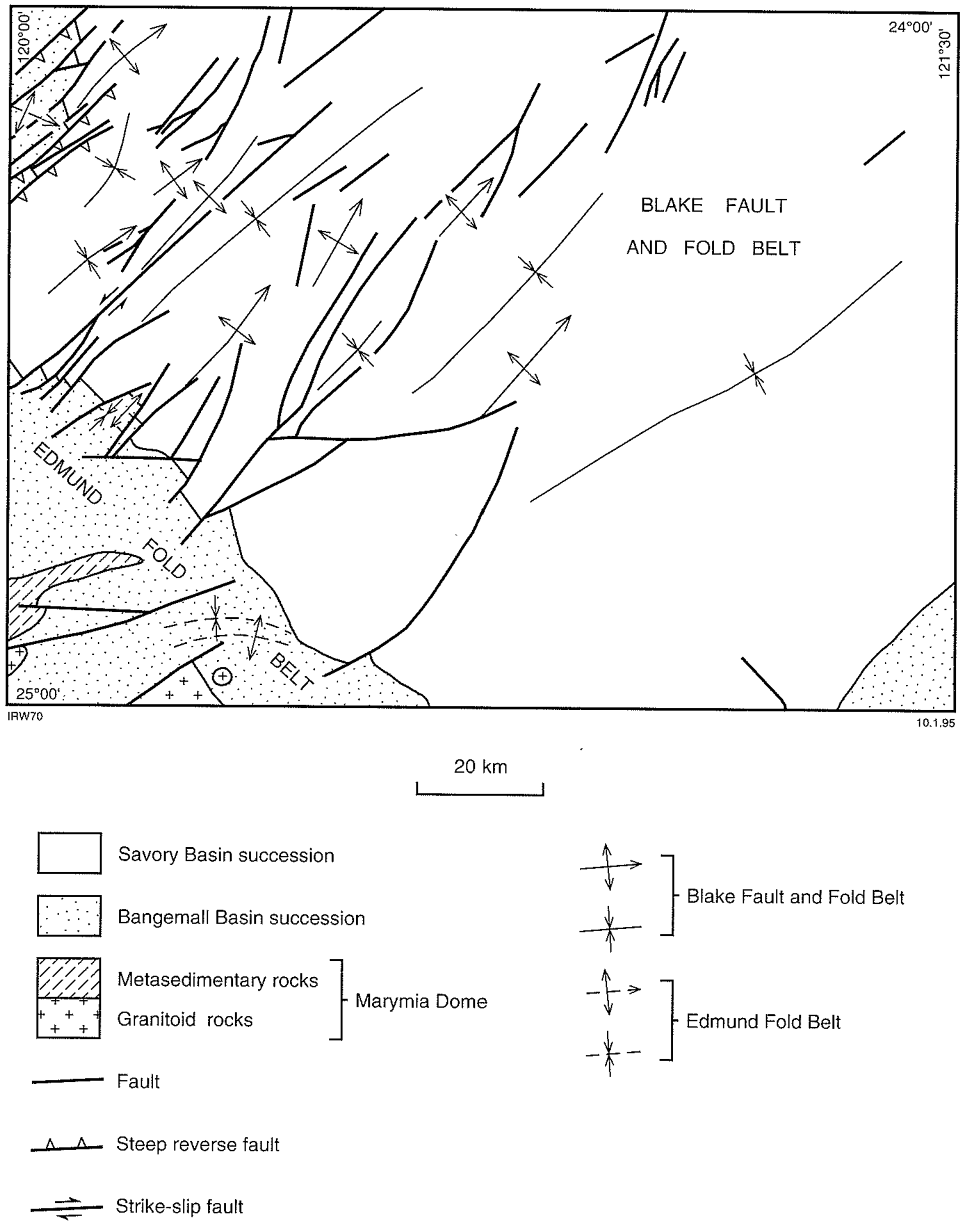


Figure 3. Tectonic sketch map, Bullen

Basin by the dramatic reversal of palaeocurrent direction from westerly directed to northeasterly directed. This was accompanied by considerable coarsening of the detrital material. The two formations of the Savory Group on BULLEN which reflect this event are the fluvial Spearhole Formation and deltaic, near-shore tidal Mundadjini Formation. These formations indicate a rapid infilling of the Savory Basin from the west and a shift of the main depocentre northeastwards (Williams, 1992). Williams (1992) has tentatively correlated the Mundadjini Formation with the 830–810 Ma formation of the Amadeus Basin sequence in the Northern Territory.

The deposition in the Savory Basin on BULLEN was brought to a close by a mild compressive event, the Blake Movement. The deformation is expressed by open northeast-trending fold axes together with near-parallel normal, steep reverse and strike-slip faults (Blake Fault and Fold Belt). The steep reverse faults in the northwestern corner of BULLEN are a southwest continuation of the Robertson Fault System and are part of a basin inversion episode which involved the northwestern margin of the Savory Basin (Williams and Tyler, 1991). A second suite of deeper level, coarse-grained dolerite sills and intrusions were emplaced in the Savory Basin at c. 640 Ma (Williams, 1992). Further Proterozoic events, which have been described from elsewhere in the Savory Basin, are not recorded on BULLEN. The final event, for which there is evidence on BULLEN, was the intrusion of a suite of north-northeast-trending mafic dykes of unknown age.

PRECAMBRIAN GEOLOGY

MARYMIA DOME

In the southwestern corner of BULLEN small outcrops of schistose and quartz-rich metasedimentary rocks and weak to strongly foliated biotite and leucocratic monzogranite constitute the northeasternmost exposures of the Marymia Dome. A small exposure of biotite monzogranite, unconformably overlain by Wonyulgunna Sandstone 15 km west of Mount Essendon, is also assigned to this tectonic unit. In addition a strong linear magnetic anomaly (BMR, 1986), in sand-dune country north of the Yibbie Range, is interpreted as banded iron-formation, a rock type known to occur with the metasedimentary rocks on adjoining COLLIER (Brakel at al., 1982). Brief lithological descriptions of these exposures are given by Leech and Brakel (1980).

The metasedimentary rocks have been previously correlated with the Early Proterozoic Glengarry Subgroup (Bunting at al., 1977) or the younger Padbury Group (Williams at al., 1978). The granitoid rocks, which intrude the metasedimentary sequence, were assigned to the Early Proterozoic Gascoyne Province (now Gascoyne Complex). More recently Gee (1990) correlated the Marymia Dome with the Southern Cross Province of the Archaean Yilgarn Craton. If this correlation is correct then the metasedimentary rocks and banded iron-formations are probably remnants of Archaean greenstone belts.

BANGEMALL BASIN

The first edition of BULLEN showed the Bangemall Group of the Bangemall Basin occupying about 99% of the sheet. However, following the recognition of the Late Proterozoic Savory Basin (Williams, 1987, 1992), this area has been reduced to about 14% although the Bangemall Group probably still underlies most of the Savory Basin (Williams, 1992).

The stratigraphic units, described in the first edition of the BULLEN explanatory notes, have been retained. In addition the Coonabildie Formation has been recognized in the southeastern corner of BULLEN. The main changes to the stratigraphy are the drastic reduction in area of the Calyie Formation (previously called the Calyie Sandstone) and its restriction to the southwestern and northwestern corners of BULLEN, and the subdivision of the Bangemall Group into subgroups (Muhling and Brakel, 1985). The Wonyulgunna, Backdoor and Calyie Formations are assigned to the Collier Subgroup and the Coonabildie Formation to the Kahrban Subgroup. The stratigraphy is summarized in Table 2.

