GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

BULLETIN 141

GEOLOGY OF THE SAVORY BASIN WESTERN AUSTRALIA

by
I. R. WILLIAMS

DEPARTMENT OF MINERALS AND ENERGY

GEOLOGY OF THE
SAVORY BASIN
WESTERN AUSTRALIA

FRONTISPIECE

An exposure of laterite-capped diamictite of the Boondawari Formation in the Savory Basin. The rocks of this formation provide the westernmost known occurrence of Late Proterozoic glacigenic rocks in Australia.

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Perth 1992

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Page 38: photographs for Figures 44 and 45 have been interchanged

Page 67: in legend for Figure 81, **ⱣSt** should read **ⱣSr**

Page 109: index entry *Bocrabree* should read *Bocrabee*

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Geology of the Savory Basin Western Australia

Abstract

The Savory Basin is a newly recognized 900–600 Ma Proterozoic sedimentary basin east and southeast of Newman; it corresponds geographically to the Little Sandy Desert region of Western Australia. Situated between the Pilbara and Yilgarn Cratons, the basin unconformably overlies the eastern part of the Middle Proterozoic Bangemall Basin. In the northeast, it is structurally delimited by the Proterozoic Paterson Orogen; and, in the east, it is unconformably overlain by rocks of the Phanerozoic Officer Basin. The thirteen defined formations that make up the Savory Group are predominantly arenaceous; but the group also contains an important glacigenic sequence, biostratigraphically significant stromatolitic dolomites, and evaporite occurrences. The previously unrecognized glacigenic sequence extends the known exposures of such rocks 400 km westwards. Newly described stromatolites found in the eastern part of the basin point to biostratigraphic links with the Amadeus Basin of Central Australia. The biostratigraphic and lithostratigraphic similarities between the Savory Basin and the Amadeus Basin have led to the tentative conclusion that the two basins are, in part, coeval, and that they may have been physically linked during specific time intervals.

KEYWORDS: Proterozoic, 900–600 Ma, sedimentary basin, stratigraphy, lithological unit, sedimentary structure, provenance, palaeocurrents, glacial sediments, structural geology, evaporite minerals, Savory Basin, Western Australia.

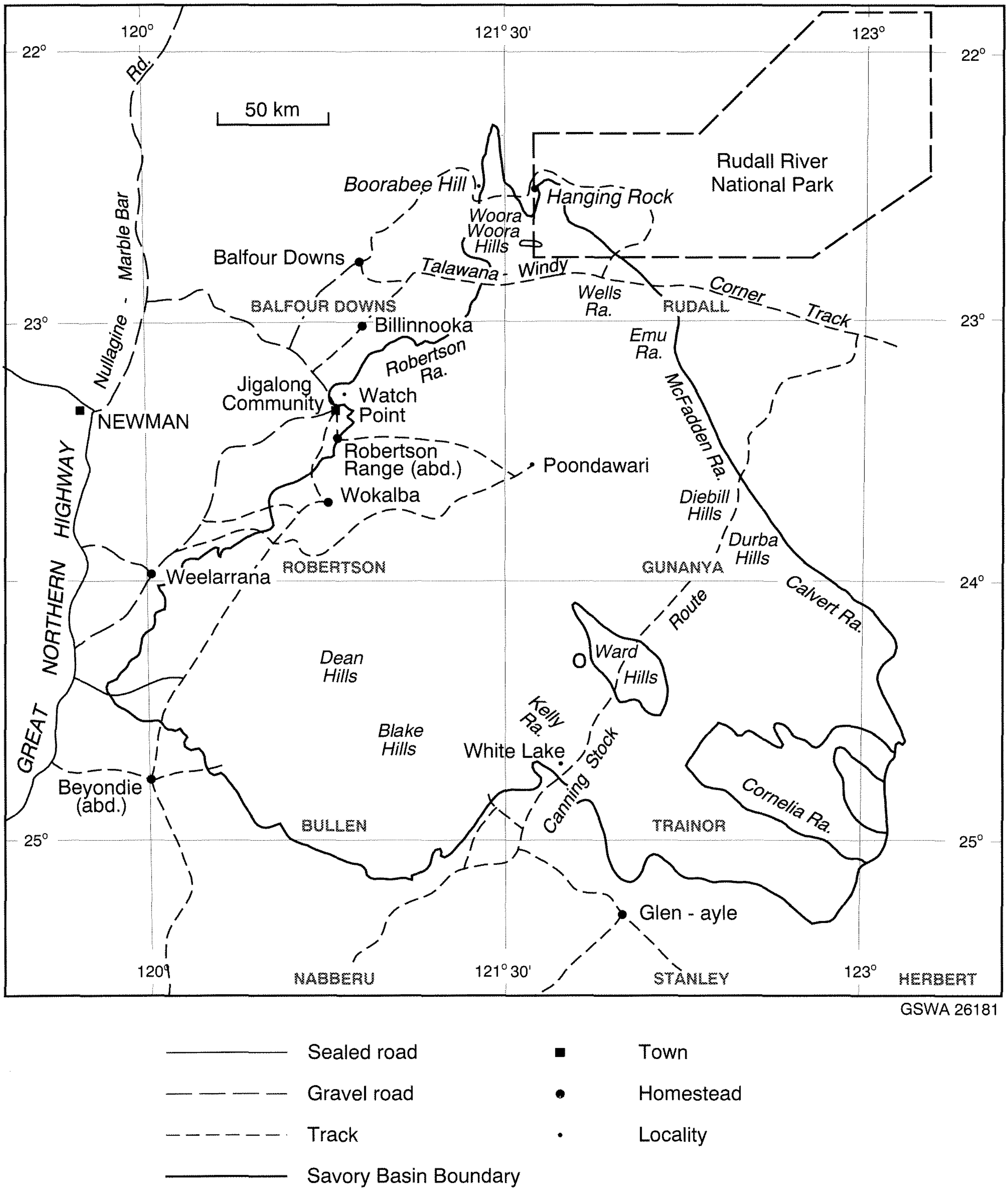

Figure 1. Locality map and sheet index

Chapter 1

Introduction

Location and access

The Savory Basin lies east and southeast of Newman in the Pilbara region, between latitudes 22°30' S and 25°30' S, and longitudes 119°45' E and 123°15' E (Fig. 1). It occupies an area of 53 000 km^2. The region is largely uninhabited. The only permanent settlement is an outcamp at Poondawari — 6 km west of the Boondawari–Savory Creek junction on GUNANYA* — which was established in 1988 by the Jigalong Aboriginal Community. The outcamp is linked by graded track to the Jigalong Community, which lies 90 km to the west, just outside the northwest margin of the Savory Basin.

Pastoralists from adjoining cattle stations, exploration and mining company personnel, and tourists who travel the Canning Stock Route, constitute a small and transitory population. Pastoral leases encroach on the northwestern, western, and southern margins of the basin; but, because of poor and unsuitable vegetation, lack of water, and difficult sand-dune terrain, the area has remained undeveloped Crown Land. Occupied pastoral leases adjacent to the basin are, from north to south, Balfour Downs, Robertson Range, Weelarrana, Bulloo Downs, Kumarina, Marymia, Glen-Ayle, and Carnegie (Fig. 1). Unoccupied Crown Land lies east and northeast of the basin.

The paved Great Northern Highway lies west of the Savory Basin. It links Meekatharra, which lies 280 km southwest of the basin, to Newman, 90 km northwest. Newman is the nearest commercial centre. Overall, access to the region is limited to a few, poorly maintained graded roads, and four-wheel-drive tracks. The Talawana–Windy Corner graded track crosses the northern salient of the basin, whilst graded pastoral station tracks on Balfour Downs, Weelarrana, Kumarina, Marymia and Glen-Ayle give access to the western and southern margins. An old exploration track follows the north bank of Savory Creek as far as its junction with Boondawari Creek. A poorly maintained track follows the abandoned No. 1 Rabbit Proof Fence along the western margin of the basin. A well-defined four-wheel-drive track follows the original course of the Canning Stock Route across the southeast part of the basin. Canning Stock Route wells, numbers 11 (Goodwin Soak) to 17 (Killagurra Spring), lie within the boundaries of the Savory Basin. At the northern edge of the basin, an infrequently used four-wheel-drive track links Christies Crossing on the Oakover River (Balfour Downs Station) to the Rudall River area via Hanging Rock. Access tracks are shown on Figure 1.

Climate and vegetation

There are no meteorological stations within the Savory Basin, but estimates based on data from peripheral stations indicate that the area is desert and has a summer rainfall maximum (Beard, 1975). Mean annual rainfalls range from just over 250 mm in the northwest corner to less than 200 mm along the eastern margin.

Summers are hot: the mean maximum temperatures range from 37°C in the south of the basin to 41°C in the north. Summer is also marked by infrequent, but heavy, rainfalls, often accompanying thunderstorms associated with dissipating tropical cyclones and monsoonal low-pressure troughs that move southeasterly across the basin. Winters are cool to mild: the mean minimum temperature is 8°C in the south of the basin and 12°C in the north. Frosts may occur in all parts of the basin during the winter months. Winter may also be marked by light, but wide-spread, rains associated with middle-level disturbances that move in from the northwest Indian Ocean. These rains are triggered by an interaction between the middle-level disturbances and cold fronts that move eastwards across the state. The cold fronts, in turn, are connected to deep Antarctic low-pressure systems in the Southern Ocean.

Evaporation rates, the highest in Western Australia, range from 3600 mm to 4200 mm a year (Australian Bureau of Statistics, 1989, p. 45.).

The Savory Basin corresponds closely to the Keartland district of the Eremaean Botanical Province of Western Australia (Beard, 1979). The region is largely a shrub steppe on sandplain and between sand ridges. The dunes, themselves, carry a distinctive tree steppe; but low, rocky hills and ranges are largely grass steppe sparsely populated by shrubs and trees (Beard 1974a,b, 1975, 1976).

Spinifex (*Triodia* sp.), a hummock grass, predominates throughout the region. The shrubs, which become more scattered northwards, include various *Eucalyptus*, *Acacia*, *Grevillea*, *Hakea*, and *Eremophila* species. Desert bloodwood (*Eucalyptus dichromophloia forma*) and low mallees (*Eucalyptus gamophylla, Eucalyptus kingsmillii*) grow along the crests of dunes. Scattered mulga (*Acacia aneura*), favouring the more loamy soils, become more numerous southward across the basin. Low, mulga woodlands occur on stony pediments adjacent to rocky

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*To avoid confusion with place names, map sheet names are printed in full capitals, i.e. GUNANYA.

Figure 2. Vegetated longitudinal (seif) dunes in Hanging Rock area, northern margin of basin

hills and ranges. Desert oak (*Casuarina decaisneana*) can be found along calcreted palaeodrainage lines. Scattered groups of grasstrees (*Xanthorrhoea thorntonii*) are locally conspicuous in the western parts of the basin. Ericoid shrubs, such as *Thryptomene maisonneuvii*, sometimes replace spinifex as the dominant vegetation in interdunal areas in the southern part of the basin. Samphire and scattered salt-tolerant shrubs occupy the margins of playa lakes.

Physiography

The Savory Basin lies mainly within the Carnegie Natural Region of Clarke (1926) and the Sandridge (Sandplain) physiographic division of Jutson (1934). It is included in the Great Sandy Desert Dunefield geomorphologic unit of Jennings and Mabbutt (1986). However, Beard (1970) proposed that the natural region corresponding to that now recognized as the Late

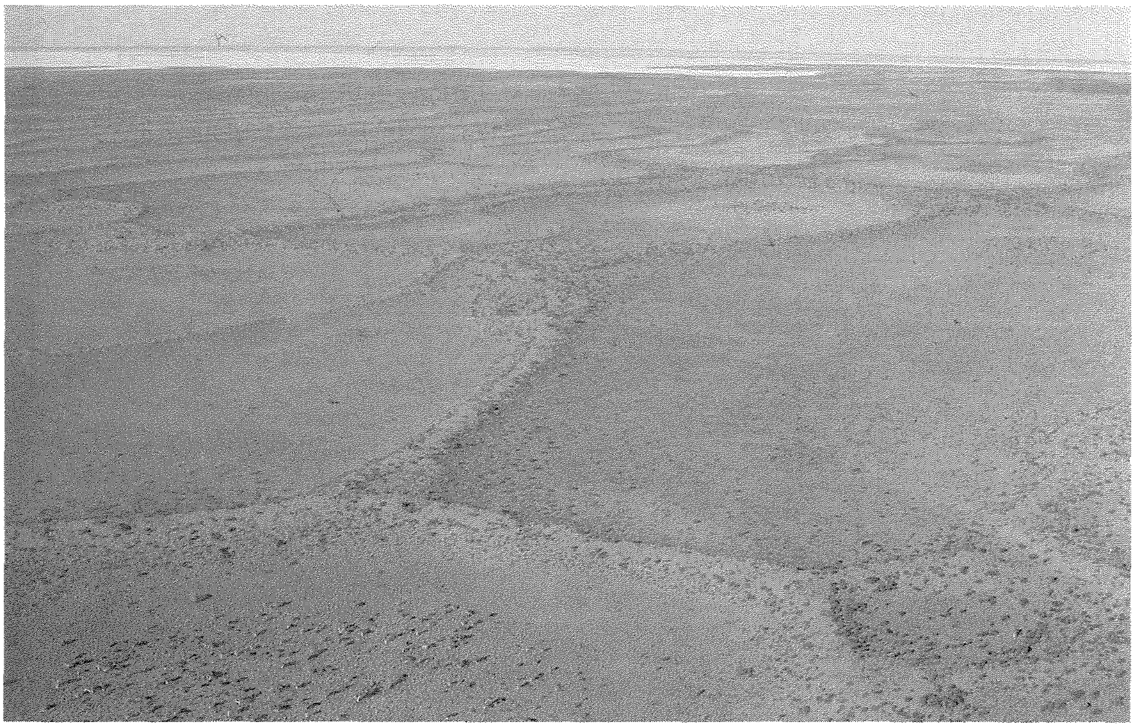

Figure 3. Net dunes, Lake Disappointment on horizon, eastern margin of basin

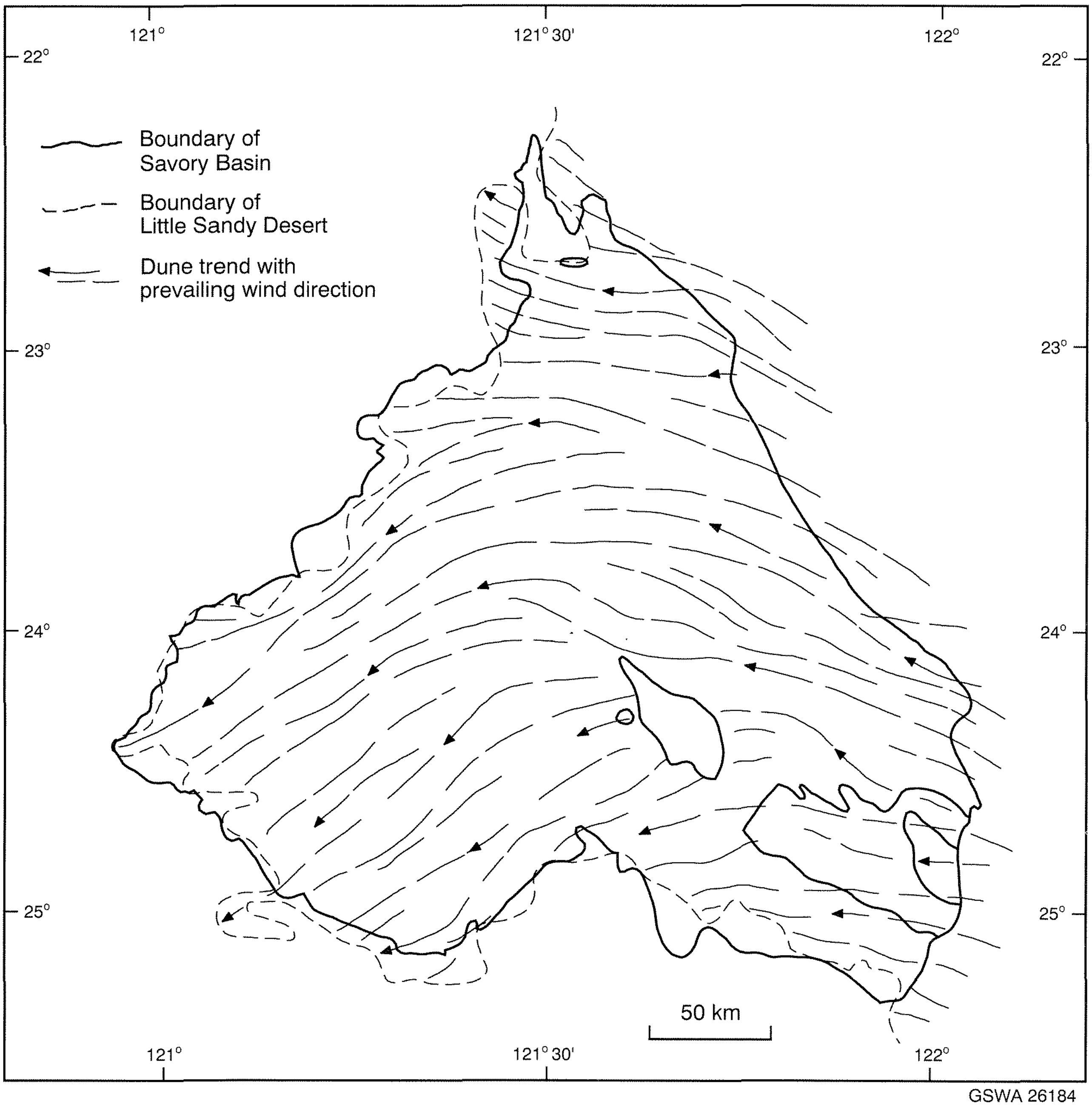

Figure 4. Trends of longitudinal dunes

Proterozoic Savory Basin be separated from the Great Sandy Desert to the north and be renamed the Little Sandy Desert. This term was formally approved by the State's Department of Land Administration (1987). The present study supports Beard's proposal. It was found that the dunes of the Little Sandy Desert differ in both morphology and provenance from those of the Great Sandy Desert.