Wonyulgunna Sandstone *(ⱣMw)*

The basal Wonyulgunna Sandstone has been described in detail by Muhling and Brakel (1985). The formation comprises two sequences. A widespread, upstanding and resistant white quartz arenite (*ᵽMw*) forms the Yibbie Range and the prominent Mount Essendon Range, whereas a siltstone-rich member (*ᵽMws*) forms low jumbled hills south of the Yibbie Range. This unit, which underlies the quartz arenite, also contains interbedded shale and sandstone. The siltstone is notable for numerous pyrite pseudomorphs.

Intraclastic sandstones occur in both sequences whereas ripple marks are more common than cross-bedding in the upper quartz arenite.

The Wonyulgunna Sandstone has been interpreted as a transgressive beach phase (Muhling and Brakel, 1985).

Backdoor Formation *(ⱣMb)*

The Backdoor Formation (Muhling and Brakel, 1985) is restricted to the northwestern and southwestern corners of BULLEN. Leech and Brakel (1980) interpreted the formation lensing out south of Bullen Hill. However recent investigations in this area have found that the gently folded Backdoor Formation passes unconformably eastwards beneath the Savory Group.

The formation is a fine-grained unit consisting mainly of grey shale and siltstone. Interbedded sandstone is generally thin bedded, fine grained and recrystallized. Some upward coarsening sequences have been identified. Chert and dolomite are minor components. The interbedded shale, siltstone and sandstone show a host of sedimentary structures including load-and-flute casts, tool marks, ripple marks and small scale cross-bedding. Pyrite, now generally pseudomorphed by limonite and goethite, is widespread as cubes and balls.

The Backdoor Formation is apparently conformable on the underlying Wonyulgunna Sandstone. The formation is part of a widespread open marine-shelf facies (Muhling and Brakel, 1985).

Calyie Formation *(ⱣMy)*

The Calyie Formation (Muhling and Brakel, 1985) (called ‘Calyie Sandstone’ by Leech and Brakel (1980)) is restricted to two small areas, one in the northwestern corner where it is faulted against the Savory Group and the other, a strip of country north of the abandoned Snake Well on the western margin of BULLEN, where it is unconformably overlain by the Savory Group. These remaining outcrops of the Calyie Formation represent a 98% reduction in area from that previously assigned to the ‘Calyie Sandstone’ by Leech and Brakel (1980).

The Calyie Formation consists of white, cream and brown recrystallized, fine- to coarse-grained sandstone, interbedded with lesser siltstone, mature granule to pebble conglomerate and minor shale. Cross-bedding, in common with palaeocurrents, is directed towards the southwest. This direction can be contrasted with the basal Glass Spring Formation of the Savory Group which has palaeocurrents strongly directed to the northwest at the uncomformity. Ripples, intraclasts, rib-and-furrow structures, synaeresis cracks and load casts have been recorded. Upward-fining sequences are also present. Glauconitic sandstone has been described from the Calyie Formation on the adjoining COLLIER.

The Calyie Formation conformably overlies the Backdoor Formation in the northwestern corner of BULLEN. The formation is interpreted as a higher energy, sandy, open marine-shelf deposit.

Coonabildie Formation *(ⱣMx)*

The Coonabildie Formation (Muhling and Brakel 1985) is restricted to the southeastern corner of BULLEN. Although not described in the first edition of the explanatory notes

Table 2. Summary of Bullen Proterozoic stratigraphy

Group	*Formation*	*Thickness (m)*	*Lithology*	*Depositional setting*
Savory Group	Mundadjini Formation *ⱣSm*	> 1 800	Fine- to medium-grained sandstone, siltstone, shale, conglomerate, dolomite, halite-bearing fine-grained sandstone	Shallow-water tidal marine prograding delta, sabkha
c. 890–c. 820 Ma	Spearhole Formation *ⱣSp*	>1 100	Coarse- to medium-grained sandstone, pebbly sandstone, pebble to boulder conglomerate sandy siltstone	Fluvial braided stream deposits
	Jilyili Formation *ⱣSj*	> 100	Fine- to medium-grained sandstone, shale, siltstone, mudstone, conglomerate	Shallow marine delta front
	Glass Spring Formation *ⱣSg*	> 1 600	Medium- to coarse-grained sandstone, pebbly sandstone, siltstone, pebbly to cobble conglomerate	Shallow marine delta front
			Unconformity	
Bangemall Group	Calyie Formation *ⱣMy*	> 1 200	Medium- to fine-grained sandstone, siltstone, pebble conglomerate, shale	High-energy, open marine shelf
c. 1400–c. 1250Ma	Coonabildie Formation *ⱣMx*	> 1 100	Fine- to medium-grained sandstone, shale, sandstone	Delta-front deposits
	Backdoor Formation *ⱣMb*	> 3 700	Siltstone, shale, fine-grained sandstone, dolomite, chert	Open marine shelf
	Wonyulgunna Sandstone *ⱣMw, ⱣMws*	> 800	Sandstone, cobble conglomerate, chert; basal siltstone, shale, fine-grained sandstone member	Transgressive beach deposits shallow marine

(Leech and Brakel, 1980), Muhling and Brakel (1985) assigned poorly exposed shale and sandstone in this area to the Coonabildie Formation. The formation consists of brown to cream, fine to medium-grained sandstone interbedded with shale and siltstone. Some siltstone interbedded with the sandstone is micaceous. Upward coarsening sequences are recorded. Cross-bedding is scarce but other sedimentary structures, such as ripple marks, load casts, tool marks, current striae, synaeresis cracks and intraclastic sandstone, are abundant.

Muhling and Brakel (1985) interpreted the Coonabildie Formation as being derived from delta-front sediments of a delta facies, probably tidally influenced in this locality.

Mafic intrusions

A number of mafic sills and irregular bodies intrude the Bangemall Group on BULLEN. The mafic bodies show a preference for the finer grained Backdoor and Coonabildie

Formations and shale interbeds in the Calyie Formation. The largest intrusion, up to 5 km long and 150 m thick, occurs around Kendenura Hill in the Backdoor Formation. Extensive mafic intrusion is also present in the Lannigan Bore area in Coonabildie Formation.

The rocks range from dark-grey, fine-grained to dark, grey-green, medium- and coarse-grained dolerite. Textures are subophitic and typically consist of plagioclase, both clinopyroxene and orthopyroxene, and magnetite. Subordinate quartz and K-feldspar occur in granophyric patches (Muhling and Brakel, 1985).

The dolerite chemistry is discussed by Muhling and Brakel (1985) who placed the suite in the continental tholeiite domain. A typical dolerite analysis, from a sample collected 9.5 km northeast of Glover Tabletop on the Rabbit Proof Fence (Muhling and Brakel, 1985), is given in Table 3.

The dolerite appears to have been emplaced early in the depositional history of the basin, probably during the extensional phase of basin development. The sills and intrusive bodies are folded with the sedimentary rocks of the Bangemall Group.

Structure

Leech and Brakel (1980) assumed that all the Bangemall Group rocks on BULLEN were essentially flat lying or gently warped. Only minor folds were recognized with axes plunging to the east and northeast. Photolineaments were interpreted as local faults and master joints. The inliers of the Marymia Dome were shown to be partly fault bounded. A graben-like structure was believed to control the distribution of the lower siltstone member of the Wonyulgunna Sandstone.

Muhling and Brakel (1985) placed BULLEN in the Bullen Platform tectonic unit and split the area into structural domains B, F and C. Following the discovery of the Savory Basin (Williams, 1992) this structural scheme is no longer valid for BULLEN.

The reclassification of a large part of the Bangemall Basin into the Savory Basin on BULLEN has required a complete reappraisal of the structural form and tectonic history of the remaining Bangemall Group which now only occupies about 14% of the area.

A review of the Bangemall Group in the light of the new tectonic picture shows that it is folded along east- to southeast-trending, open fold axes. These linear axes appear most likely to be a continuation of structural domain M, a unit described on COLLIER by Muhling and Brakel (1985) as lying between the Marymia Dome and the Tangadee Lineament. In general the fold axes in the Bangemall rocks in the western half of BULLEN swing around the northern end of the Marymia Dome. It is suggested that they are an easterly extension of the Edmund Fold Belt (Fig. 3).

In the northwestern corner of BULLEN an open east-trending, east-plunging anticlinal axis is truncated by steep east-dipping reverse faults marking the western edge of the Savory Basin. Fold axes in the southwestern part of BULLEN are oblique to the unconformity at the base of the Savory Group in this region. North-northwest of Kulonoski East Well kinking has been observed in siltstone and shale units of the Calyie Formation. The kinking is attributed to superposition of the mild deformation of the Savory Group on the underlying Bangemall Group.

Structural trends in the Kahrban Subgroup, which is poorly exposed in the southeastern corner of BULLEN, are less clear. However they appear to be dominated by east- and southeast-trending fold axes, similar to those of the Bangemall Group in the western half of BULLEN, rather than the north-northeast trend shown in previous studies (Muhling and Brakel, 1985).

The unconformity between the Savory and Bangemall Groups along the southwestern margin of the Savory Basin is intersected by a series of northeast-trending faults. Slickensides associated with these brittle faults, show both normal and strike-slip movements. The faulting is the product of the Late Proterozoic Blake Movement (Williams, 1992).

SAVORY BASIN

The Savory Group of the Savory Basin occupies 85% of the surface area of BULLEN. Four out of the thirteen formations that make up the Savory Group occur on BULLEN. They are, from oldest to youngest, the basal Glass Spring, Jilyili, Spearhole and Mundadjini Formations. The lower three formations were described and defined from exposures on BULLEN (Williams, 1992). The Mundadjini Formation was described and defined on adjoining ROBERTSON (Williams and Tyler, 1991). The stratigraphy is summarized in Table 2.

Glass Spring Formation (*ESg*)

The basal Glass Spring Formation (Williams, 1992) occupies an arcuate zone across BULLEN extending from the eastern boundary near Snell Bore to the northern boundary northwest of the abandoned Cooma Well. In both areas the formation continues only a short distance onto adjoining sheets; ROBERTSON to the north (Williams, 1992) and TRAINOR to the east (Williams, in prep.). The formation is terminated in both areas by major faults, the Kimberley Well Fault to the north and the Kelly Fault in the east.

The type area lies between Nip and Gallon Soak in Ilgarari Creek (COLLIER) (lat. 24°25'S, long. 119° 55'E) and Glass Spring, 12 km to the east-southeast (lat. 24°27'13"S, long. 120° 03'15"E) (Williams, 1992). The formation consists mainly of medium- to coarse-grained sandstone. Beds of pebbly sandstone and pebble to cobble conglomerate are more abundant in the lower parts of the formation. A few beds of siltstone are also present. The sandstones range from thick-bedded to flaggy units characteristically dark red to purple-red in colour. The coarse-grained sandstones are not well sorted and many contain granule patches and scattered pebbles. Unlike the strongly recrystallized sandstone of the Bangemall Group, the Glass Spring sandstones show little recrystallization or crystal overgrowth. Although feldspar grains are minor, a clay matrix is dominant throughout the sandstones. Some of the clay may have come from weathered feldspar. The pebbles and cobbles of both matrix- and clast-supported conglomerate are sub-angular to sub-rounded. Clasts are silica rich and mature and consist of sandstone (orthoquartzite), chert, vein quartz and quartzite.

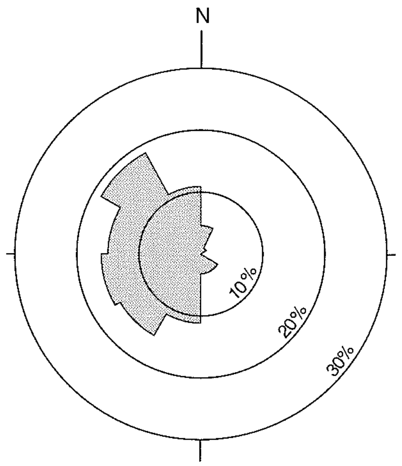
Sedimentary structures are dominated by cross-bedding. These range from solitary large scale (2–3 m) tabular units with both angular-planar or asymptotic foresets to multiple cosets of tabular and trough cross-beds up to 5 m thick. Although some possible herringbone cross-bedding has been recorded from Glass Spring most cross-bedding indicates a strong unidirectional flow. In some areas individual cross-beds are overlain by flat-bedded sandstones with current striae or asymmetric ripple marks.

Palaeogeographic reconstruction, carried out on the Savory Basin (Williams, 1992), suggests that the Glass Spring Formation may represent sandy, near-shore, marine-shelf conditions with a strong longshore current. Palaeocurrent directions are strongly east to west skewed towards the northwest (Fig. 4A). These currents appear to be roughly parallel to the present

Table 3. Chemical analyses for mafic intrusions—BULLEN

	Bangemall Basin *GSWA No. 37463*		*Savory Basin* *GSWA No. 76386*
		Percentage	
SiO_2	51.1		54.1
Al_2O_3	13.6		14.0
Fe_2O_3	3.3		3.01
FeO	8.76		8.27
MgO	5.17		4.14
CaO	8.34		7.71
Na_2O	2.40		2.60
K_2O	1.78		1.84
H_2O	0.63		0.32
H_2O+	2.67		1.45
CO_2	0.05		0.14
TiO_2	1.77		1.31
P_2O_5	0.21		0.16
S	–		0.04
MnO	0.17		0.28
O=S	–		0.02
Other	–		0.22
Total	99.9		99.6
		Parts per million except where indicated	
Ba	1 000		367
Cd	<1		–
Ce	40		54
Cr	–		6
Co	40		–
Cu	170		56
Ga	18		20
Hf	–		7
La	<20		24
Li	<20		29
Nb	<5		9
Ni	80		22
Pb	20		41
Mo	1		–
Pd	–		<5 ppb
Pt	–		<10 ppb
Rb	55		88
Sc	35		31
Ag	<5		–
Sn	6		<4
Sr	240		157
Th	<10		11
U	<1		2
V	300		283
Y	30		35
Zn	115		252
Zr	180		166
	K/Na 0.79		K/Na 0.83
	K/Rb 174		K/Rb 269
	Rb/Sr 0.56		Rb/Sr 0.23

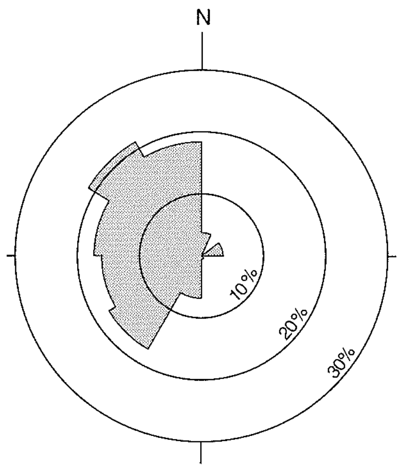
Key: Sample 37463–dolerite 24°55'15"S, 120°05'30"E
Sample 76386–dolerite 24°46'28"S, 120°45'00"E



212 measurements

30° class interval

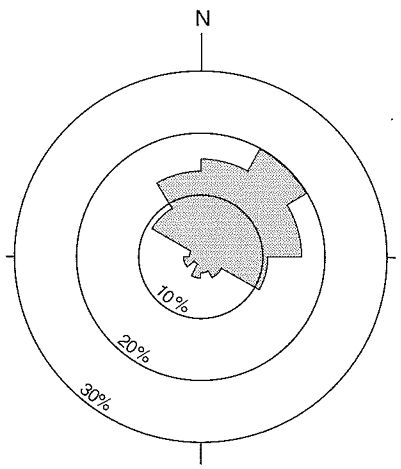
A. Palaeocurrent data for Glass Spring Formation