Red sand dunes are common throughout the basin. The dunes range from sinuous, but simple (single-crest), longitudinal dunes (seif dunes) through chain dunes (multiple-crest) to net dune complexes (Figs 2, 3). Individual longitudinal and chain dunes may be up to 30 km long and 20 m high; but, more generally, they average 5–10 km long and 8–10 m high. They are generally between 500 m and 1 km apart; but in extreme cases, depending on the availability of sand, may be less than 250 m or up to several kilometres apart. The net-dune complexes are found between rocky hills and low ranges, or in broad valleys containing calcreted palaeodrainage systems. Southeast of the Durba Hills, net-dune complexes cover more than 2000 km^2. As described by Crowe (1975), these three types of dunes form a continuous series, and the prevailing form is largely dependent on local topography. Pimple, or pyramidal dunes, over 17 m high, occur along the southern margin of the basin near Bullen Hill. Lunette dunes, composed of flour gypsum and silt (kopi), occur adjacent to playa lakes.

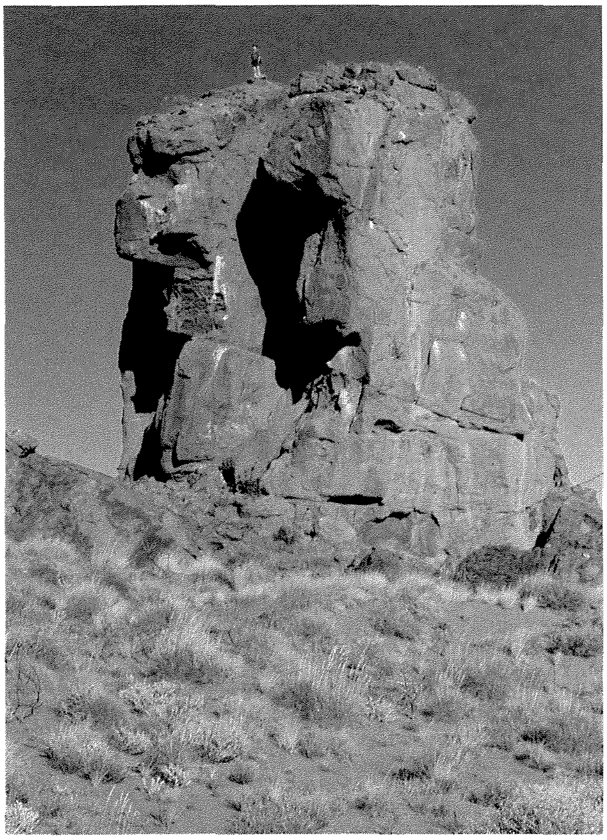

Figure 5. **Hanging Rock, sandstone butte, Tchukardine Formation, northern margin of basin**

All types of dunes are elongated parallel to the prevailing wind direction. The trends change from between 315° and 320° along the eastern margin of the basin to between 210° and 220° along the southwestern margin. Tuning-fork junctions (Crowe, 1975) indicate that the direction of the prevailing wind changes from southeasterly in the east of the basin to northeasterly in the west. This arcuate swing also appears to reflect the triangular shape of the Savory Basin (Fig. 4).

The dune structures in the Little Sandy Desert are smaller and less continuous but more complex than those in the adjoining Great Sandy Desert. In addition, the sand appears to be coarser grained and less silty than the sands of the Great Sandy Desert. The sand of the Great Sandy Desert is believed to have been largely derived from Phanerozoic sediments of the Canning Basin; whereas the sand of the Little Sandy Desert has been derived from the breakdown of Late Proterozoic sandstones, and not from a presumed, thin veneer of Phanerozoic sediments as suggested by Beard (1970).

There is also a close relationship between distribution of sand dunes and the underlying lithologies in the Savory Basin. Dunes are distinctly less abundant and smaller over non-arenaceous rocks — the glacigenic Boondawari Formation for example. In addition, the rapid disappearance of the dunes outside the basin and away from the sandstone bedrock of the Savory Group strongly suggests that the longitudinal dunes have not moved far from their source. Brakel and Leech (1980) reached a similar conclusion regarding the dunes on TRAINOR.

Figure 6. McFadden Range, eastern margin of basin

Figure 7. Western scarp of Durba Hills, eastern margin of basin

The best rock exposures in the basin are found in broad, elongate ranges, parallel, and close, to the northern, western, and southern margins of the basin. These include the Robertson Range along the northwestern margin; the Boorabee Hill, formerly known as Bocrabee Hill (Department of Land Administration, 1992), Hanging Rock, and Wells Range areas along the northern margin (Fig. 5); and the Glass Spring–Bullen Hill area and Brassey Range along the southern margin.

Within the basin, scattered, rocky, island hills, such as the Poisonbush Range, Horsetrack Range, Dean Hills, and Jilyili Hills, rise above the surrounding dunes. Dissected tablelands and mesas, such as the Diebil and Durba Hills, and the McFadden and Calvert Ranges, form prominent outcrops in the eastern parts of the basin (Figs 6, 7). Discontinuous sandstone and laterite erosion scarps, known locally as breakaways, such as those in the Kelly Range and the Boondawari Creek area, occur along major drainage divides (Fig. 8).

Overall, the basin presents a broadly rolling aspect: elevations range from a maximum of about 690 m above sea level near Glass Spring in the southwest corner of the basin, to around 350 m adjacent to Lake Disappointment on the northeast margin. Local relief is generally less than 50 m, although the Diebil Hills rise abruptly 125 m above the sand dunes (Fig. 9). Ranges near Ilgarari Creek rise gradually to more than 100 m above the valley floors.

Topographically, the Savory Basin forms a large scoop-like structure inclined towards, and open to, the northeast. The distribution of present and former drainage systems reflects the east to northeast fall of the region. All drainage within the Savory Basin is internal and converges on Lake Disappointment. In the Early Tertiary, Lake Disappointment was part of a larger and more extensive drainage system which drained northeasterly into the Percival Palaeoriver and then, finally, northwesterly into the Indian Ocean (van de Graaff et al., 1977).

Three major drainage basins are contained within the Savory Basin (Fig. 10.). The Savory Creek drainage system in the north is still operative via Savory Creek, which, after prolonged, heavy rain, empties into Lake Disappointment (Fig. 11). Boondawari and Bobbymia Creeks are active, but ephemeral, tributaries in this drainage system. Other tributaries are now sand-choked, palaeodrainage lines that can be traced beneath the sand-dune cover by scattered outcrops of valley calcrete. The gradient of Savory Creek is about 1 in 100.

The Ilgarari Creek palaeodrainage basin is only active in the upper reaches as far east as Terminal Lake. Downstream from this lake, the former course of the Ilgarari Palaeoriver, although now sand filled, can be

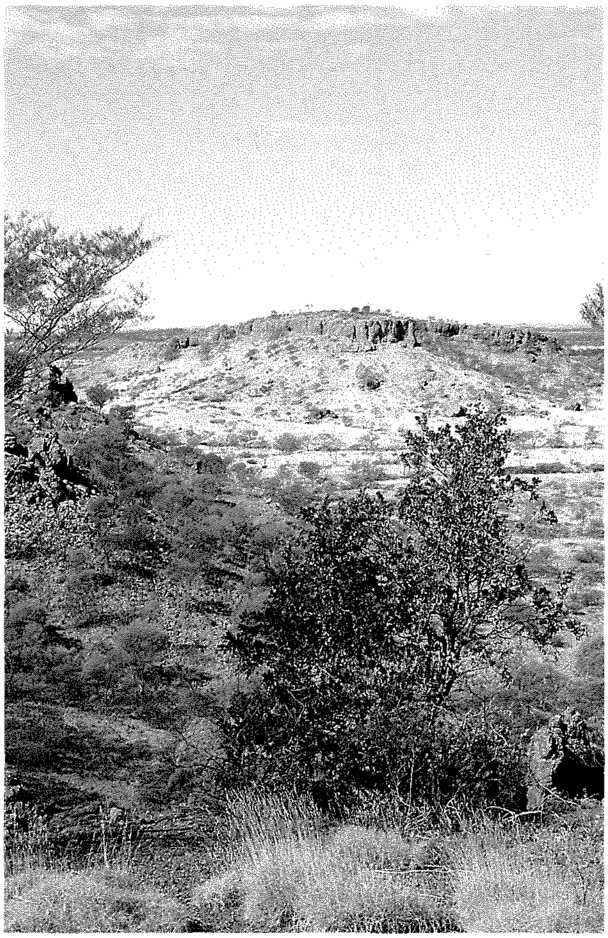

Figure 8. Laterite breakaways, Boondawari Creek area

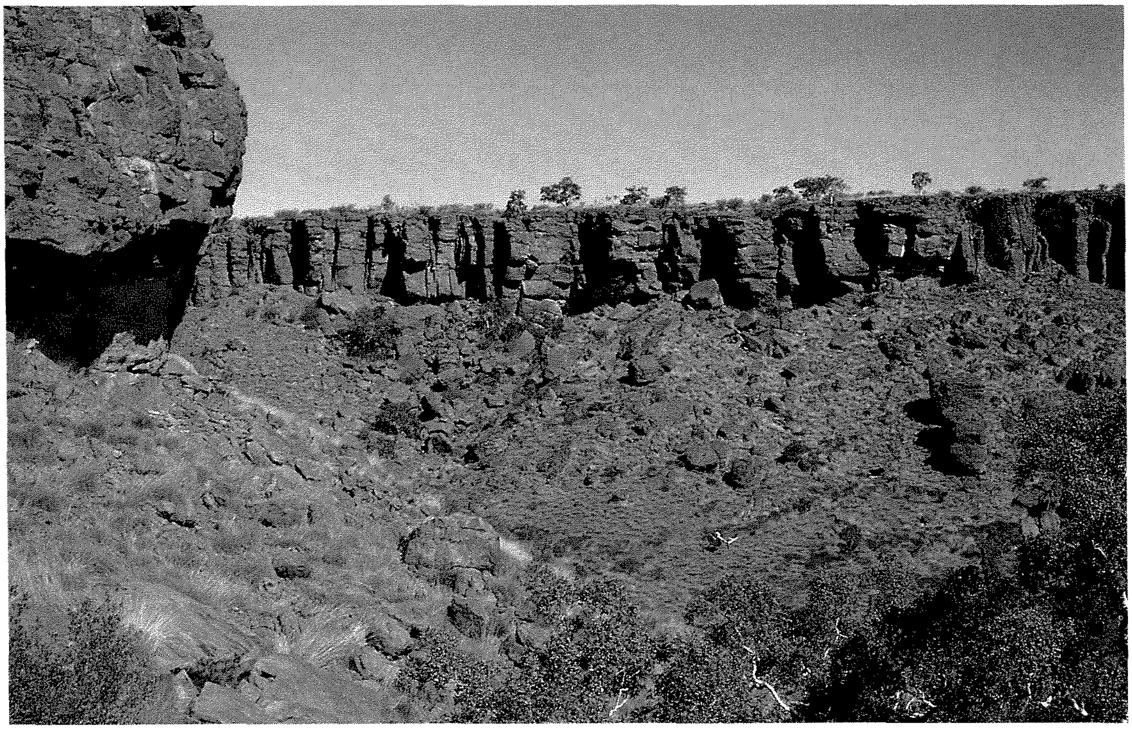

Figure 9. Western scarp of Diebil Hills, eastern margin of basin

traced by a series of playa lakes, claypans, and scattered outcrops of valley calcrete. It can be followed eastwards, to where it joins the Disappointment Palaeoriver west of the Skates Hills (van de Graaff et al., 1977). The Disappointment Palaeoriver flowed north into Lake Disappointment.

The third, and smallest, drainage basin is the Durba, which lies between the lower portions of the Savory Creek and Ilgarari–Disappointment Palaeoriver drainage basins. The Durba palaeodrainage also flowed northeast into Lake Disappointment, but is now completely blocked by a net-dune complex.

More detailed accounts — accompanied by sketch maps — of the regional physiography can be found in the ten published 1:250 000 Geological Series Explanatory Notes and Maps that cover parts of the Savory Basin (Kennewell, 1975; Chin et al., 1980; Leech and Brakel, 1980; Brakel and Leech, 1980; Commander et al., 1982; Williams and Williams, 1980; Brakel et al., 1982; Bunting et al., 1982; I. R. Williams, 1989; Williams and Tyler, 1991). These are shown on Figure 1.

Previous investigations

The Savory Basin is amongst the least accessible areas in Western Australia. Exploration did not start until the 1870s; and the systematic search for good pastoral land, not until the late 1890s. The first geological reconnaissance was carried out by H. W. B. Talbot, who accompanied A. W. Canning's well-sinking party along the proposed Canning Stock Route in 1908–09 (Talbot, 1910). Apart from some reconnaissance work along the western margin of the region (Talbot, 1920), regional geological mapping did not start until 1959 (de la Hunty, 1964). Some ground surveys and photo-interpretation were carried out by oil-company personnel along the eastern margin of the region in the late 1950s and early 1960s (Leslie, 1961; Mack and Herrman, 1965). Between 1960 and 1982, the region has been systematically covered by ten 1:250 000-scale geological sheets published by the Geological Survey of Western Australia (Appendix 1). This work was reviewed by Muhling and Brakel (1985). Between 1962 and 1988, the Bureau of Mineral Resources (BMR), surveyed the area and published 1:250 000-scale total magnetic intensity maps and Bouguer anomaly gravity maps for all 1:250 000 scale sheets covering the region (Fig. 1).

A summary of investigations in the region before 1983 is given in Appendix 1.

Current investigations

Early mapping treated this area as part of the Bangemall Basin (Daniels, 1975; Williams et al., 1976; Muhling and Brakel, 1985). Muhling and Brakel (1985) assumed that the lithological differences between the western Bangemall Basin and eastern Bangemall Basin — as the area of Savory Basin was then called — could be satisfactorily explained in terms of a major facies change.