85 measurements

30° class interval

B. Palaeocurrent data for Jilyili Formation

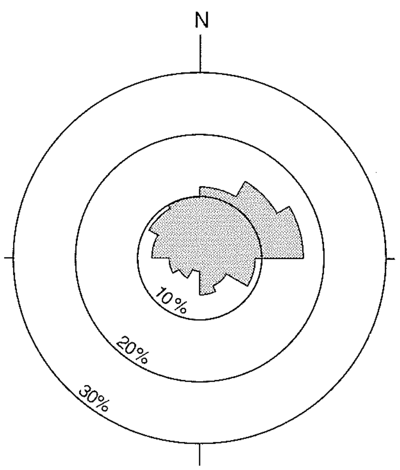


301 measurements

30° class interval

C. Palaeocurrent data for Spearhole Formation

IRW72



286 measurements

30° class interval

D. Palaeocurrent data for Mundadjini Formation

28.09.94

Figure 4. Comparative palaeocurrent data for the Savory Group

southwestern margin of the Savory Basin. However the truncation of this direction along the northwestern margin of the basin indicates that the Savory Basin may have extended further to the northwest during deposition of the Glass Spring Formation.

The provenance for the coarse detrital material appears to lie to the east and south. Clasts in the conglomerate match rocks found in the adjoining Bangemall and Nabberu Basins which lie east and south of the Savory Basin.

The Glass Spring Formation, together with the overlying Jilyili Formation and adjacent Brassey Range Formation (on TRAINOR), constitute depositional sequence A of the Savory Basin (Williams, 1992). All three formations have similarly consistent palaeocurrent directions, broadly east to west. Each formation represents a different but interrelated palaeographic environment.

Jilyili Formation *(ꓒSj)*

The Jilyili Formation conformably overlies the Glass Spring Formation and mimics the arcuate distribution of the latter formation across BULLEN. It lenses out north-northeast of the abandoned Cooma Well, a short distance inside ROBERTSON. It is terminated to the east by the Kelly Fault on the western edge of TRAINOR. The type area for the formation is the Jilyili Hills where it is exposed in a series of low cuestas, between 24°45'S, 120°45'E and 24°54'S, 120°55'E.

The Jilyili Formation is characterized by a variety of rock types ranging from mudstone to conglomerate. The main components are white to brown, fine- and medium-grained sandstones with less abundant coarse-grained, dark-red sandstone at the top of the sequence. The fine-grained sandstone is generally colour banded, well sorted and thin bedded whilst the coarse-grained varieties are typically massive or cross-bedded. Blue-grey to purple shale, micaceous siltstone and purple mudstone some of which is pebbly, are important units in localized areas particularly within and northwest of the Jilyili Hills. Clast- and matrix-supported, pebble to small boulder conglomerate occurs in lenses or thin beds; some beds appear to be channel fills in the lower half of the formation. A particularly coarse boulder conglomerate occurs 12 km northwest of Snell Bore. Boulder clasts are very mature and consist of sandstone, quartzite, vein quartz, chalcedonic agate and coloured chert.

Cross-bedding is not prominent in the formation except for the coarse-grained sandstone at the top of the sequence. Here large-scale cross-beds, up to 5 m thick, have been recorded. Small-scale cross-beds (less than 5 cm) occur in the fine-grained sandstone and siltstone. Ripple bedding and current striae have also been observed in these rocks. Graded bedding occurs in some sandstone–siltstone sequences and a number of upward-fining sequences have been found in the Jilyili Hills. Synaeresis cracks occur in sandstones interbedded with shales and siltstone.

The Jilyili Formation constitutes part of depositional sequence A of the Savory Basin (Williams, 1992). Palaeocurrent directions are very similar to the underlying Glass Spring Formation with a strong east to west flow direction (Fig. 4B). The variety of rock types in the Jilyili Formation indicates both high and low energy depositional environments. Upward-fining sequences point to waning current conditions. Sedimentary structures also suggest a mixed environment that could range from shallow marine with tidal channels and mud flats to possible fluvial. Overall the formation becomes coarser grained eastwards.

Deltaic conditions have been postulated for the Jilyili Formation with the fluvial source lying to the east-southeast (Williams, 1992).

Spearhole Formation *(ḆSp)*

The Spearhole Formation disconformably overlies the Jilyili Formation. It overlaps this formation on ROBERTSON to rest disconformably on the underlying Glass Spring Formation. It is separated from the Coondra Formation on ROBERSTON to the north by the Kimberley Well Fault. Unlike the lower Glass Spring and Jilyili Formations, the Spearhole Formation is not constrained by the Kelly Fault to the east. The Spearhole Formation, although it is partly disrupted by the fault, continues southeastwards into adjoining TRAINOR.

The formation occupies a broad arcuate zone through the middle of BULLEN. The name 'Spearhole' is the alternative name for Hann Rockhole (lat. 24°23'19"S long. 120°23'26"E) on BULLEN. Type areas for the Spearhole Formation on BULLEN are the Dean Hills (lat. 24°14'45"S long. 120°45'45"E) and an area 20 km east of the abandoned Moffetah Well (lat. 24°14'24"S long. 120°23'29"E).

The Spearhole Formation is an arenaceous sequence consisting mainly of coarse- to fine-grained sandstone. Granule and pebble sandstone and pebble to boulder conglomerate are a feature of the lower parts of the formation whereas fine-grained sandstone and sandy micaceous siltstone appear towards the top. The coarse-grained sandstones are generally poorly sorted and characterized by the occasional widely spaced pebbles. Single pebble-width conglomerate beds occur at the base of some sandstone units.

Thick conglomerate beds are fairly well sorted, mature and generally clast supported. Some conglomerate beds, overlying sandstone, form upward coarsening units. Other conglomerates occur in channels eroded in underlying sandstone. One such channel has been traced for over a kilometre in an area 12 km east-northeast of Hann Rock Hole. Clasts in all conglomerates consist of sandstone (some of which are locally derived from the margins of channels), quartzite, vein quartz, jasper and coloured and banded chert.

Cross-bedding is widespread throughout the formation, particularly moderate to large trough cross-beds; some of which are up to 20 m wide and 5–6 m thick. Many of these have asymptotic foresets indicative of strong current conditions. Tabular cross-beds, both single alpha-type and grouped cosets, are also present. Cross-bedding also occurs in the pebble and cobble conglomerate. Some cross-beds are deformed and have overturned tops of the foresets. Cross-bedding is the dominant sedimentary structure in the Spearhole Formation but in a few places ripple-marked sandstone beds occur between large cross-bedded sets, and current lineation is found on flat-bedded sandstone.

The numerous cross-beds record a remarkable unidirectional palaeocurrent direction which flowed from the southwest to the northeast (Fig. 4C). This direction is almost a complete reverse of palaeocurrent directions measured in the underlying Glass Spring and Jilyili Formations (Williams, 1992). The single pebble bands at the base of sandstone units, interpreted as lag gravels in distributary channels, the conglomerate filled channels scoured in underlying sandstone, the abundant trough cross-beds with asymptotic foresets, the cross-bedded conglomerate beds, and the deformed and overturned tops of cross-bedded units, all point to a high-energy fluvial regime.

The Spearhole Formation belongs to depositional sequence B. The formation is interpreted as a braided-stream deposit with a provenance lying west and southwest of the Savory Basin (Williams, 1992).

Mundadjini Formation *(ESm)*

The Mundadjini Formation is exposed in the northeast corner of BULLEN. It is the southwestern portion of a wide-spread formation which occupies the central part of the Savory Basin (Williams, 1992). The formation was originally defined on ROBERTSON (Williams and Tyler, 1991). One of the type areas lies just north of the BULLEN boundary at 23°54'15"S, 120°50'15"E, about 20 km west of Mystery Hill.

The contact between the Mundadjini Formation and underlying Spearhole Formation is not exposed on BULLEN but its regional distribution suggests that it is disconformable (Williams, 1992).

The Mundadjini Formation on BULLEN consists mainly of fine- to medium-grained sandstone with interbedded siltstone and minor shale, dolomite, coarse-grained sandstone, quartzite, chert, jasper and vein quartz. Dark maroon and grey shale overlain by brown siltstone and fine-grained sandstone and capped by grey-brown coarse-grained sandstone form an upward coarsening sequence at Mystery Hill. Five kilometres southeast of Mystery Hill pink, thin-bedded dolomite and sandy dolomite occur along the edge of a salt lake. A distinctive rock type found throughout the Mundadjini Formation is a fine-grained, thin-bedded, red-brown sandstone which carries scattered halite pseudomorphs up to 1 cm size. Halite pseudomorphs have been found 8 and 9 km south and 34 km southeast of Mystery Hill.

The Mundadjini Formation is characterized by a wide variety of shallow-water sedimentary structures. Ripple marks, both symmetrical (wave) and asymmetrical (current) are the dominant forms. Interference ripples (ladderback) and bevelled ripple tops point to shallow-water, tidal, mud-flat conditions. Halite pseudomorphs and mud cracks have been found in conjunction with these structures. Thin-bedded sandstones, interbedded with shale and siltstone, generally show bottom structures such as load casts and tool marks, and some show graded bedding. Most coarse-grained sandstone is cross-bedded.

Measurement of palaeocurrent directions from cross-bedding indicates a strong flow to the east and northeast, similar to that measured in the underlying Spearhole Formation (Fig. 4D).

The Mundadjini Formation on BULLEN is a mixed lithologic association which is interpreted as a shallow-water, tidal environment intermixed with prograding deltaic and fluvial sediments. Evaporite minerals indicate periodic drying out of mud flats or supersaturation of water in ponds suggesting possible sabkha environments with an accompanying arid climate.

The Mundadjini Formation belongs to the depositional sequence B of the Savory Basin which has its provenance west and southwest of the basin. The formation has been correlated with the Skates Hills Formation on TRAINOR (Williams, 1992). The Skates Hills Formation, in turn, has been correlated with the Loves Creek Member of the Bitter Springs Formation which occurs in the Amadeus Basin sequence in the Northern Territory (Grey, 1989). This correlation is based on the similarities of the stromatolite taxa and lithologies.

Mafic intrusions

Three separate groups of mafic rocks can be identified intruding the Savory Group on BULLEN. The oldest, emplaced during the early extensional phase of basin development, consists of basalt, amygdaloidal basalt and fine-grained dolerite sills and dykes. The second group consists of large, medium-to coarse-grained dolerite sills and irregular bodies that are correlated with the 'Boondawari Dolerite' which gives a preliminary Rb–Sr isotopic date of c.640 Ma (Williams, 1992). The youngest mafic rocks are north-northeast-trending dykes which post-date all Proterozoic events.

High-level intrusions

A suite of unusual amygdaloidal and vesicular basalt and fine-grained dolerite sills and dykes have been described on ROBERTSON (de la Hunty, 1969; Williams and Tyler, 1991). Similar rocks have been found in shallow boreholes drilled on magnetic anomalies north and south of Cooma Well on the abandoned Rabbit Proof Fence. Chip samples indicate that amygdaloidal basalt and fine-grained dolerite occur beneath the sandy laterite cover. Leech and Brakel (1980) described an unusual, altered, partly trachytic-textured, partly amygdaloidal basalt from 14 km west of the abandoned Moffetah Well which they suggested was extrusive. The recent survey was not able to confirm that these rocks had been extruded. However, a petrographically similar rock was found in a dyke intruded into sandstone in the vicinity. Fine-grained dolerite and basalt sills occur 6 km northwest of the abandoned Canning Well. The sandstone, overlying the basalt at this locality, is recrystallized. These mafic rocks consist of plagioclase, mainly saussuritized labradorite, clinopyroxene and abundant magnetite. Some clinopyroxene is partly replaced by secondary amphibole. Amygdales are filled with crystalline quartz, chalcedonic silica (mostly agate), and green chlorite. The total magnetic intensity map of BULLEN (BMR, 1986) shows a series of northeast-trending anomalies near the northwestern margin of the Savory Basin which may indicate further sand-covered mafic intrusions in this area. It is possible that some of the mafic rocks in the Savory Basin on BULLEN are extrusive. However no direct evidence has yet been documented (Williams, 1992).

Large dolerite intrusions

The Jilyili Formation is host to at least four large coarse-grained dolerite intrusions. The largest, in the Jilyili Hills, is a sill that has intruded a shale–siltstone horizon. The sill is up to 200 m thick and can be traced over 20 km. However if this body extends southeast beneath laterite cover and links up with other known dolerite exposures, the body could be up to 50 km long. Magnetic signatures in this region suggest that this may be the case. Other large bodies in the Jilyili Formation occur 12 km north of the Jilyili Hills and 23 km northwest of Snell Bore. A large dyke-like body occurs in the Dean Hills where it intrudes the Spearhole Formation. The Jilyili Formation, along the entire length of its outcrop, has a distinctive magnetic signature which may indicate the presence of further mafic intrusions beneath the sand cover.

The dolerite is medium to coarse grained with ophitic to sub-ophitic textures. The mineral assemblage comprises labradorite and clinopyroxene with accessory skeletal magnetite, and minor orthopyroxene, olivine, brown hornblende and quartz. The dolerite is characterized by granophyric quartz-rich patches. The chemistry of these rocks suggests they are slightly silica-enriched tholeiites. An analysis from the Jilyili Hills intrusion is given in Table 3. The co-existence of quartz and granophyric patches with olivine could be explained by wallrock assimilation during the intrusion of the body into the sedimentary rocks (Williams, 1992).

Late mafic dykes

The youngest rocks on BULLEN are north-northeast-trending mafic dykes. These occur across the whole of BULLEN but are most numerous towards the western margin of the basin. These dykes have been assigned to the d_7 suite of the southeastern Pilbara region (Williams and Tyler, 1991).

Individual dykes are up to 50 km long but are mostly less than 10 m wide. Most dykes are thoroughly kaolinized and converted to saprolite but relict textures indicate an origin as fine- to medium-grained dolerite.

Structure

The Savory Basin is a superimposed basin (Williams, 1992) and although the northwestern margin of the basin on BULLEN is strongly faulted, the southwestern margin can be seen to unconformably overlie the Bangemall Group of the Bangemall Basin. The tectonic units within the Savory Basin are independent of pre-existing tectonic units and structural style within the older Bangemall Basin.

The Glass Spring, Jilyili, Spearhole and Mundadjini Formations of the Savory Group all fall within the Blake Fault and Fold Belt tectonic unit of the Savory Basin (Williams, 1992) (Fig. 3). This tectonic unit is characterized by sub-parallel, generally northeast-plunging, fold axes and numerous north-northeast- to east-northeast-trending faults which increase in abundance westwards. Penetrative foliations and regional metamorphism are absent.