In 1983, while working in the southeastern part of BALFOUR DOWNS, R. C. Chin noted that rocks, which had been mapped as Calyie Sandstone of the Bangemall

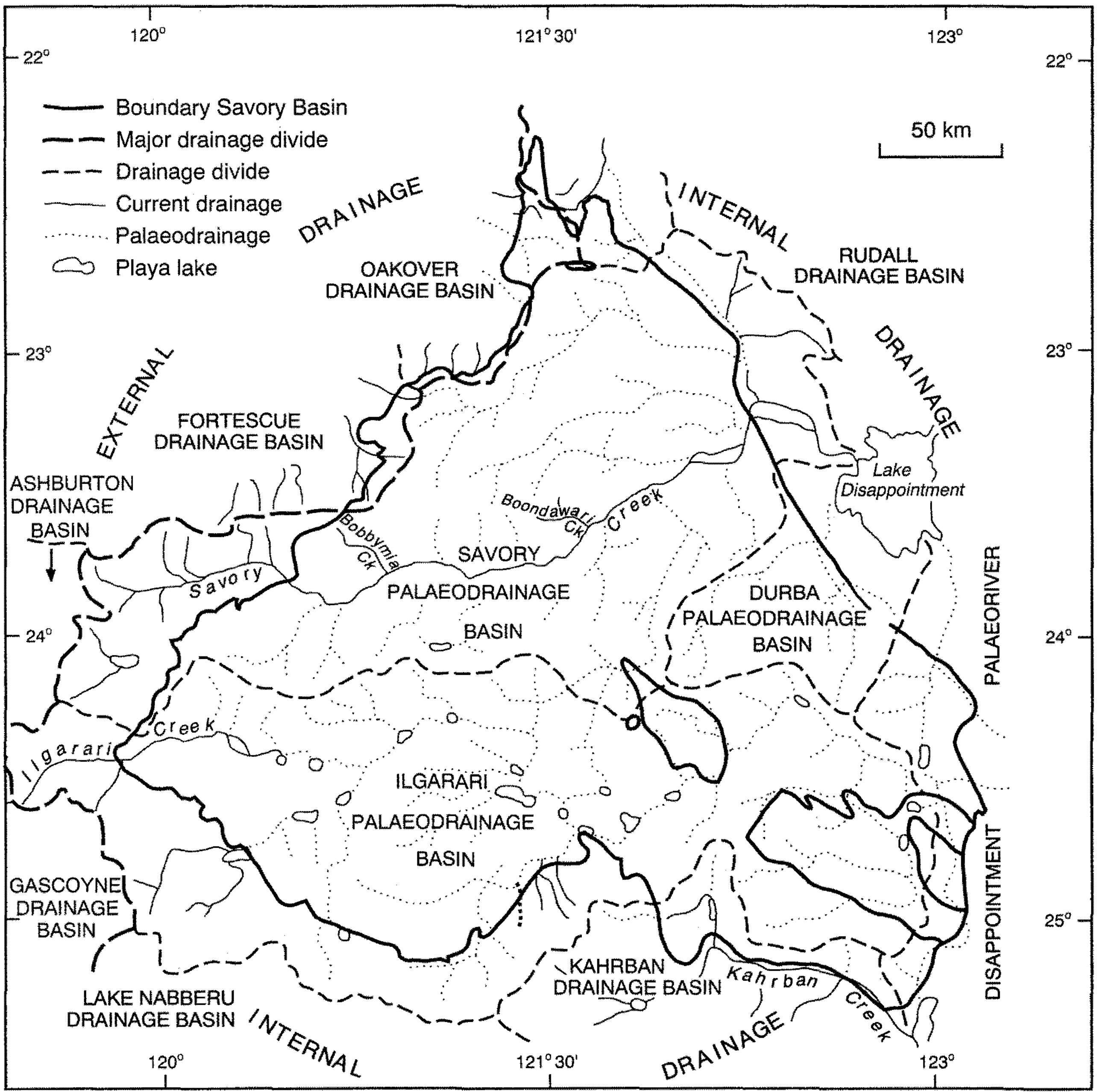

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Figure 10. Palaeodrainages coincident with basin

Group, occupied an anomalous stratigraphic position. He confirmed the interpretation of Williams et al. (1976) that the Calyie Sandstone unconformably overlies the Yeneena Group. However, it was also noted that the Yeneena Group unconformably overlies a northward extension of the Manganese Subgroup.

As the Manganese Subgroup had also been accepted as part of the Bangemall Group (Muhling and Brakel, 1985), Chin's mapping raised the problem that, if both the Calyie Sandstone and the Manganese Subgroup were part of the Bangemall Group of the Bangemall Basin, then the Manganese Subgroup must have been folded, uplifted, and eroded, to form a major unconformity — all before the deposition of the Calyie Sandstone.

Furthermore, this hiatus must have lasted long enough to allow for the deposition of the entire Yeneena Group of the Paterson Orogen. Chin (pers. comm., 1983) suggested that the Calyie Sandstone and the coeval McFadden Sandstone to the east might constitute a younger and separate sequence from the Bangemall Group. Subsequent field work on ROBERTSON in 1985 identified an unconformity between folded and faulted Manganese Subgroup and flat-lying Calyie Sandstone in the Robertson Range area (Williams and Tyler, 1991).

Williams (1987) replaced the broadly defined Calyie Sandstone with four newly defined formations, the Watch Point, Coondra, Mundadjini, and Boondawari Formations. These, apparently conformable, units were named the

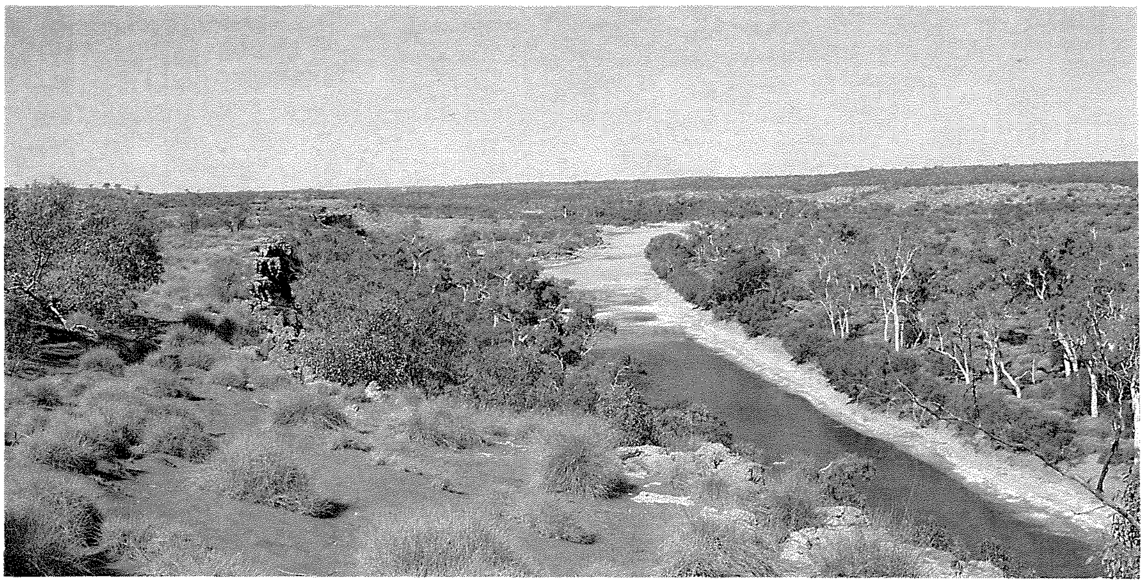

Figure 11. Ephemeral saline pools in Savory Creek, calcrete cliffs on left, 17 km south of Boondawari Soak

Savory Group, and a new tectonic division, the Savory Basin, was proposed. The name *Savory* is taken from the Savory Creek, a large, but ephemeral, drainage that flows east-northeastwards across the basin to Lake Disappointment.

Between 1986 and 1989, during the course of detailed mapping on BULLEN, COLLIER, NABBERU, TRAINOR, and STANLEY, Williams traced the unconformity south, thence southeasterly to the margin of the Phanerozoic Officer Basin near Lake Burnside.

Chapter 2

Regional geology

Tectonic setting

The Savory Basin (Williams, 1987; Williams and Tyler, 1991) is a discrete sedimentary basin that exhibits a distinct depositional and tectonic history. It formed in a region whose long history of tectonic instability began in the Early Proterozoic, when the Pilbara and Yilgarn Cratons collided to initiate the formation of the Capricorn Orogen (Myers, 1990). The major tectonic units of the Capricorn Orogen, the Gascoyne Complex (Myers, 1990), and the Ashburton (Thorne, 1990) and Nabberu Basins (Gee, 1990), are separated from the Savory Basin by the extensive, and younger Bangemall Basin (Muhling and Brakel, 1985) (Fig. 12).

The Savory Basin is a superimposed basin in the sense of Playford et al. (1975). It is underlain almost entirely by the Bangemall Basin. The unconformity between the two basins is disrupted by extensive faulting along the northwest margin. In the southeastern part of the Savory Basin, the Ward and Oldham Inliers contain a sedimentary sequence — the Cornelia Formation — which is correlated with the Collier Subgroup of the Bangemall Basin. It should be noted that, in earlier publications (Williams, 1990), the Ward and Oldham Inliers were not recognized as separate inliers, but were shown combined as the Trainor Inlier (Fig. 13).

The northeast margin of the Savory Basin is in mainly faulted contact with the north-northwest-trending Paterson Orogen (Williams and Myers, 1990). In this region, the orogen comprises three major tectonic units, the oldest of which is the Early to Middle Proterozoic Rudall Complex (Williams, 1990c). This is unconformably overlain by the Middle to Late Proterozoic Yeneena Basin (Williams, 1990e); and it, in turn, is unconformably overlain by the Late Proterozoic Karara Formation; (Williams, 1990b). The Savory Basin unconformably overlies the sedimentary rocks of the Yeneena Basin and, presumably, those of the Karara Formation, which crops out northeast of the Durba Hills. This poorly exposed unconformity has been disrupted in many places by faulting associated with the Paterson Orogeny.

To the southeast, the Savory Basin is onlapped by Permian and Cretaceous sedimentary rocks of the Officer Basin. Regional geological mapping; aeromagnetic, gravity, and seismic surveys; and follow-up stratigraphic drilling; have shown that a thick Proterozoic sequence continues southeastwards from the margin of the Savory Basin beneath a thin Phanerozoic cover (Iasky, 1990).

The lithostratigraphic and biostratigraphic similarities between the rocks of the Savory Basin and the Late Proterozoic rocks of the Amadeus Basin (central Australia) are discussed in later chapters.

The Savory Basin, which is centrally located in Western Australia, has also been described as an intracratonic basin (Trendall and Cockbain, 1990). However, three features suggest that this may not be correct — at least not in the early stages of development. Firstly, there is the asymmetry of the sedimentary sequence, which becomes progressively younger towards the northeastern margin of the basin. Secondly, although the Savory Basin is close to two recognized cratons, the Yilgarn and Pilbara, there is no evidence to suggest that either craton extends far beneath the area now occupied by the basin. Thirdly, the presence of marginal and internal faults, which were active in the initial stages and intermittently throughout the development of the basin, point to an underlying instability in the region occupied by the Savory Basin. These faults are particularly evident along the north-western margin of the basin, adjacent to the Pilbara Craton. This weakness is thought to correspond to the buried edge of the Pilbara Craton.

Hence, the Savory Basin, at least in its middle stages of development, resembled a marginal sag basin (Chapter 7). Subsequent tectonic activity — the Paterson Orogeny — in the adjoining Paterson Orogen resulted in the formation of an incipient foreland basin along the northeastern margin of the Savory Basin. The south-westerly directed folds and compressional faults generated during the Paterson Orogeny encroached on the Savory Basin and terminated sedimentation there. This final tectonic activity changed the marginal sag basin into an interior continental sag basin (*see* Kingston et al., 1983).

By definition, an intracratonic basin is a basin that lies on a craton (Bates and Jackson, 1987). From the above discussion, it can be seen that the Savory Basin, strictly speaking, does not fit this criterion. It overlies a zone that may contain, at depth, an extension of the Capricorn Orogen, which was generated during the collision of the Pilbara and Yilgarn Cratons between approximately 2.0 and 1.8 Ga. It is apparent that the Savory Basin formed in an area that has had a history of intermittent, alternating, tensional and compressional tectonism, which lasted more than 1.0 Ga from the end of the Capricorn Orogeny. This activity produced a series of superimposed sedimentary basins that migrated eastwards; the youngest of these is the Savory Basin.

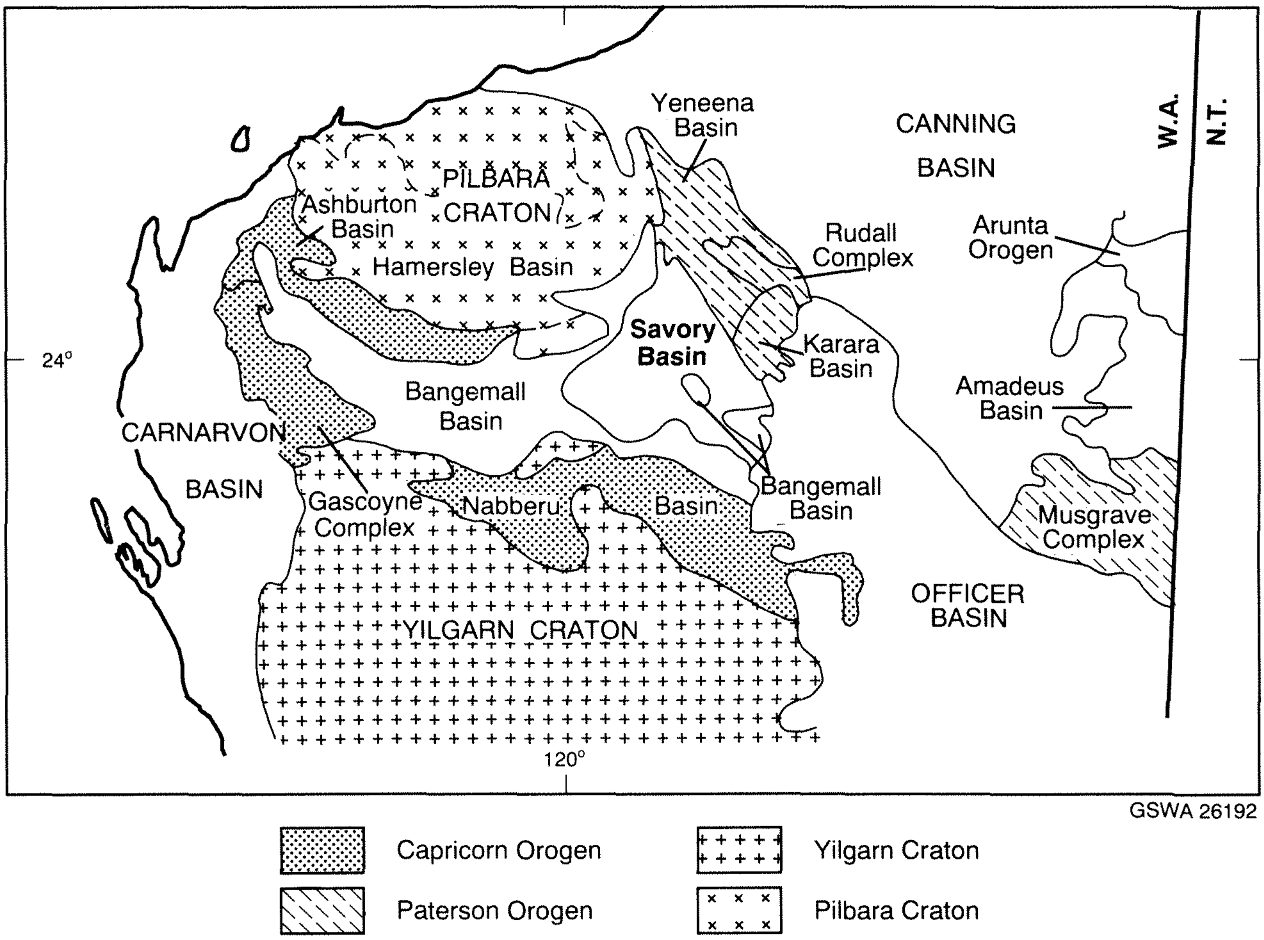

Figure 12. Regional tectonic setting of basin

Apart from the already mentioned easterly extension of the Savory Basin beneath the Phanerozoic cover of the Officer Basin and tentative connection to the Amadeus Basin, there is little evidence to suggest that the Savory Basin ever occupied an area much larger than is currently exposed. Although the present western and southern margins are erosional, clasts in the basal units indicate a proximal provenance for these epiclastic rocks.

Age

The regional tectonic setting offers some constraints on the probable age of the basin. The Savory Group unconformably overlies the Manganese Subgroup, the uppermost unit of the Bangemall Group; Rb–Sr data obtained from glauconites in the Stag Arrow Formation of the Manganese Subgroup yield an age range of 1330–1260 Ma (de Laeter, unpublished data, 1991). These results suggest that the Manganese Subgroup may be older than previously published age of c. 1050 Ma (Williams, 1990a).

In the southeastern part of the Savory Basin, two basement inliers — the Ward and Oldham Inliers — are unconformably overlain by the Savory Group. These inliers consist of Cornelia Formation, which is correlated with the Collier Subgroup of the Bangemall Group. The Collier Subgroup is, in turn, a correlate of the Manganese Subgroup. The unconformity along the northeastern side of these two inliers is markedly more angular than that on the southwestern side, a partly faulted, low-angle unconformity. It should also be noted that the formations along the northeastern sides of the inliers are younger than those along the southwestern sides — a relationship which emphasizes the asymmetric distribution of formations in the Savory Basin. To summarize, the oldest formations of the Savory Basin lie along the western and southern margins, where they unconformably overlie the Bangemall Basin. Successively younger formations are exposed northeasterly across the Basin.

Previously published data have shown that the Yeneena Group of the Paterson Orogen unconformably overlies the Manganese Subgroup of the Bangemall Basin (I. R. Williams, 1989, 1990e). The younger formations of the Savory Group also unconformably overlie the Yeneena Group and Karara Formation of the Paterson Orogen. This unconformity, which occurs along the northern and northeastern margins of the Savory Basin, also appears to correspond to disconformities and local unconformities

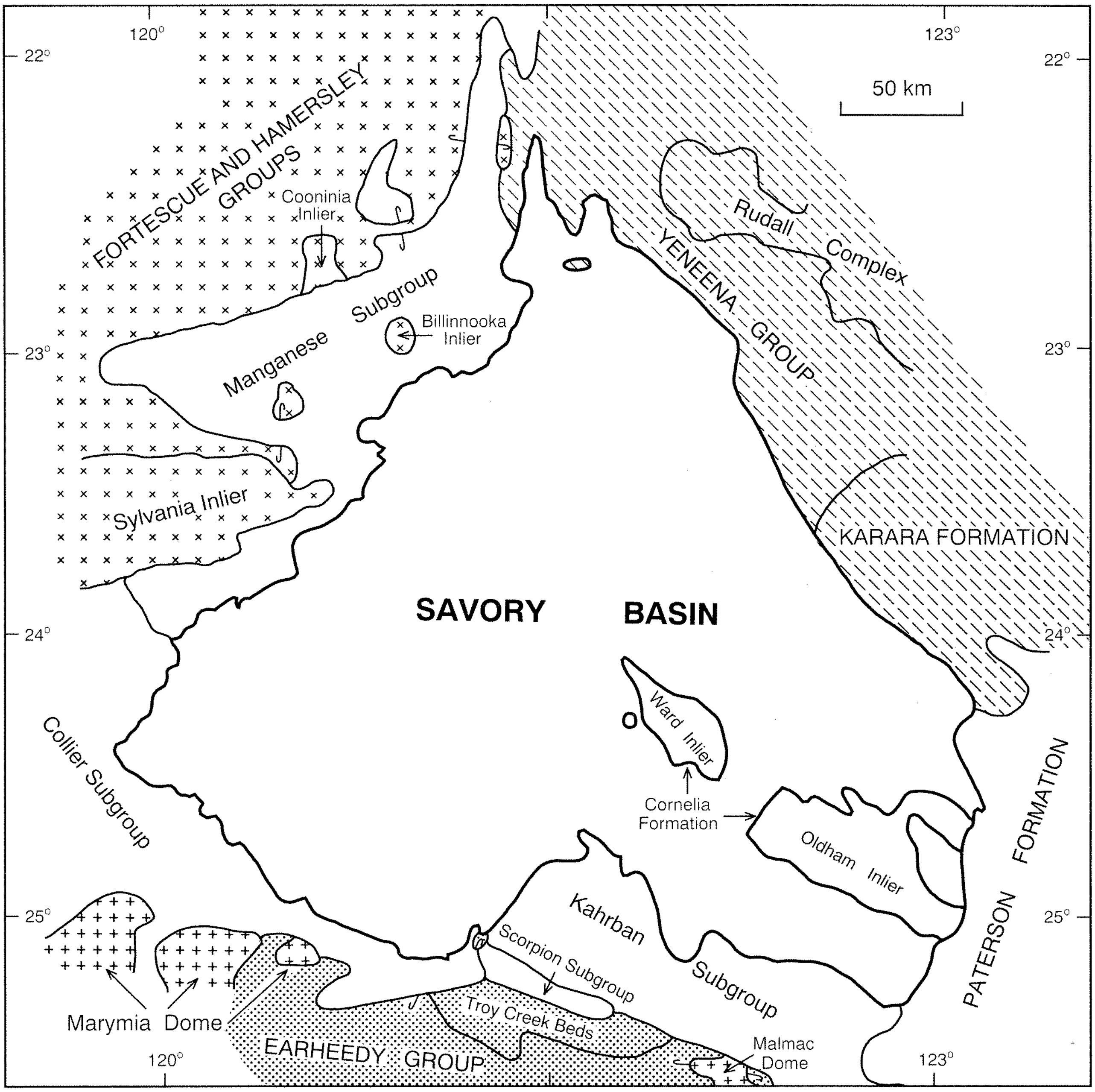

Figure 13. Detailed tectonic setting of basin (Refer to Figure 12 for key)

within the Savory Basin succession — particularly between the glacigenic Boondawari Formation and underlying and overlying formations.

The age of the Yeneena Group is not well documented. Lead model ages from galena, and preliminary Rb–Sr ages from mafic intrusions in the Yeneena Group, yield ages ranging from approximately 900 Ma to approximately 750 Ma (Williams, 1990e). Recent, unpublished U–Pb zircon-crystallization data indicates that the Yeneena Group was probably deposited some time after 1250 Ma and within a slightly wider age range (Nelson, written communication 1991). The Yeneena Group was intruded by the post-tectonic Mount Crofton Granite at around 601 ± 42 Ma — recalculated from Rb–Sr date of Trendall (1974). A Pb–Pb date of 690 ± 48 Ma was obtained for the same granite by McNaughton and Goellnicht (1990).

The Bangemall Group was folded, uplifted, and eroded, before the Savory Group was deposited. It appears — with the proviso discussed later — that the area occupied by the Paterson Orogen underwent a similar history prior to the deposition of the Savory Basin. Both regions subsequently became the important source areas for the epiclastic rocks deposited in the Savory Basin.

The northeast margin of the Savory Basin was influenced by compressional events generated by the Paterson Orogeny between 620 and 600 Ma. Firstly, it received detrital material that had been eroded from the folded and uplifted Rudall Complex, Yeneena Group, and Karara Formation. Secondly, the margin of the basin was affected by the waning episodes of southwesterly directed folding and thrusting that occurred near the southwestern margin of the Paterson Orogen (Clarke, 1991). It has been assumed that tectonic activity in this part of the Paterson Orogen was largely completed by the time the post-tectonic Mount Crofton Granite intruded the Yeneena Basin.

Investigations carried out in the Skates Hills area on the eastern edge of the exposed part of the Savory Basin, clearly identified stromatolites — particularly *Acaciella australica* — belonging to taxa that allow correlation with the lower two units of the Loves Creek Member of the Bitter Springs Formation in the Late Proterozoic of the Amadeus Basin (Grey, 1989), which has a reported age range of 815 to 820 Ma (Lindsay and Korsch, 1991). Both the Skates Hills and Mundadjini Formations of the Savory Basin carry evaporite minerals similar to those of the Bitter Springs Formation of the Amadeus Basin.

An important component of the Savory Basin is the glacigenic Boondawari Formation, which was tentatively correlated by Williams (1987) with the Late Proterozoic glacigenic rocks in the Amadeus Basin. No attempt was made at that time to correlate these glacial rocks with either the Sturtian (750 Ma) or Marinoan (670 Ma) event (Preiss and Forbes, 1981). More recent work in the Boondawari Creek area suggests that the Boondawari Formation is very similar to the Pertatataka sequence of the Amadeus Basin. The basal diamictite and the interbedded and overlying sandstone and conglomerate of the Boondawari Formation are very similar to the Olympic Formation and Pioneer Sandstone. The overlying shale, siltstone, sandstone, and carbonate units, resemble the Pertatataka Formation (M. Walters, written communication 1991). If this correlation is valid, then the glacial component of the Savory Basin is more likely to be Marinoan than Sturtian in age. These rocks would then fall within the 670–650 Ma age range (Lindsay and Korsch, 1991).

Sampling for Rb–Sr age determination has been carried out on the unmetamorphosed, but faulted, Boondawari Dolerite, a large mafic body intruded into faulted and folded glacigenic Boondawari Formation (Williams and Tyler, 1991). Preliminary results give an age of about 640 Ma, which represents a minimum age for the glacigenic rocks.

In summary, the Savory Basin is a Late Proterozoic basin that evolved sometime between 900 and 600 Ma. The preliminary geochronological and biostratigraphical data also suggest that the Savory Basin and Late Proterozoic rocks of the Amadeus Basin are coeval. The stratigraphic and geochronological relationships between the two basins are discussed in Chapter 7.

However, one important problem remains unresolved. This is the time relationship between the older formations of the Savory Group (deposited in the southwestern part of the Savory Basin) and the youngest components of the Paterson Orogen, namely the Karara Formation and, possibly, the upper parts of the Yeneena Group. Although an unconformable relationship between the Savory Basin and the Paterson Orogen can be seen (Williams, 1990), it should be emphasized that this unconformity is only between the younger formations of the Savory Group and the Paterson Orogen (Chapter 5). Therefore, it is possible that the oldest formations of the Savory Group — laid down between 900 and 800 Ma — may correlate with the youngest components of the Paterson Orogen. This possibility applies particularly to the Karara Formation, which appears to be a western extension of the Gibson Sub-basin of the Officer Basin (Iasky, 1990).

The folding and faulting of the Savory Basin in the closing stages of the Paterson Orogeny brought to a close the growth and development of the Savory Basin at about 600 Ma.

Cainozoic geology

The Savory Basin is largely (more than 92%) covered by unconsolidated or semi-consolidated Cainozoic deposits. Only a brief review of these deposits is given in this bulletin. More detailed accounts can be found in the Explanatory Notes accompanying the published 1:250 000-scale geological sheets (Fig. 1). A simplified reference is presented in Plate 1, where a six-fold division has been adopted.

Eolian, or windblown, sand (*Qs*) is ubiquitous, covering almost the whole of the basin. The sand forms both sheets (sandplains) and dune fields of mainly longitudinal (seif) and chain dunes. Complex net dunes occur in broad paleodrainage valleys and depressions between rocky hills.

The sand is composed of medium to medium-coarse, subrounded to subangular, iron-stained or coated quartz grains. It is moderately to fairly well sorted and contains occasional ferruginous grains derived from the breakdown of laterite or ferruginous duricrust. Frequently, the sandplain and interdunal areas adjacent to weathered outcrops have a scattered ironstone-pebble veneer. The sand in these areas also contains ironstone pebbles within the profile. The pebbles have been concentrated at the surface by deflation to produce a lag deposit. Such pebbles generally indicate a shallow, ferruginous, weathered bedrock.

Although the relief of the dunes may be as much as 20 m, they average 8–10 m high. In interdunal areas along the western margin of the basin, percussion drilling has shown the sand to average about 5 m deep, but it may as much as 15 m in complex dune areas. Despite the well-developed sand-dune terrain of the Savory Basin, the lateral transport of sand has probably been less than 5 km. The size and number of dunes depends on the amount of sand available; and this ultimately depends on the average composition of the underlying or adjacent bedrock, which, for large tracts of the Savory Basin, has been found to be predominantly a medium- to coarse-grained sandstone. As discussed in the Physiography section (*see* Chapter 1), the present investigations confirm that the sand in the Little

Sandy Desert has been derived from the breakdown of Proterozoic sandstones (Brakel and Leech, 1980), and not from a thin veneer of Phanerozoic sediments as proposed by Beard (1970).

Although colluvial deposits, such as scree and low-slope pebbly deposits, occur adjacent to rocky outcrops, they are not well developed within the Savory Basin. They contain a large component of windblown sand, which tends to bury the scree, particularly on the eastern or windward sides of the hills. Sandy and clayey loams with pebble veneers (*Qc*) form small colluvial areas on formations which have a low sandstone content. Such areas occur over the siltstone-rich Watch Point Formation on the western margin of the basin. Laterite, ferruginous and siliceous duricrusts, and semi-consolidated hardpan surfaces (*Czc*) also occur where sandstones are a minor component. The glacigenic Boondawari Formation is commonly marked by laterite breakaways and widely spaced sand dunes. Laterite and colluvium are commonly associated with weathered dolerite sills which intrude the Savory Group.

True alluvial deposits (*Qa*) of unconsolidated silt, sand, and gravel, are restricted to the Savory and Ilgarari Creeks. The lower reaches of Savory Creek also contain much windblown sand. However, there is sufficient run-off to maintain open channels to Lake Disappointment. The run-off in these channels is actively eroding the encroaching sand dunes. Some poorly developed sandy washes occur in the Boondawari Creek area.

At present, Ilgarari Creek empties into the Yanneri and Terminal Lakes. Further east, lines of small playa lakes mark the palaeodrainage lines. They are generally both saline and gypsiferous. The bare brown mud, or salt-encrusted surface, is underlain by black to deep red-brown clay and silt containing halite, gypsum crystals, and a very shallow, hypersaline watertable. Lunette dunes composed of kopi or flour gypsum and recrystallized seed gypsum occur at the margins of the larger playas. Lake deposits in general are included in one unit (*Qd*).

The paleodrainage systems also contain extensive valley calcrete (*Czk*). These are of chemical limestone, which was formed by subsurface replacement and cementation by calcium carbonate of fluvial valley-fill sediments. Where the calcrete has been exposed and eroded, opaline silica has replaced much of the carbonate, particularly in the higher levels of the calcrete. Up to 20 m of calcrete is exposed in cliffs along Savory Creek (Fig. 11). The calcrete intertongues with, and overlies, older valley fill and fluvial deposits, some of which are ferruginous (*Czc*). Good sections can be found downstream of the Boondawari–Savory Creek junction. In general, the calcrete is younger than the main laterite profiles.

Economic geology

There has been relatively little mineral exploration within the Savory Basin. Economic mineral deposits and metalliferous mineral occurrences are unknown. However, the basin does provide a potentially favourable environment for mineralization. It has potential source and host rocks, deep-seated faulting, and extensive brittle fracture systems. The regional tectonic setting also shows that the basin overlies pre-existing mineralized units such as occur in the Yeneena and Bangemall Basins.

Metalliferous potential

The present survey did not locate any occurrences of metalliferous mineral in the Savory Basin. The copper occurrence on GUNANYA, recorded during helicopter reconnaissance work (Williams and Williams, 1980) could not be verified in this survey. The Bureau of Mineral Resources (BMR) has published both aerial magnetic and Bouguer anomaly maps for the entire basin at scale of 1:250 000. Over the last decade, several exploration companies have carried out more detailed aerial and ground magnetic and gravity surveys in selected areas. This has been followed up with rock-chip, pisolite, gravel, loam, soil, and stream-sediment sampling in selected areas. Regional geochemical surveys have been directed towards base metals (copper, lead, zinc), gold, platinum-group metals, and uranium. All exploration to date has proved negative. Most exploration surveys carried out in the last decade are on open file at the Geological Survey of Western Australia.

Non-metallic occurrences

The discovery of halite pseudomorphs and seed-gypsum casts in fine-grained sandstone of the Mundadjini Formation 13 km southeast of Twelve Mile Pool on Savory Creek led to the recognition of sabkha-type conditions prevailing in the middle stages of development of the Savory Basin (Williams and Tyler, 1991). A further four occurrences of halite-pseudomorphs were found in later mapping of the Mundadjini Formation: two, 7 km and 10 km south of Mystery Hill; one, 10 km southwest of Gemini Rock Hole; and one, 22 km northwest of Hann Rock Hole. A sixth occurrence was found in the upper part of the Boondawari Formation just east of the Boondawari Stockyards. All occurrences are in fine-grained sandstone. Cauliflower cherts, interpreted as silicified pseudomorphs after anhydrite, have been found in the Skates Hills Formation north of Phenoclast Hill and on the northern edge of the Skates Hills. The Skates Hills Formation is a correlative of the Mundadjini Formation. Both are correlated with, and coeval with, the Bitter Springs Formation of the Amadeus Basin. Although possibly present in the sequence, massive evaporite beds were not found at the surface.