Folds in the Blake Fault and Fold Belt are broad and open. Bedding is locally steep adjacent to some fault planes. Caution is required in distinguishing large tabular and trough cross-bed dips from regional-bedding dips in poorly exposed areas. The large Blake syncline, a northeast-trending structure on the eastern side of BULLEN (see tectonic sketch map on the 1:250 000 sheet), is wholly contained within the Spearhole Formation. This fold does not involve the overlying Mundadjini Formation northwest of Hann Rock Hole. This observation suggests that there may be an unconformity between the Spearhole Formation and overlying Mundadjini Formation in this region. In the western half of BULLEN fold axes are generally paralleled by faults, some of which juxtapose two anticlinal axes and cut out intervening synclines.

The Blake Fault and Fold Belt is a brittle-fracture domain (Williams, 1992). Fault planes are generally steep and sharp with well-formed slickensides on glassy surfaces. Normal, steep reverse, and both dextral and sinistral strike-slip movements are present. Quartz-filled shear zones and quartz veins or reefs are not found in the Savory Basin on BULLEN. However sandstone adjacent to fault zones generally shows criss-cross or en echelon arrays of millimetre-thick siliceous veins. In thin section the veins have been found to consist of recrystallized quartz, and some have been shattered and comminuted then annealed by later silica. Kinking, on a millimetre scale, also occurs adjacent to some faults (Williams, 1992).

In the northwestern corner of BULLEN, steep reverse faults and dextral strike-slip faults mark the northwestern margin of the Savory Basin. These faults are the southwestern extension of the Kimberley Well Fault on ROBERTSON (Williams and Tyler, 1991). This fault, in turn, is part of the Robertson Fault System, a series of steep reverse faults which are the culmination of a basin inversion episode along the northwestern margin of the Savory Basin, and the final outcome of the Blake Movement (Williams, 1992).

The southwestern margin of the Savory Basin is intersected by a number of faults. Some like the Terminal Lake Fault (or system) and Bullen Fault are sinistral strike-slip faults (confirmed by slickensides). Others appear to be steeply dipping normal faults with an apparent offset caused by erosion. Faulting and fold intensity decrease eastwards across BULLEN.

SUPERFICIAL DEPOSITS

The descriptive, morphologic scheme used for the Cainozoic superficial deposits on BULLEN is a modification of the scheme first proposed in the BALFOUR DOWNS explanatory notes (Williams, 1989). The superficial deposits can be divided into three main groups. The first group comprises unconsolidated Holocene deposits: drainage deposits (*Qa*), lacustrine deposits (*Ql, Qd*), and eolian deposits (*Qs, Qp*). Unconsolidated silt, sand and gravel in well-defined drainage lines (Nanyerinny, Gum and 477 Creeks) is mostly restricted to areas underlain by Bangemall Basin rocks (Gascoyne Natural Region, Fig. 1). The large Ilgarari Creek, which penetrates the Little Sandy Desert as far as Terminal Lake, has its source to the west on COLLIER, in areas underlain by Bangemall Basin rocks. The lower reaches of Ilgarari Creek are saline and consist of a maze of silt- and sand-filled channels, salt marshes and salt lakes (playas). A few short sandy creeks issue from rocky hills within the Savory Basin.

The extensive palaeodrainage system, discussed under **Climate, vegetation and physiography**, hosts strings of salt lakes and claypans (*Ql*) and mixed lacustrine and eolian deposits (*Qd*). Most of the latter are gypsiferous. Large lunette dunes, consisting of kopi (flour gypsum and clay) and seed gypsum, rim the margins of the large salt lakes. The salt lakes consist of bare brown mud or white salt-encrusted surfaces. At depth this passes into black or deep red-brown clay. A hypersaline water table is generally encountered less than 0.5 m below the lake surface.

Wind-blown sand (*Qs*) is the main Holocene unit on BULLEN, covering 90% of the area. The sand occurs in sheets 2 to 10 m thick, and in dunes up to 20 m high. The eolian sand is largely confined to the Savory Basin where it is called the Little Sandy Desert (Beard, 1970). However, some sand sheets and dunes occur north of the Yibbie Range and around Mount Essendon where it overlies Bangemall Group rocks. The sand consists of medium- to coarse-grained, sub-rounded to sub-angular, iron-stained or coated quartz grains. Some interdunal and sandplain areas are covered with a thin veneer of ironstone pebbles (*Qp*). These are lag deposits derived from the breakdown of nearby or underlying laterite surfaces. The ironstone pebble veneer generally indicates a shallow bedrock beneath the sand cover.

The second group of superficial deposits includes transported, unconsolidated low-slope deposits away from or adjacent to major drainage lines (*Qw*) and deposits in regions undergoing contemporaneous erosion adjacent to bedrock (*Qc*). The low-slope deposits (*Qw*) are generally described as sheetwash and, on BULLEN, are characterized by a striped vegetation air-photo pattern. This pattern may be cellular or arcuate. The arcuate forms are developed on low but even slopes, the concave side faces upslope. The rounded, cellular patterns occur in the flatter areas. These deposits consists of interlocking vegetated, silt and sand banks surrounding bare pebble-veneered clay flats and small clay pans. The *Qc* deposits are a mixture of alluvium and colluvium modified to some extent by deflation. They include scree and talus represented by a quartz-pebble and rock-fragment veneer on clay, silt and sand. Both units involve currently active processes and can be assigned to the Holocene. The first unit (*Qw*) is mostly depositional whilst the second unit (*Qc*) covers both depositional and erosional regimes.

The third group of superficial deposits consists of semi-consolidated and consolidated colluvium (*Czc*), laterite and ferruginous duricrust (*Czl*) and calcrete (*Czk*). The *Czc* unit is old valley fill and is exposed along incised active creeks such as Nanyerinny Creek. It consists of consolidated fluvial pebbles, sand and silt. Laterite and ferruginous duricrust surfaces (*Czl*) occur scattered around the western and southern margins of BULLEN. The *Czl* unit may also occur at shallow depth beneath *Qp* units in sand-dune country. Laterites are best exposed along the edges of erosion scarps or breakaways, particularly where the bedrock is dolerite. The Jilyili Formation, which hosts large dolerite sills, is traceable on the surface by patchy laterite outcrops and the attendant *Qp* unit.

Valley calcrete (*Czk*) is patchily exposed along the old palaeodrainage lines which flowed east across BULLEN (Fig. 2). The calcrete ranges from hard, cellular, weathered, blue-grey limestone to fawn-brown to grey, earthy and crumbly calcareous silt and sand. In some places opaline silica replaces the upper parts of the calcrete unit but it is not abundant on BULLEN. Large areas of calcrete occur where recent, active drainages are blocked by sand of the Little Sandy Desert. Examples are the Ilgarari Creek drainage, Gum Creek and the Ten Mile Lake area. The calcrete is generally younger than the laterite (Williams, 1992).

The age of the third group is not clear although traditionally such units are postulated to be Tertiary. Further descriptions of the superficial deposits can be found in Leech and Brakel (1980).

ECONOMIC GEOLOGY

There are no known mineral deposits on BULLEN and mineral exploration to date has largely been reconnaissance work. Ground-level exploration has probably been inhibited by the difficult access to the region.

Broad-based geochemical, geophysical and rock-chip and soil sampling have been carried out on BULLEN with little indication of positive results so far. More detailed reconnaissance work has been carried out 15 km northeast of Kulonoski East Well for base metals (Oilmin NL et al., 1980–1983). Magnetic anomalies have been drilled (<55m) in areas 10 km northeast and 3 km southwest of Cooma Well on the abandoned Rabbit Proof Fence. Fine-grained dolerite and basalt have been intersected beneath laterite and sand cover in these regions.

Diamond exploration surveys have been conducted across BULLEN. Some of this work has been summarized in a CRA Exploration Pty Ltd report (1989).