Barite-cemented sandstone has been described from an area 17 km east of the Boondawari–Savory Creek junction. The barite may have replaced carbonate, and constitutes as much as 40% of the rock. No base-metal anomalies have been recorded in this area (Fander, 1982).

The Savory Basin has been widely prospected for diamonds. A magnetic anomaly, thought to be a kimberlitic pipe, has been drilled 10 km west of the Wells Range. The results failed to explain the anomaly (CRA Exploration Pty Ltd, 1985). Three diamonds were discovered during loam sampling in the Goodwin Soak–Mackintosh Hill area on the southern margin of the Savory Basin. Follow-up work proved disappointing (CRA Exploration Pty Ltd, 1987).

Small agates, some with carnelian banding, can be found associated with scattered outcrops of weathered amygdaloidal basalts in the Robertson Range area between the Savory Creek and Tardanya Rock Hole.

Chapter 3

Stratigraphy

Introduction

The entire region, previously called the eastern Bangemall Basin (Williams et al., 1976), was interpreted as a facies equivalent of the more lithologically complex western Bangemall Basin (Muhling and Brakel, 1985). Muhling and Brakel (1985) divided the rocks of the region now designated the Savory Basin into two subgroups, the Collier and Diebil Subgroups of the Bangemall Group. The Collier Subgroup, in this region, comprised one formation, the Calyie Sandstone; whereas, the Diebil Subgroup comprised three, the Skates Hills Formation, the McFadden Sandstone, and the Durba Sandstone.

Following the recognition of the Savory Basin as a separate tectonic unit, a new group, the Savory Group, was proposed and defined by Williams (1987) and Williams and Tyler (1991). This group comprised the Watch Point, the Coondra, the Mundadjini, and the Boondawari Formations. These four formations replaced Calyie Sandstone on ROBERTSON. The terms Collier Subgroup and Calyie Sandstone were redefined and retained for use in the Bangemall Group (Williams, 1990a). Although the name, Diebil Subgroup, was dropped, the three named formations, the Skates Hills Formation, the McFadden Sandstone, and the Durba Sandstone, were modified and retained for use in the Savory Group (Williams, 1990a).

This bulletin introduces and defines six more formations, bringing to thirteen the component formations of the Savory Group (Fig. 14).

Savory Group

(Williams, 1987; Williams and Tyler, 1991)

Derivation of name: The name is derived from the Savory Creek, an ephemeral, east-northeasterly flowing creek that crosses ROBERTSON and GUNANYA, and empties into Lake Disappointment.

The constituent formations are: Glass Spring Formation, Jilyili Formation, Brassey Range Formation, Watch Point Formation, Coondra Formation, Spearhole Formation, Mundadjini Formation, Skates Hills Formation, Boondawari Formation, McFadden Formation, Tchukardine Formation, Woora Woora Formation, and Durba Sandstone.

Thickness: The asymmetric disposition of the component formations of the Savory Group makes it difficult to estimate their total thickness. This problem is compounded by the difficulty of measuring true sections amongst scattered, and generally poor, outcrop with low dips. Fault repetition also contributes to the problem. Representative diagrammatic sections are given in the reference panel of Plate 1, where it can be seen that no section across the basin contains all thirteen formations in stratigraphic sequence (Fig. 14). Although individual formations may have considerable thickness, i.e. greater than 1500 m, the total thickness in any particular area of the basin probably does not exceed 7500–8000 m. No subsurface stratigraphic data are available.

Distribution: The Savory Group occupies the entire area of the Savory Basin as defined.

Stratigraphic relationships: The Savory Group rests unconformably on the Middle Proterozoic Bangemall Group of the Bangemall Basin, and the Middle to Late Proterozoic Yeneena Group (Yeneena Basin) and Karara Formation (Karara Basin). The Yeneena and Karara Basins are components of the Paterson Orogen. The Savory Group is, in turn, unconformably overlain by Phanerozoic rocks of the Officer Basin (Fig. 13).

Glass Spring Formation

(new name)

Derivation of name: Glass Spring (lat. 24°27'13"S, long. 120°03'15"E) BULLEN.

Type area: The type area lies between Nip and Gallon Soak on Ilgarari Creek (lat. 24°25'S, long. 119°55'E) and Glass Spring 12 km east-southeast. The unconformity at the base of the formation is exposed 9 km south of Glass Spring.

Lithology: Predominantly medium- to coarse-grained sandstone with granule patches and scattered small pebbles; interbedded pebbly sandstone, pebble and cobble conglomerate; and, very occasionally, siltstone interbeds.

Thickness: Estimated maximum thickness from airphotos is about 1600 m.

Stratigraphic relationships: The formation is restricted to the base of the Savory Group in the southwestern quarter of the Savory Basin (Fig. 15). It rests with angular

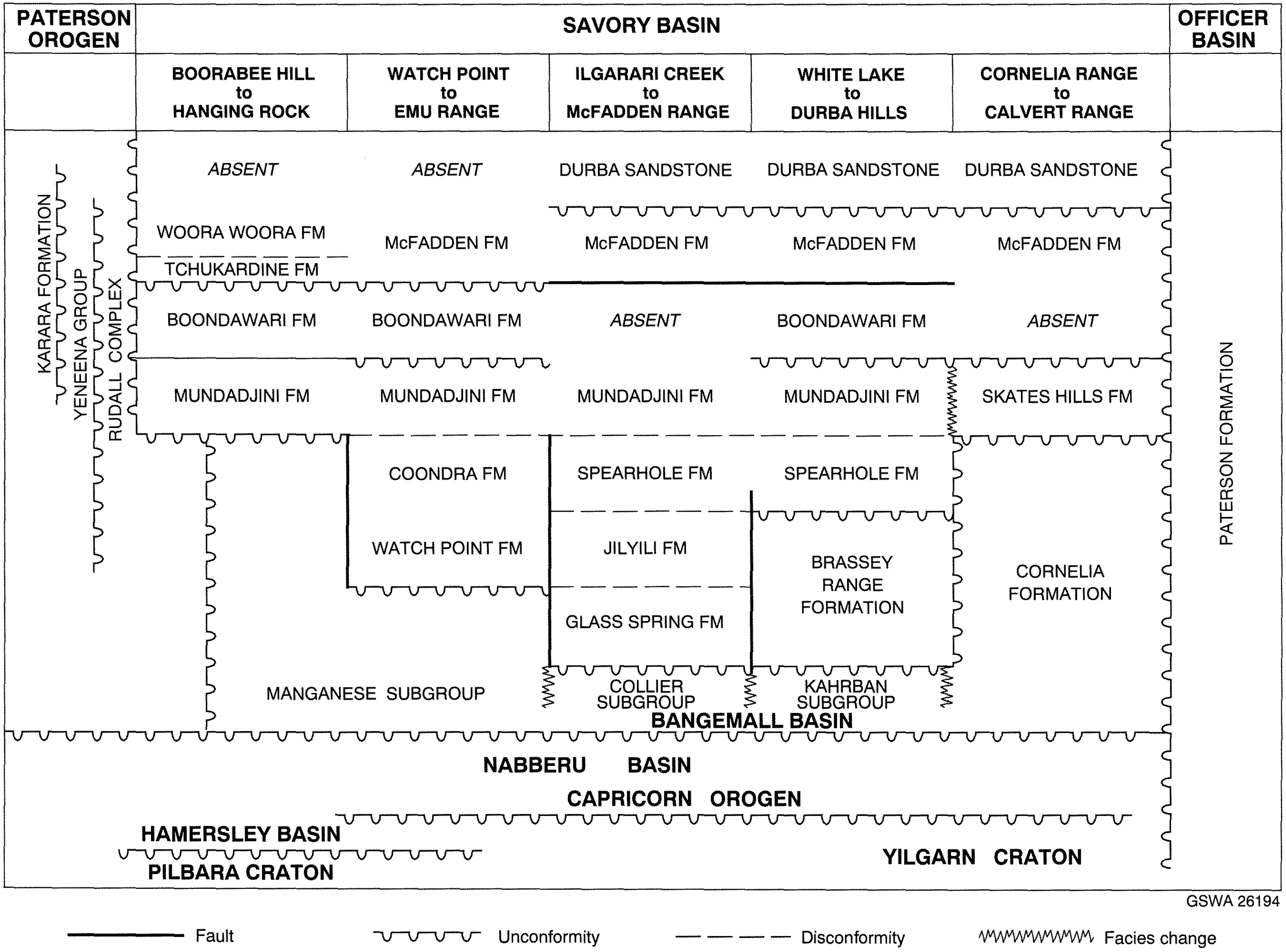

Figure 14. Regional stratigraphic relationships, selected sections

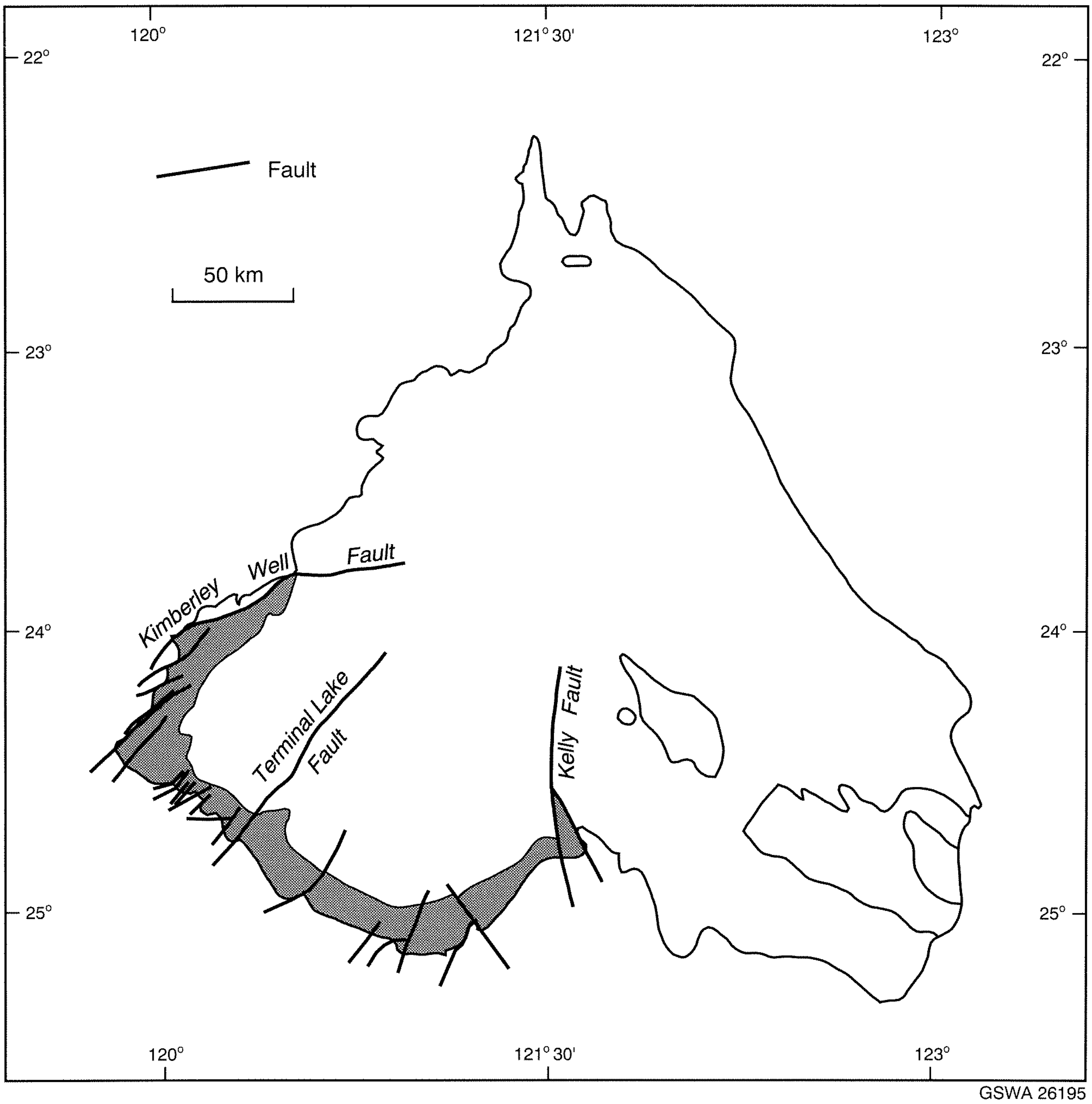

Figure 15. Distribution of the Glass Spring Formation

unconformity on the Calyie and Backdoor Formations of the Collier Subgroup of the Bangemall Basin. The contact with the Collier Subgroup north of Ilgarari Creek is extensively faulted. This formation is also faulted against Watch Point Formation in the north and Brassey Range Formation in the east; both of these are also basal units of the Savory Group. The stratigraphic relationship to the Watch Point Formation cannot be determined from field relationships. However, the Glass Spring Formation is probably coeval to at least part of the Brassey Range Formation. The formation is conformably overlain by Jilyili Formation.

Description: The formation is predominantly arenite. It forms rocky outcrops of dark red-brown to purple-red, massive, thick-bedded to flaggy, quartz sandstone, and is commonly cross-bedded. The sandstone is medium- to coarse-grained. It is not well sorted for size, however; and patches of granules and scattered small pebbles are a characteristic. The weathered surface may be silicified (case hardened), but thin sections display a moderate content of clay between subangular to subrounded quartz grains. Feldspar grains are not common, but the clay matrix may have been partly derived from the breakdown of detrital feldspar. Pebbly sandstone, and pebble–cobble conglomerate are not well sorted for size. Conglomerate generally occurs in lenses, where it is seen to be both matrix and clast supported. Clasts, which consist entirely of vein quartz, quartzite, sandstone (orthoquartzite), and chert, are very mature. Siltstone interbeds, which

Figure 16. Tabular cross-bedding — Glass Spring Formation

sometimes host dolerite or basalt intrusions, are rare. The coarser sandstone, lenses of conglomerate, and less well-sorted rocks in general, occur in the lower parts of the formation. Coarse to medium sandstone predominates in the upper parts of the formation.

Cross-bedding is prominent (Fig. 16), and almost always large (more than 5 cm). It ranges from solitary, large-scale (2 or 3 m), tabular units with both angular-planar and asymptotic foresets, to multiple cosets of both tabular and trough cross-bedding as much as 4 or 5 m thick. Possible herringbone cross-bedding occurs near Glass Spring; however, much of the cross-bedding indicates a strong unidirectional flow. Some asymmetric current ripples, generally overlying cross-bedded units, and flat-bedded current striae are minor sedimentary structures in the formation.

Jilyili Formation

(new name)

Derivation of name: Jilyili Hills (lat. 24°52'30"S, long. 120°52'30"E) BULLEN.

Type area: Jilyili Hills, a series of low cuestas lying between lat. 24°45'S, long. 120°45'E and lat. 24°54'S, long. 120°55'E.

Lithology: Fine- to medium-grained sandstone with interbedded siltstone, subordinate coarse-grained sandstone, pebbly sandstone, and conglomerate; shale, mudstone, and pebbly mudstone, are important components in localized areas.

Thickness: Estimated maximum thickness, from airphotos, about 1000 m.

Stratigraphic relationships: The Jilyili Formation is restricted to the southwest quadrant of the Savory Basin, where it rests conformably on Glass Spring Formation (Fig. 17). It extends from just north of the abandoned Cooma Well southeastwards to the Kelly Fault. The overlying Spearhole Formation, although appearing in outcrop to be conformable, overlies Jilyili Formation with a regional disconformity. Although Jilyili Formation is in faulted contact with Brassey Range Formation (Kelly Fault), it is believed to be coeval with that formation.

Description: The Jilyili Formation is a mixed sequence of lutite, arenite, and rudite. Sandstone ranges from white, cream, grey-brown, and light red-brown, fine- to medium-grained sandstone, to dark red-brown and purple-red, coarse-grained sandstone. The fine-grained sandstone is commonly colour banded, thin bedded, flaggy, and well sorted; whereas the coarse-grained sandstone is more massive, thick bedded, less well sorted, and contains gritty (granule) patches and scattered pebbles. The pebbles, which are always well rounded, may occur at the base of individual sandstone units, commonly in single-pebble-width layers, or they may be sparsely scattered throughout the sandstone.