The southwestern corner of BULLEN, which is underlain by the Marymia Dome, may be considered prospective for gold in view of the recent gold discoveries in the Marymia Dome southwest of BULLEN at Marymia and Plutonic Bore (Bruce et al., 1991).

The presence of halite in the Mundadjini Formation of the Savory Group on BULLEN and the known occurrence of gypsum, possible anhydrite, and barite in this formation elsewhere in the Savory Basin, enhances the possibility of finding larger evaporite deposits.

The Savory Basin is possibly prospective for hydrocarbons, especially the younger sequences in the northeast part of BULLEN. The basin is unmetamorphosed, is gently folded, has brittle fracture and annealed fault systems, has potential source rocks and can be correlated with the Amadeus Basin (Williams, 1992) which has known gas and oil reserves (Roe, 1991). The correlation of the Savory Basin with the Amadeus Basin in Central Australia adds a new dimension to mineral and hydrocarbon exploration in the area (Williams, 1992).

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AUSTRALIA 1:250 000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SG 51-1

SYMBOLS

Geological boundary, accurate

Fault: accurate; inferred; inferred and concealed; marked with dip of fault plane; reverse: accurate, inferred and concealed; relative displacement

Fold, showing direction of plunge: anticline; syncline; minor, asymmetric

Bedding, showing strike and dip: inclined; horizontal

Direction of movement of sediment-bearing currents, from cross-bedding

Air photo lineament

Mineral field boundary

Road

Track

Homestead

Yard

Horizontal control, major

Sand dune

Watercourse, ephemeral

Bore, well

Windpump

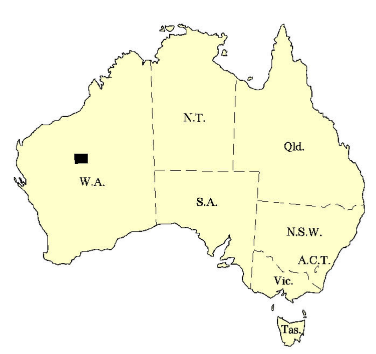
Spring, soak, pool

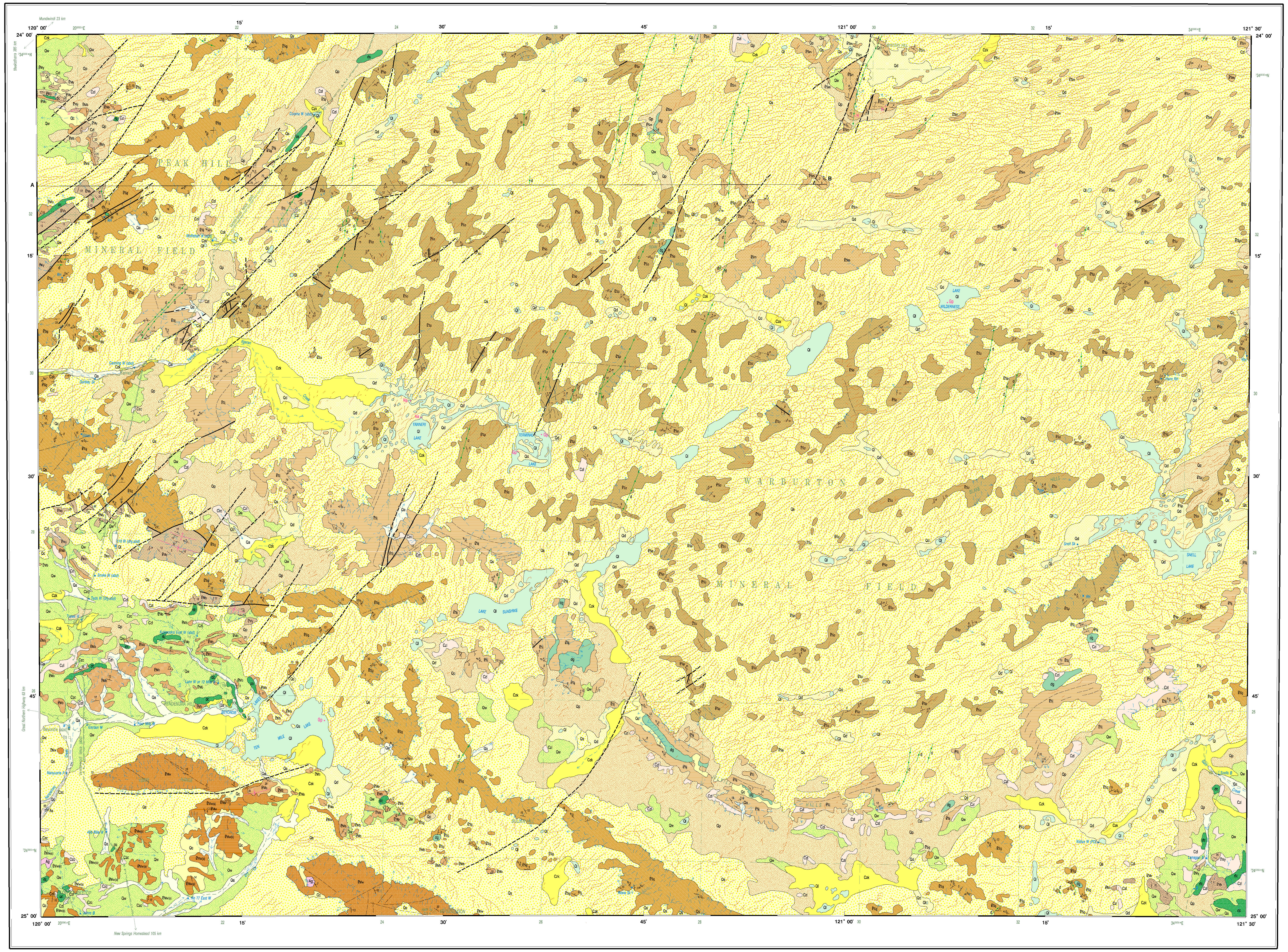
Rockhole, gnamma hole

Abandoned

Position doubtful

Industrial mineral occurrence: Gypsum; Halite (pseudomorphs); Salt (in playa lakes)





REFERENCE

PHANEROZOIC — CAINOZOIC — QUATERNARY

Qa	Ql	Qd	Qs	Qp	Qc	Qw

Qa Alluvium—clay, silt, sand, and gravel; in drainage channels and adjacent flood plains

Ql Lacustrine deposits—clay, mud, and silt, mostly saline; commonly gypsiferous

Qd Mixed lacustrine and eolian deposits—clay, mud, silt, and sand; mostly saline; gypsum dunes (kopi)

Qs Eolian sand—in sheets and dunes; longitudinal (seif), chain, net, and pyramidal dunes

Qp Eolian sand—in sheets and interdunal areas; sand, ferruginous sand with ironstone pebble veneer, derived from Czl

Qc Colluvium and minor alluvium—quartz pebble and rock fragment veneer on sand and silt adjacent to bedrock; scree deposits

Qw Colluvium and alluvium—clay, silt, sand, and gravel on broad sheetwash areas; distinctive striped air photo pattern to vegetation

Czk	Czl	Czc

Czk Calcrete—carbonate in sheets, mainly confined to palaeodrainage lines; some secondary silicification at surface

Czl Laterite—massive, pisolitic, pebbly, and nodular ferruginous deposits; overlies leached bedrock

Czc Colluvium—partly consolidated and consolidated ferruginized silt, sand, gravel; old valley-fill deposits dissected by present drainage

d Fine-grained dolerite dykes; kaolinized weathered outcrop; various ages

PROTEROZOIC — LATE PROTEROZOIC — SAVORY BASIN

dg Medium- to coarse-grained dolerite, granophyric in places; in sills, dykes, and irregular intrusions

ds Basalt, amygdaloidal and porphyritic basalt, fine-grained dolerite; in sills, dykes, and small intrusions

c. 810 Ma — Savory Group

ꞒSm MUNDADJINI FORMATION: fine- to coarse-grained sandstone, siltstone; minor shale, mudstone, conglomerate, dolomite, halite-bearing sandstone

ꞒSp SPEARHOLE FORMATION: coarse- to medium-grained sandstone, pebbly sandstone, granule sandstone, conglomerate and siltstone lenses

ꞒSj JILYILI FORMATION: fine- to medium-grained sandstone, siltstone; subordinate shale, mudstone, pebbly mudstone, thin-bedded conglomerate

ꞒSg GLASS SPRING FORMATION: medium- to coarse-grained sandstone, granule sandstone, conglomerate lenses; minor siltstone

MIDDLE PROTEROZOIC — BANGEMALL BASIN

dc Medium- to coarse-grained dolerite; in sills, dykes, and irregular intrusions

c. 1300 Ma — Bangemall Group — Collier Subgroup

ꞒMy CALYIE FORMATION: medium- to fine-grained sandstone, siltstone, shale

ꞒMb BACKDOOR FORMATION: shale, siltstone, medium- to fine-grained sandstone, minor chert

ꞒMw WONYULGUNNA SANDSTONE: coarse- to medium-grained sandstone; minor conglomerate

Shale, siltstone, minor sandstone

Kahrban Subgroup

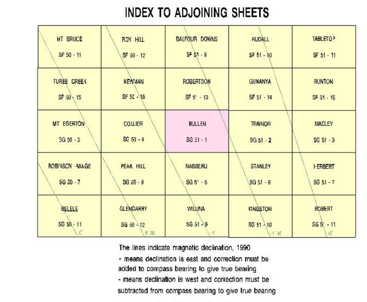
ꞒMo COONABILDIE FORMATION: coarse- to fine-grained sandstone, micaceous siltstone, shale

ARCHAEAN — MARYMIA DOME

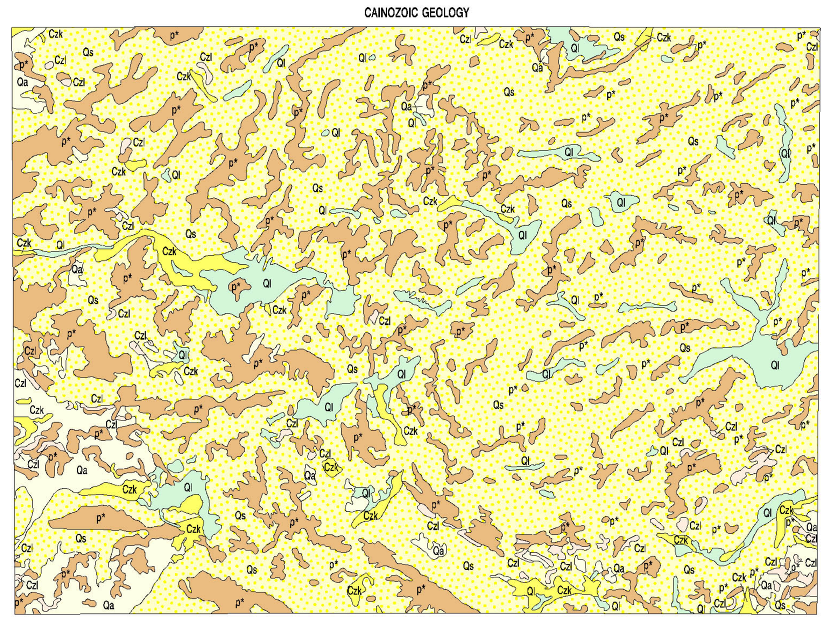
Ag Granitoid rock; foliated; gneissic

As Schist, quartzite, metasedimentary rocks

INDEX TO ADJOINING SHEETS



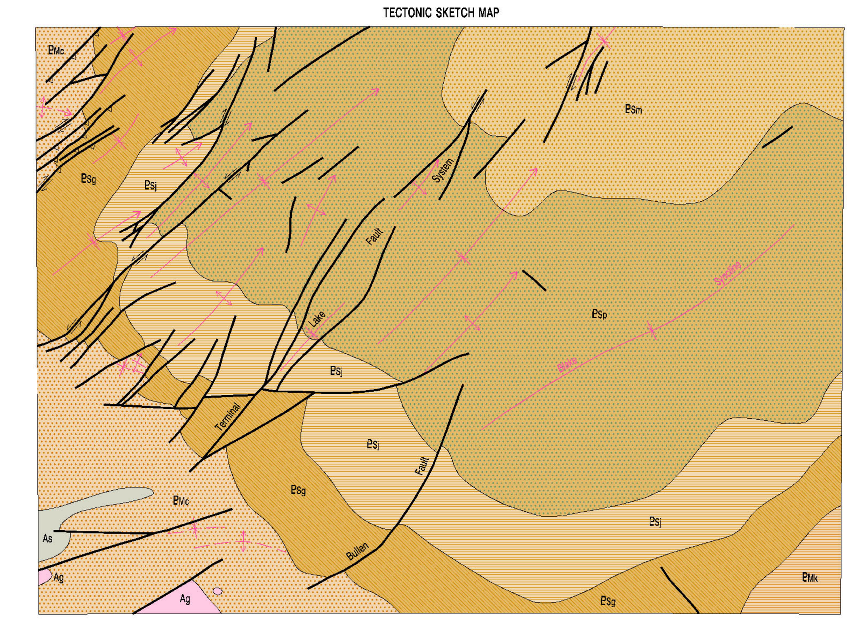
CAINOZOIC GEOLOGY



Qa Alluvium and colluvium; Ql Lacustrine and associated deposits; Qs Eolian sand; Czk Calcrete; Czl Laterite, older colluvium; ꞒR Precambrian bedrock

SCALE 1:1 000 000

TECTONIC SKETCH MAP



ꞒSm Mundadjini Formation; ꞒSp Spearhole Formation; ꞒSj Jilyili Formation; ꞒSg Glass Spring Formation — SAVORY BASIN

ꞒMc Collier Subgroup; ꞒMk Kahrban Subgroup — BANGEMALL BASIN

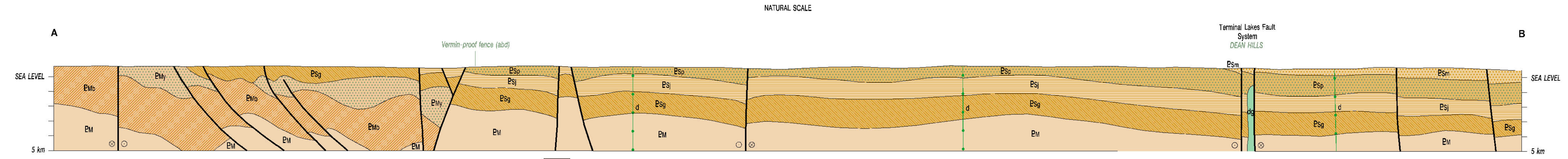
Ag Granitoid rocks; As Metasedimentary rocks — MARYMIA DOME

Anticline; Syncline — Fold axes Bangemall Basin

SCALE 1:1 000 000

DIAGRAMMATIC SECTION

NATURAL SCALE



ꞒM Undifferentiated Bangemall Group rocks

Strike-slip fault — ⊙ movement towards viewer ⊗ movement away from viewer

SCALE 1:250 000

5000 Metres 0 5 10 15 20 25 30 Kilometres

TRANSVERSE MERCATOR PROJECTION

Grid lines indicate 20 000 metre interval of the Australian Map Grid Zone 51

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SHEET SG 51 - 1

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