Thin- to thick-bedded, laminated siltstone that weathers to white, grey, blue, purple, and green, is prominent in some areas. Micaceous siltstone is rarely seen. Blue-grey to purple shale and mudstone locally forms thick lenses, particularly in the Jilyili Hills area. Poorly outcropping purple, pebbly mudstone, superficially resembling the diamictite of the younger Boondawari Formation, occurs near the Jilyili Hills and 5 km south of

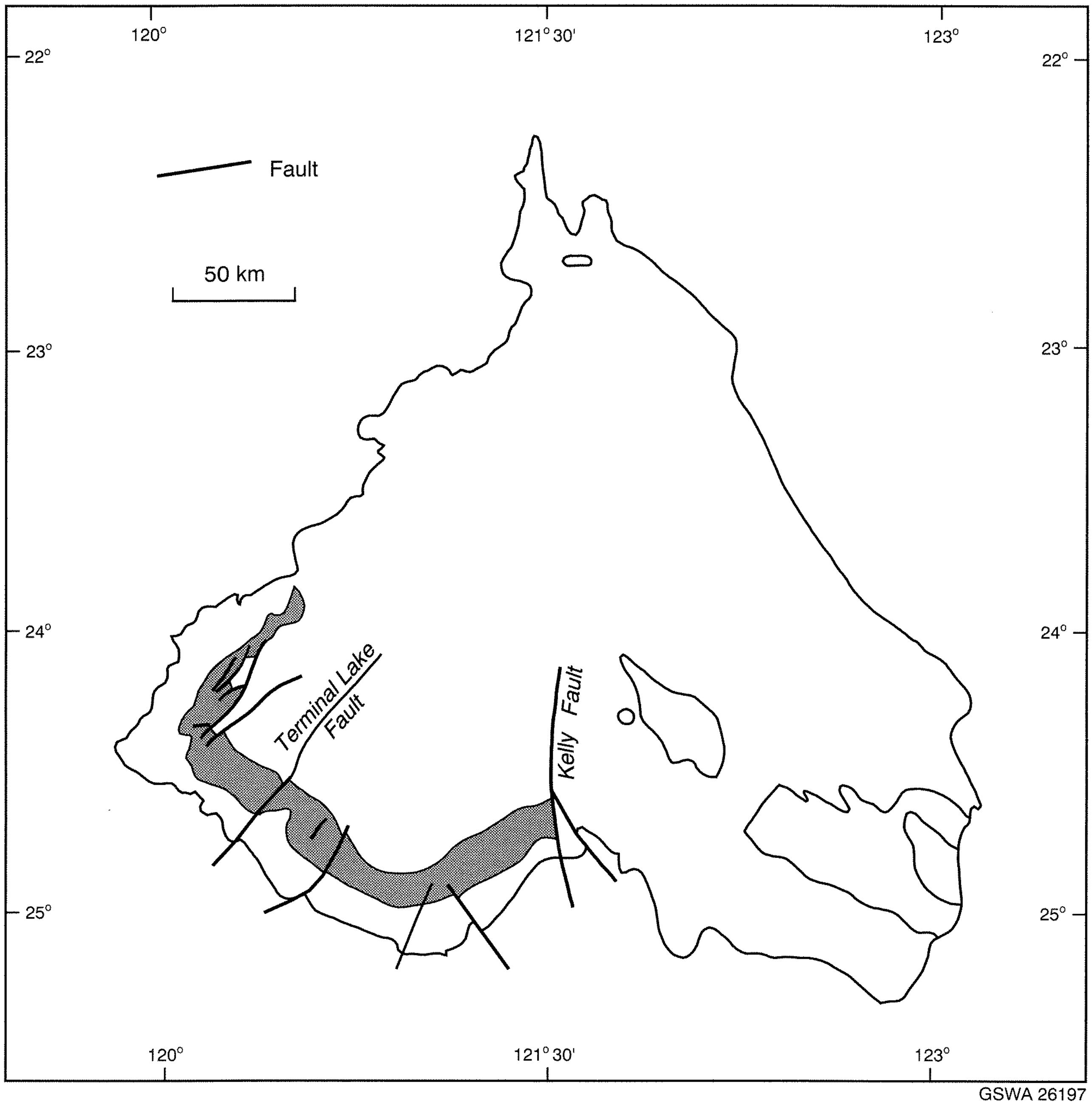

Figure 17. Distribution of the Jilyili Formation

Lake Sunshine. In some parts of the formation, lutite horizons host thick dolerite sills. The largest of these, which is in the Jilyili Hills, is more than 30 km long and up to 200 m thick.

Both matrix- and clast-supported conglomerate are found in the formation. Neither occurs as thick beds, but the beds may persist for many kilometres along strike. Lenses of clast-supported pebble- and cobble-conglomerate are associated with cross-bedded, coarse-grained sandstone, some of which appears to be channel infill. In the Jilyili Hills, a persistent bed of conglomerate occurs at the base of an upward-fining sequence of conglomerate, sandstone, siltstone, and shale. Poorly sorted, matrix-supported cobble to boulder conglomerate occurs 9 km southwest of the abandoned Cooma Well and 10 km northwest of Snell Bore. In all cases, the clasts, which range from pebbles to boulders more than 0.5 m in size, are well rounded and mature. Clast lithologies include sandstone, quartzite, vein quartz, chalcedony, agate, and a variety of coloured cherts.

Although some of the sandstone is cross-bedded, such structures are not as strongly developed as they are, for example, in the lower part of the Glass Spring Formation. Some large-scale trough cross-beds (up to 5 m), and single, or grouped, tabular cross-beds (up to 3 m) occur in the coarse-grained sandstone. Small-scale, tabular cross-beds

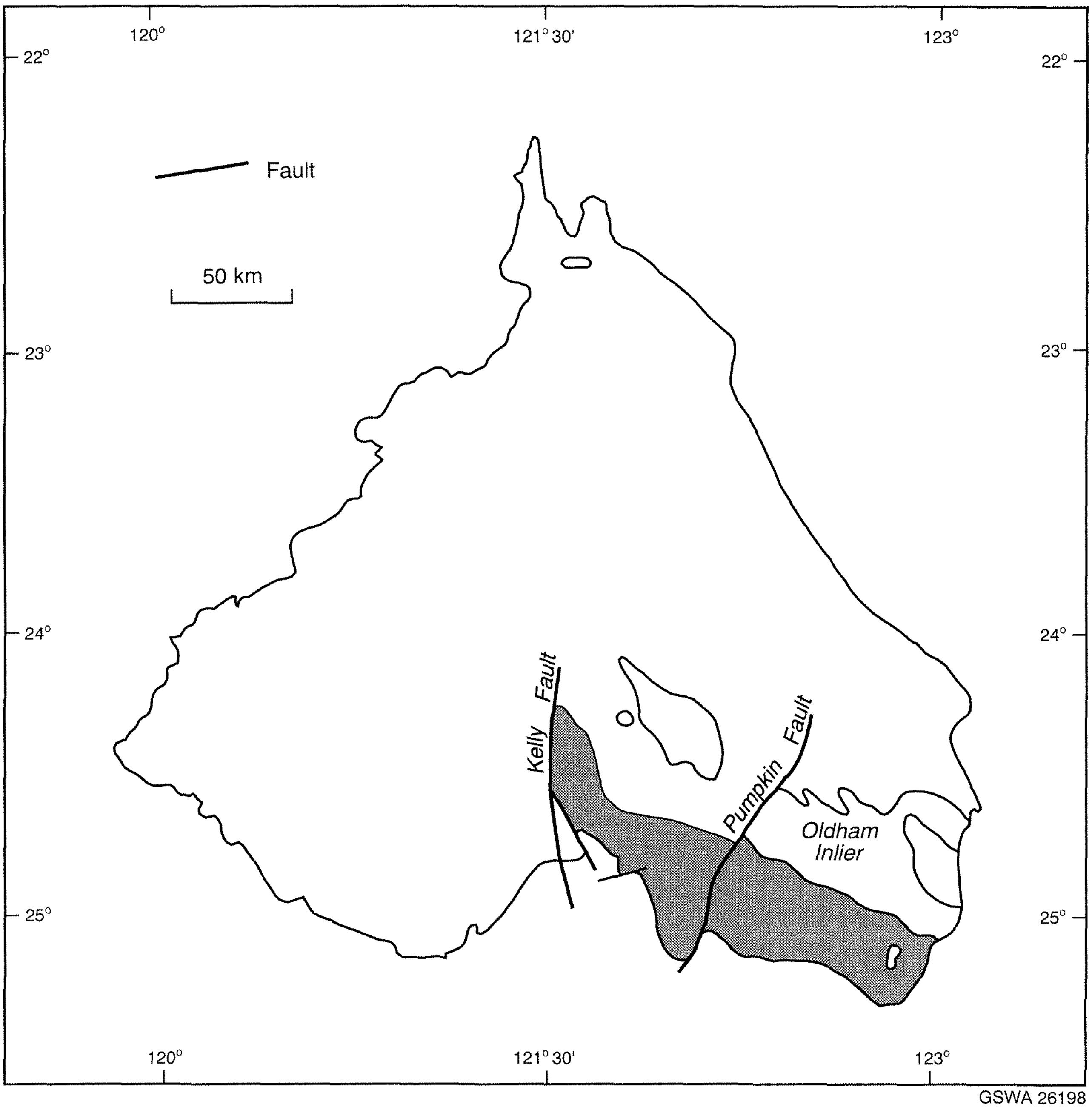

Figure 18. Distribution of the Brassey Range Formation

(less than 5 cm) are seen in the fine-grained sandstone. Commonly, the cross-bedded units in coarse-grained sandstone are capped by thin-bedded sandstone showing asymmetric current-ripple marks. These, in turn, are overlain by a further cross-bedded unit. Ripples, both symmetrical and asymmetrical, are found in the fine- to medium-grained sandstone.

Minor graded bedding has been found in the upward-fining sequences of sandstone to siltstone. Flat-bedded, medium-grained sandstone sometimes shows primary current lineation. Such sandstone is interbedded with the cross-bedded units. In the Jilyili Hills area, synaeresis cracks were observed at the base of fine-grained sandstone units interbedded with shale.

Brassey Range Formation

(new name)

Derivation of name: Brassey Range (lat. 25°00'S, long. 122°15'E) TRAINOR and STANLEY.

Type area: The generally poor exposure of the Brassey Range Formation has made the selection of a representative type area difficult. However, the Kelly

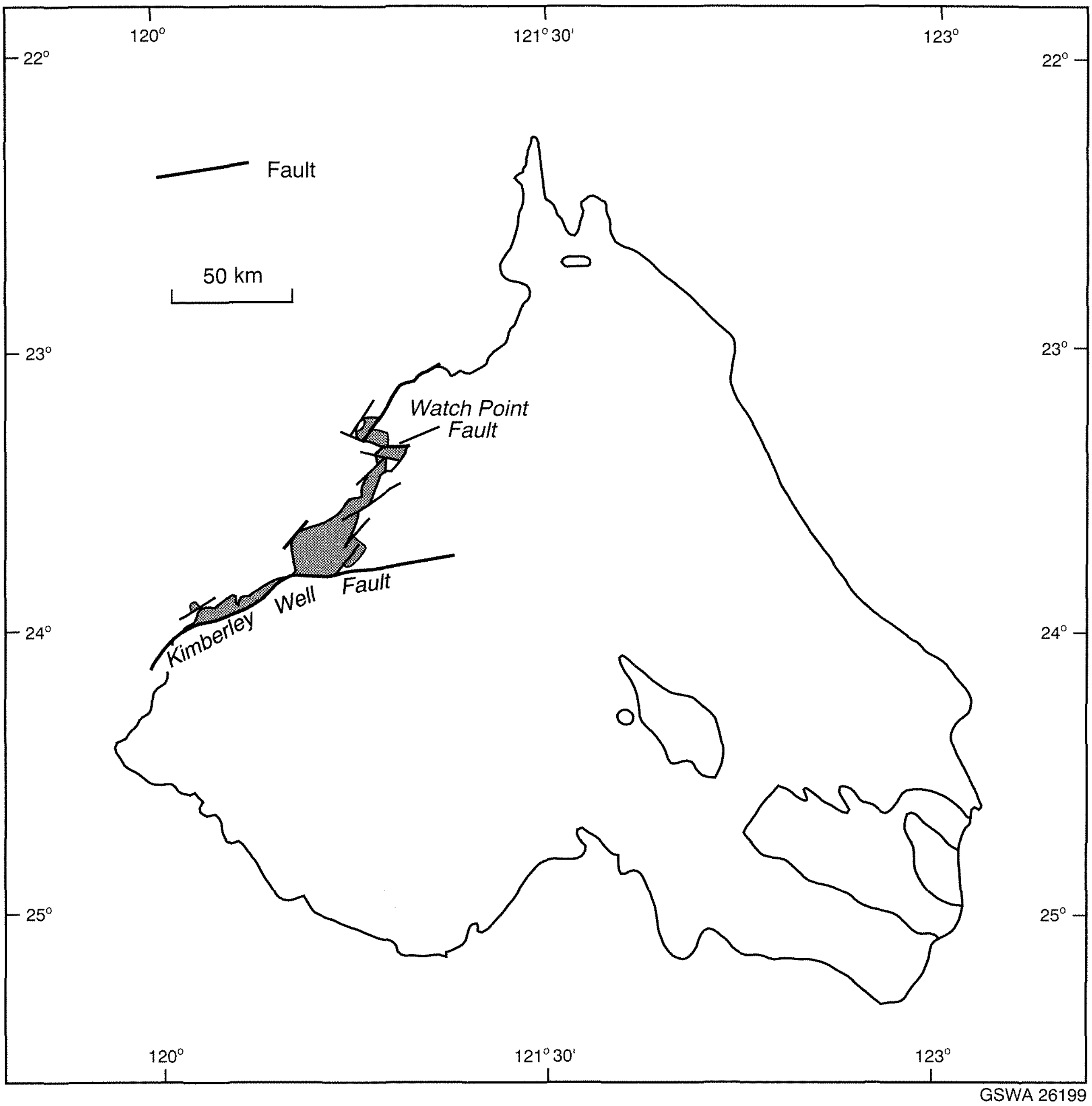

Figure 19. Distribution of the Watch Point Formation

Range (lat. 24°27'30"S, long. 121°32'E) and rocky hills (lat. 24°58'S, long. 122°42'E) 29 km northeast of Mt Normanhurst are representative of the unit.

Lithology: Medium- to fine-grained sandstone with a minor component of coarse-grained sandstone, commonly interbedded with siltstone, shale, and mudstone; thick-bedded siltstone, micaceous siltstone, and silty sandstone are locally important.

Thickness: Maximum thickness estimated from airphotos about 1700 m.

Stratigraphic relationship: The Brassey Range Formation is restricted to the southern margin of the Savory Basin east of the Kelly fault and south of the Oldham Inlier (Fig. 18). The unconformity between this formation and rocks of the underlying Bangemall Group — the Kahrban Subgroup to the south, and the Cornelia Formation to the north — is not exposed. It is possible that the latter contact may be modified by faulting.

The formation is distinguished from the underlying rocks of the Bangemall Group by shallow dips and lack of recrystallization in the sandstone units. Both the Kahrban Subgroup and the Cornelia Formation of the

Bangemall Group are moderately folded. A corresponding event was not recorded in the overlying Brassey Range Formation.

The Brassey Range Formation is disconformably overlain by Spearhole Formation. It is probably coeval with, and a possible facies equivalent of, both the Glass Spring and Jilyili Formations.

Description: The Brassey Range Formation contains several varieties of sandstone. They range from white, grey, cream, brown, and red-brown, medium- to fine-grained sandstone (the major component) to red-brown to purple-brown, coarse-grained sandstone (the minor component). The sandstone ranges from laminated to medium bedded for fine-grained varieties to very thick bedded for medium- and coarse-grained varieties. Although much of the sandstone is arenite, many samples contain feldspar, detrital mica, and abundant clay in the matrix, together with scattered, small, chert and lithic clasts. These rocks can be classified as wackes, and this suggests that the Brassey Range Formation is, overall, less mature than the Glass Spring and Jilyili Formations.

White, brown, chocolate, green, and blue-grey siltstone, and subordinate shale, are also important components of the formation. These components may form single, thick-bedded units, or thin-bedded, laminated units that are interbedded with the sandstone. Where associated with sandstone, the siltstone may grade into silty sandstone, silty shale, and mudstone. Detrital mica is prominent in some siltstones. The lutite component occurs with sandstone in upward-coarsening units, as in the Kelly Range, or upward-fining units, as in the area north of Sunday Well. The sandstone and wacke in these successions contain numerous siltstone and shale intraclasts.

Trough and tabular cross-beds are common in sandstone and coarse siltstone units. The size of cross-beds seems proportional to the grain size of the rock: large trough cross-beds occur in coarse-grained sandstone; and small-scale tabular cross-beds occur in siltstone. Slumping, convolute bedding, and oversteepening of cross-bedding, have been recorded from sandstone. Rippled bedding is not often seen, but some fine-grained sandstone shows directional ripple marks. Current lineation on bedding surfaces occurs in sandstone interbeds between cross-bedded units. The upward-fining units show some graded bedding, but this is not widespread.

The formation hosts numerous, small, fine-grained dolerite and basalt sills and anastomosing vein-like intrusions. Recrystallization of the sandstone is evident adjacent to these intrusions.

Watch Point Formation

(Williams and Tyler, 1991)

Derivation of name: Watch Point (lat. 23°17'09"S, long. 120°50'35"E), ROBERTSON.

Type area: A type area lies 6.5 km bearing 105° from Robertson Range Homestead (lat. 23°28'29"S, long. 120°52'12"E). A section at Watch Point (lat. 23°17'09"S, long. 120°50'35"E) is conformable with the overlying Coondra Formation.

Lithology: A mixed unit of fine- to medium-grained sandstone, silty sandstone, micaceous siltstone, and shale; and minor glauconitic sandstone.

Thickness: Estimated maximum thickness about 400 m.

Stratigraphic relationships: The Watch Point Formation is restricted to the central part of the western margin of the Savory Basin, where it rests unconformably on the Manganese Subgroup of the Bangemall Basin (Fig. 19). At Watch Point, it passes conformably upwards into Coondra Formation. However, steep reverse faults along the western side of the Robertson Ranges have complicated this relationship in other areas. The Watch Point Formation is also in faulted contact (Kimberley Well Fault) with Glass Spring Formation. The stratigraphic relationship of the Watch Point Formation and the Glass Spring Formation is discussed in Chapter 5.

Description: The types of rock that constitute the Watch Point Formation were first described in detail by Muhling and Brakel (1985). However, at that time they were described in conjunction with the Backdoor Formation (southern exposures) and the Balfour Shale (northern exposures), stratigraphic correlates within the Bangemall Group. Williams and Tyler (1991), in a reassessment of the Watch Point and Robertson Range areas, identified a group of younger rocks that did not show the more complex structure or incipient metamorphism of the adjacent Manganese Subgroup of the Bangemall Basin. These younger rocks were renamed the Watch Point Formation.

The formation is a mixture of maroon-brown to grey, fine- to medium-grained sandstone, interbedded with grey, olive-green, micaceous siltstone, silty sandstone, and brown to blue-grey shale and mudstone. Fine-grained, greenish glauconitic sandstone is a minor component. Both sandstone and siltstone contain up to 15% of feldspar, together with a variable amount of clay matrix and detrital mica. Tourmaline is commonly seen. Both sandstone and siltstone range from laminated to thickly bedded.

A wide range of sedimentary structures has been recorded. Both trough and planar cross-beds, some of which have broad, shallow forms, are present. Symmetrical and asymmetrical ripples occur in the fine-grained sandstone and sandy siltstone. Also present in the fine-grained rocks are climbing ripples, cutoffs, load casts, and graded bedding. Siltstone and shale intraclasts are common in sandstone, but siltstone contains shale flakes and rip-up clasts. Small-scale erosion features, such as eroded bases of coarse-grained units and scours, have also been found. There are small exposures of mudcracked shale, and some fine-grained sandstone contains synaeresis cracks. The formation is intruded by small fine-grained dolerite bodies.

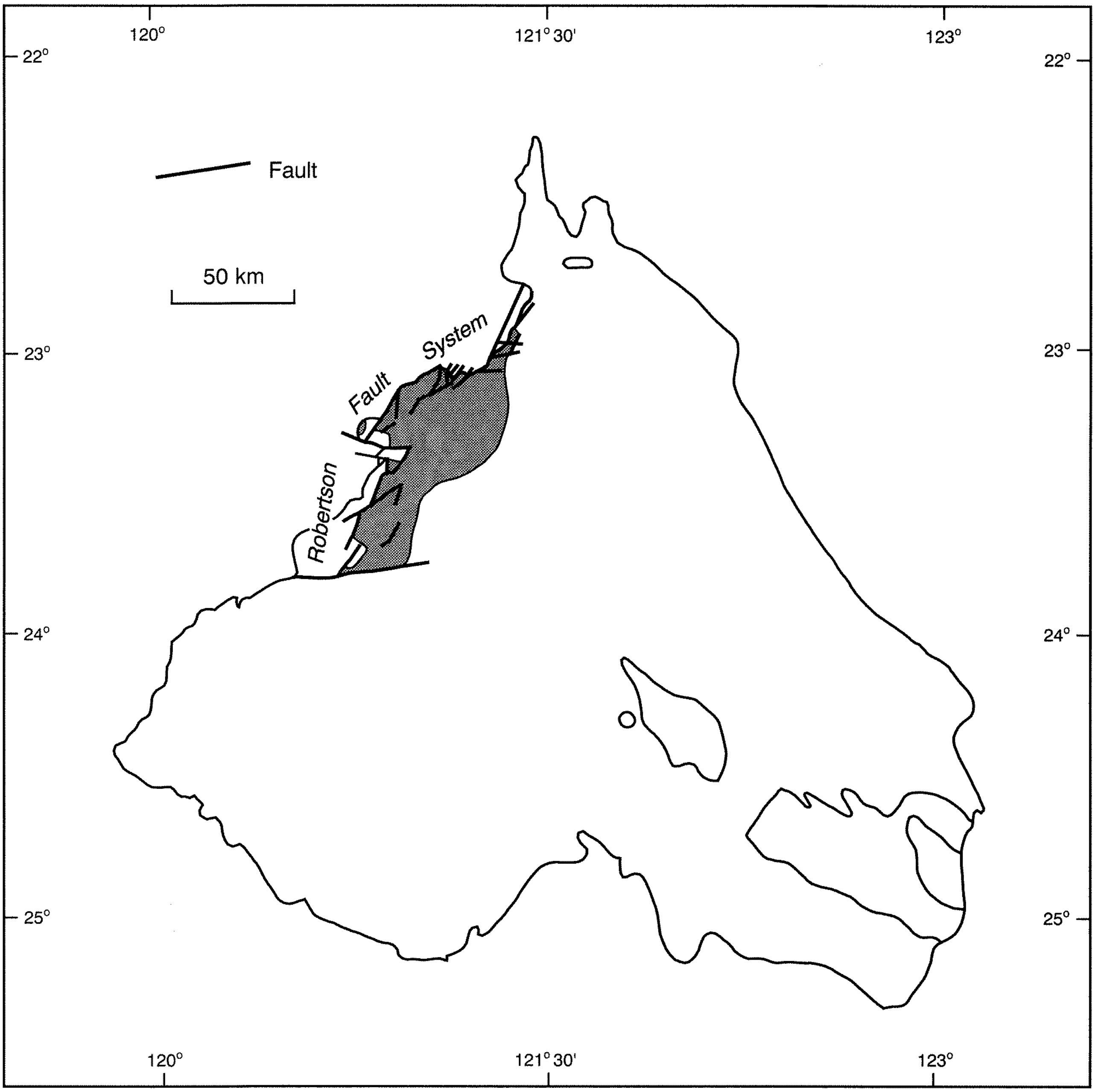

Figure 20. Distribution of the Coondra Formation

Coondra Formation

(Williams and Tyler, 1991)

Derivation of name: Coondra Coondra Springs (lat. 23°06'37"S, long. 121°01'30"E).

Type area: Two type areas are given. The area between Coondra Coondra Springs and Boolginya Rock Hole (lat. 23°06'28"S, long. 121°05'05"E) is representative of matrix-supported boulder conglomerate and coarse-grained sandstone. The Yooldoowindi Spring area (lat. 23°06'28"S, long. 121°05'05"E) is representative of mixed, coarse to medium coarse sandstone and interbedded pebble and cobble conglomerate.

Lithology: Coarse to medium coarse sandstone; pebbly to boulder-bearing sandstone; pebble to boulder conglomerate; and debris-flow, matrix-supported conglomerate.

Thickness: Maximum thickness, estimated from airphotos, about 1000 m.

Stratigraphic relationships: The Coondra Formation is restricted to the northwestern quadrant of the Savory Basin, north of Savory Creek (Fig. 20). It conformably overlies Watch Point Formation. However, this contact is extensively disrupted by the Robertson Range Fault System (Williams and Tyler, 1991). These faults are now

Figure 21. Fluviatile boulder conglomerate with sandy matrix, Coondra Coondra Springs area

mainly steep, reverse faults produced during a basin-inversion episode (*see* Chapter 6). North of Watch Point, Coondra Formation has overridden Watch Point Formation, and lies with faulted contact on the Manganese Subgroup of the Bangemall Basin. In general, Mundadjini Formation disconformably overlies Coondra Formation. Mundadjini Formation overlaps Coondra Formation northwards in an area 15 km northeast of Millari Bore. Coondra Formation is also faulted against Spearhole Formation. Although the two formations may be coeval, an analysis of current directions suggest that they have different source areas (*see* Chapter 5).

Description: The Coondra Formation is a very coarse-grained siliciclastic sequence. Although red to red-brown, coarse to medium coarse sandstone is the dominant

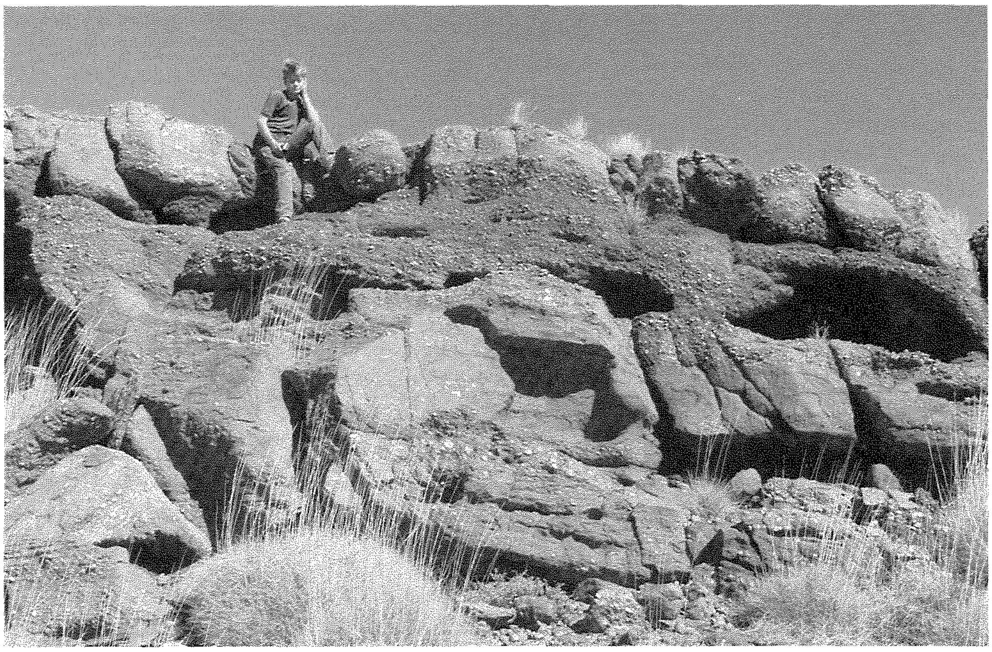

Figure 22. Interbedded coarse-grained sandstone and pebble conglomerate in fluviatile deposits — Coondra Formation

Figure 23. Reworked conglomerate (left of hammer) derived from Manganese Subgroup — Coondra Formation

lithology, the outstanding feature of the formation is a prominent rudaceous component that increases north-westwards towards the edge of the Savory Basin. Between Coondra Coondra Springs and Boolginya Rock Hole, thick beds of boulder and cobble conglomerate are prominent (Fig. 21). These beds range from structureless, matrix-supported debris flows, poorly sorted for size and content, to bedded, clast-supported cobble to boulder conglomerate. These units are interbedded with trough cross-bedded, coarse-grained sandstone, granule sandstone, pebbly sandstone, and sandstone carrying scattered pebbles, cobbles, and boulder clasts (Fig. 22).

North of Coondra Coondra Springs, boulders up to 2.8 m have been recorded. Most clasts range from subangular to subrounded, but roundness improves in the better-sorted beds. The clasts include sandstone, quartzite, vein quartz, a variety of coloured cherts, jasper, and a distinctive pebble conglomerate (Fig. 23). These conglomerate clasts are distinguished by the presence of red jasper and blue chert pebbles, and are identical to conglomerate beds that are found *in situ* in the nearby Manganese Subgroup. Hence, the provenance of some boulders in the Coondra Formation is the adjacent Manganese Subgroup of the Bangemall Basin.

East of Boolginya Rock Hole, and further south around Yooldoowindi Spring, the formation comprises thick-bedded, massive, and cross-bedded sandstone. Trough cross-beds are common and reach a maximum thickness of 5 m. Tabular cross-beds, both single beds and grouped unidirectional cross-bed sets, are also present. Interbedded with these units are flat-bedded, current-lineated sandstones. Cross-bedded sandstone sometimes contains scattered pebbles and cobbles. Pebble, cobble, and subordinate boulder-conglomerate beds and lenses, are interbedded with the sandstone. The conglomerates are graded, cross-bedded, have eroded bases, and may occur

Figure 24. Channel containing large-cobble conglomerate, incised in coarse-grained sandstone — Coondra Formation

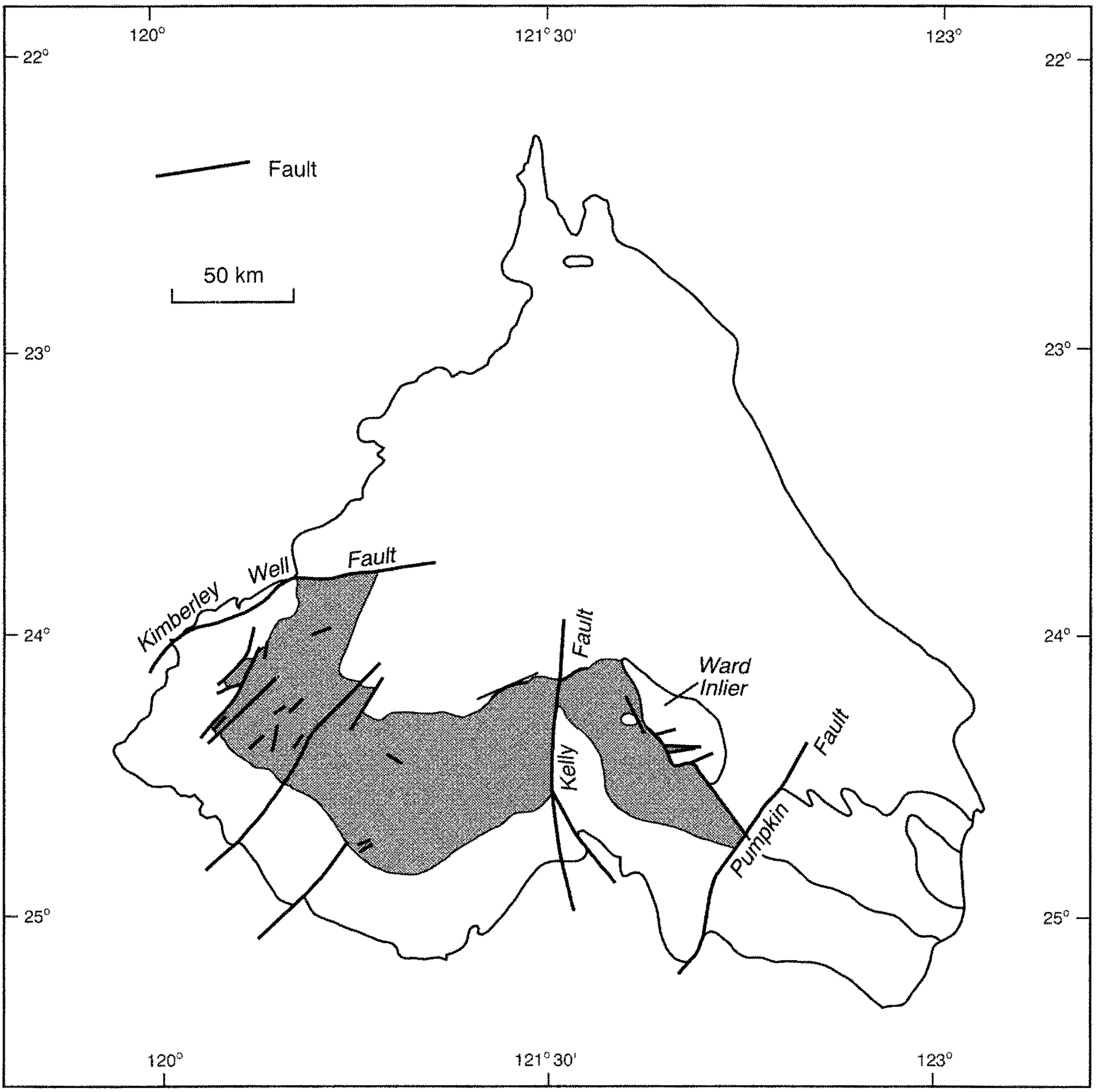

Figure 25. Distribution of the Spearhole Formation.

in defined channels cut into the underlying sandstone beds (Fig. 24). Mostly, the conglomerates are clast-supported, polymodal varieties, and are better sorted for size than those around Coondra Coondra Springs. The composition of the clasts is similar to that of the coarser deposits further north.

The Coondra Formation hosts scattered intrusions of amygdaloidal and vesicular basalt and fine-grained dolerite. The sandstone adjacent to, and overlying, these intrusions is recrystallized and shows well-formed columnar (prismatic) jointing.

Spearhole Formation

(new name)

Derivation of name: 'Spearhole' is the alternative and local name for Hann Rock Hole, (lat. 24°23'19"S, long. 120°23'24"E), BULLEN.

Type area: The area occupied by the Spearhole Formation is difficult of access. However, typical exposures may be seen in several localities. They are the Dean Hills, lat. 24°14'45"S, long. 120°45'45"E; the area east of the abandoned Moffetah Well at lat. 24°14'24"S,

Figure 26. Channel conglomerate containing large blocks of sandstone — Spearhole Formation.

long. 120°23'29"E; and 21 km west of No. 14 Well (Canning Stock Route) on the western side of the Ward Hills at lat. 24°16'43"S, long. 121°35'40"E.

Lithology: Coarse- to medium-grained sandstone; granule sandstone; pebbly sandstone; pebble and cobble conglomerate; subordinate boulder conglomerate and fine-grained sandstone and sandy siltstone.

Thickness: Estimated maximum thickness from airphotos is about 1100 m.

Stratigraphic relationships: The formation lies mainly in the southwest quadrant of the Savory Basin, between Savory Creek and Ward Hills (Fig. 25). At its eastern contact, the formation rests unconformably on the Ward Inlier, which contains folded rocks of the Cornelia Formation, a correlate of the Collier Subgroup of the Bangemall Basin. West of the Ward Inlier, Spearhole Formation rests disconformably and, locally, unconformably on Brassey Range, Jilyili, and Glass Spring Formations. The northern margin of the formation is faulted against Coondra Formation, which may be coeval and laterally equivalent. The Spearhole Formation is disconformably overlain by Mundadjini Formation.

Description: The Spearhole Formation is a coarse-grained arenaceous sequence with a prominent, but variable, rudaceous component. Siltstone and shale are absent from the lower parts of the formation, which is, typically, brown to dark red-brown, coarse- to medium-grained, quartz sandstone ranging from massive to flaggy. The coarse-grained sandstones are generally poorly sorted, and contain interstitial clay. Some small quartz clasts are distinctive in that they show fluid inclusion trains, whilst others are heavily sutured and polygonized. Both types suggest a metamorphic provenance. Other small clasts are cherty to chalcedonic, and suggest a weathered provenance. Feldspar grains are not common, but patchy interstitial clay may have been derived from the breakdown of detrital feldspar. Tourmaline ranges from abundant to absent, but zircon is a regular accessory. Scattered single pebbles and cobbles are also a feature of the coarse-grained sandstones. Randomly distributed patches of granules are common, and layers of pebbles, one pebble thick, occur at the base of some units. Such units generally show upward fining.

Lenses and thin beds of pebble and cobble conglomerate that contain some small boulders are interbedded with the sandstone. The conglomerate is better sorted and more mature than that in the Coondra Formation. It is generally clast supported, but the sizes of the clasts vary. Some bodies of conglomerate that overlie sandstone are parts of upward-coarsening sequences. Most clasts are subangular to subrounded: they comprise sandstone; quartzite; vein quartz; chert of various colours, some of which is banded; and minor amounts of jasper.

In sandstone 12 km east-northeast of Hann Rock Hole, penecontemporaneous channels filled with cobble and boulder conglomerate have been found. These channels also contain large rafts of sandstone that have been broken off the adjacent channel walls (Fig. 26). A similar channel, eroded in the Cornelia Formation of the Ward Inlier,

Figure 27. Channels filled with boulders of underlying Cornelia Formation — Spearhole Formation

Figure 28. Large, trough cross-beds, asymptotic foresets — Spearhole Formation

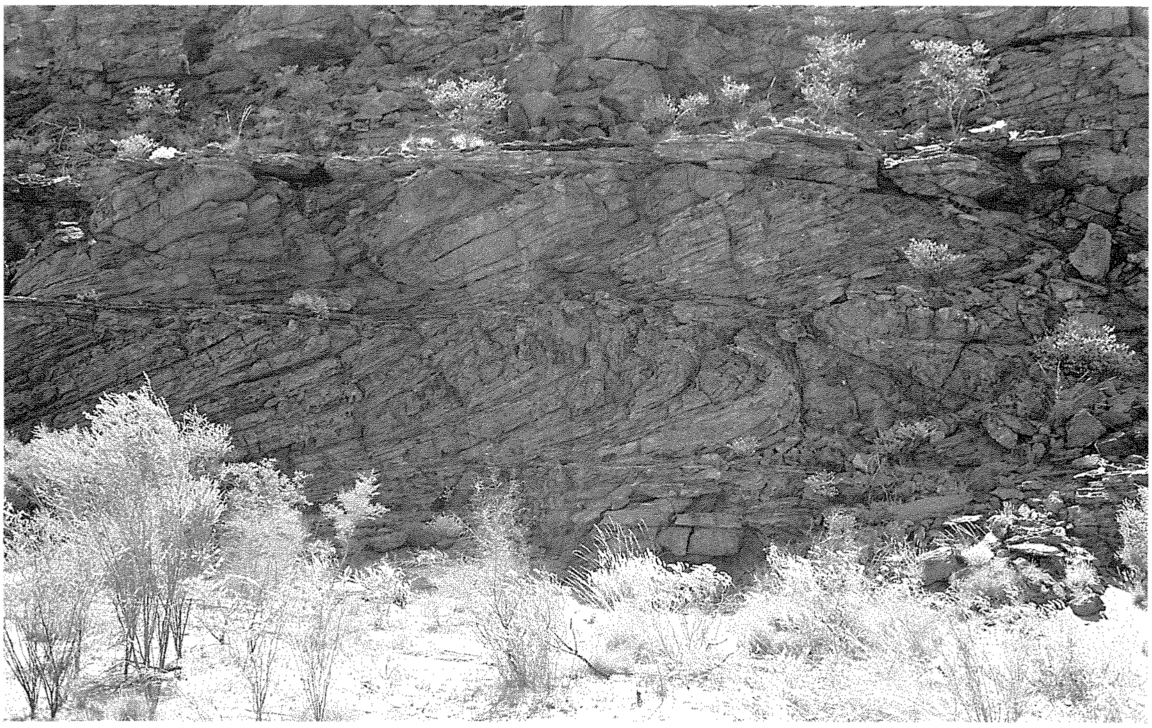

Figure 29. Cross-bedding with overturned foresets — Spearhole Formation

occurs 3 km northwest of No. 13 Well (Canning Stock Route). Sandstone boulders in this conglomerate, some of which are as much as 2.5 m across, can be lithologically matched with the sandstone of the nearby Cornelia Sandstone (Fig. 27).

Lenses of coarse-grained, sandy, and micaceous siltstone occur towards the top of the Spearhole Formation.

Cross-bedding is a common sedimentary structure, and large trough cross-beds up to 20 m wide and 5 m thick have been recorded in the lower parts of the formation. Tabular cross-beds, both single, alpha type, and grouped cosets, are also present. Some cross-beds have been recorded from coarse-grained sandstone carrying scattered cobbles and pebbles. Many of the trough cross-beds, both large and moderately sized, have asymptotic foresets (Fig. 28) indicative of strong current conditions. Overturned and disrupted tops of cross-beds have been recorded in several localities (Fig. 29). Ripple bedding is uncommon in the Spearhole Formation, although both symmetrical and asymmetrical ripples have been found in thin-bedded sandstone between large alpha-type cross-bedded units. Similarly flat-bedded sandstone units sometimes show current lineation.

Mundadjini Formation

(Williams and Tyler, 1991)

Derivation of name: Mundadjini Spring (lat. 23°23'01"S, long. 121°10'40"E), ROBERTSON.

Type area: Three type areas are given:

(a) 20 km bearing 193° from the Savory–Bobbymia Creek junction (lat. 23°59'15"S, long. 120°50'15"E);

(b) 16 km bearing 065° Savory–Bobbymia Creek junction (lat. 23°45'08"S, long. 121°51'25"E);

(c) Ripple Hill (lat. 24°01'54"S, long. 121° 51'25"E).

Lithology: Interbedded fine- to medium-grained sandstone, siltstone, sandy siltstone; small amounts of coarse-grained sandstone; pebbly sandstone; conglomerate; shale; claystone; dolomite; stromatolitic dolomite; and evaporite-bearing sandstones and siltstones.

Thickness: Estimated maximum thickness from airphotos is 1800 m.

Stratigraphic relationships: The Mundadjini Formation occupies the central part of the Savory Basin (Fig. 30). The northern extension is faulted against the Manganese Subgroup of the Bangemall Basin between Boorabee Hill and the Talawana–Windy Corner track. At Boorabee Hill, and further north towards Marloo Marloo Rock Hole, a thin basal conglomerate and sandstone that rests unconformably on the Yeneena Group may be a correlate of the Mundadjini Formation. Similar rocks occur at an unconformity 12 km south of Hanging Rock. In both cases, this thin unit is overlain by diamictite, which is tentatively correlated with the Boondawari Formation (*see*

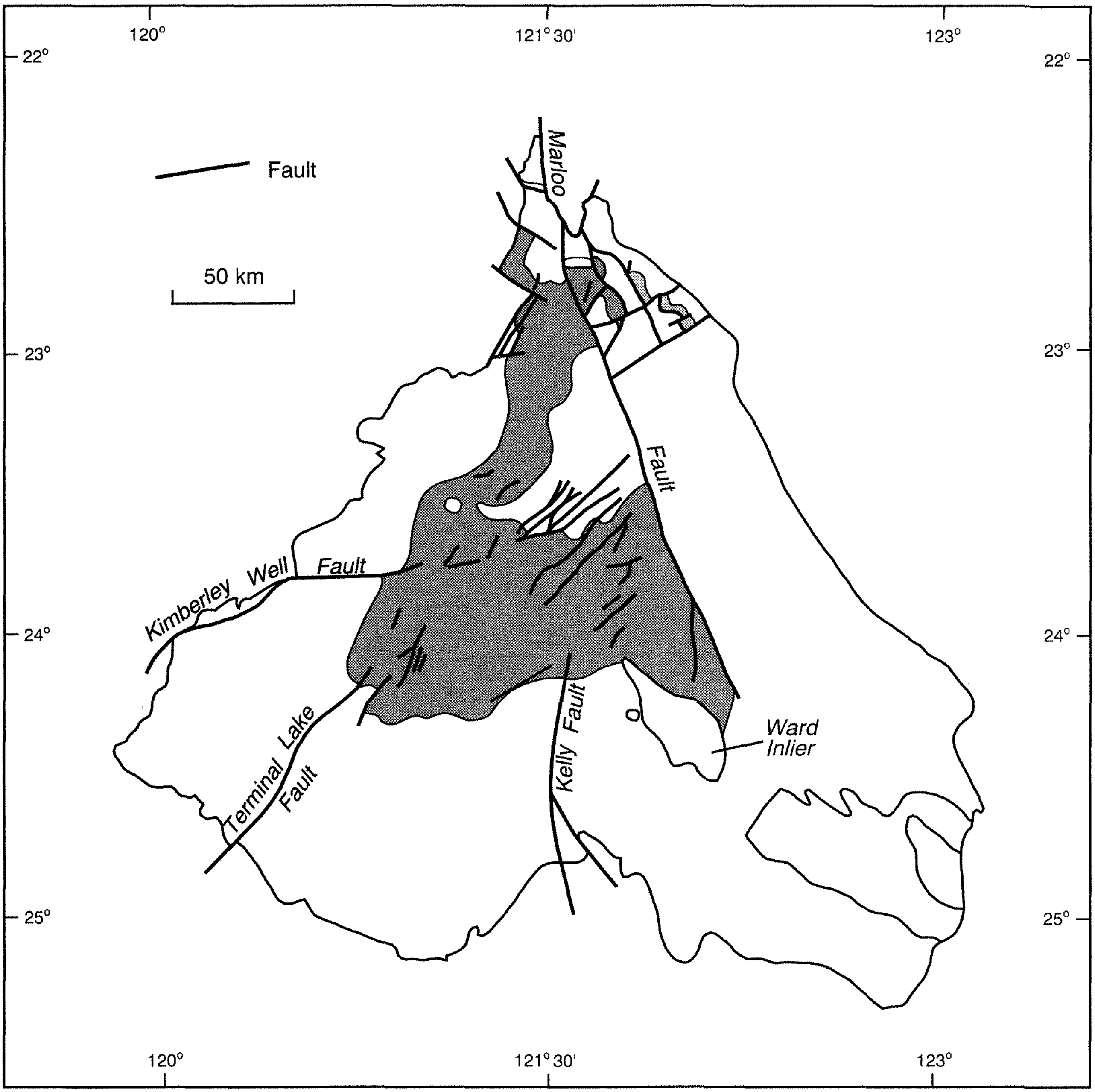

Figure 30. Distribution of the Mundadjini Formation

sections on Boondawari Formation and Tchukardine Formation for further details).

The eastern part of the Mundadjini Formation lies, with angular unconformity, on the Cornelia Formation of the Ward Inlier; the Cornelia Formation is a correlate of the Collier Subgroup of the Bangemall Basin (Fig. 31). Elsewhere, the formation disconformably overlies the Coondra and Spearhole Formations of the Savory Group.

The contact between overlying, discontinuous Boondawari Formation and Mundadjini Formation is not well exposed. Although earlier mapping on ROBERTSON (Williams and Tyler, 1991), suggested a conformable contact between the two formations, the overlap of Boondawari Formation on the Ward Inlier, and the disappearance of Mundadjini Formation in this area, suggest that this upper contact may be unconformable in places. In the northern parts of the Savory Basin, the Boondawari Formation lenses out allowing the stratigraphically higher Tchukardine Formation to rest disconformably on Mundadjini Formation north of Wells Range. Further west, around the Woora Woora Hills, both Boondawari and Tchukardine Formations are missing, and the stratigraphically higher Woora Woora Formation rests disconformably on Mundadjini Formation. In the central part of the Savory Basin, north of Ripple Hill, Mundadjini

Figure 31. Angular unconformity between steeply dipping Cornelia Formation of the Ward Inlier and flat-lying Mundadjini Formation, north of the Ward Hills

Formation is in faulted contact with McFadden Formation, a possible stratigraphic equivalent of the Tchukardine Formation which lies further to the north.

Description: Although the Mundadjini Formation is characterized by a wide variety of rock types, sandstone is the most commonly seen variety in outcrop. Most often, it is cream to red-brown, medium- to fine-grained quartz sandstone. It is laminated to thick bedded, commonly flaggy, and sometimes colour banded. It exhibits a wide range of sedimentary structures. The finer grained sandstone is usually interbedded with silty sandstone, siltstone, micaceous siltstone, shale, and mudstone. These fine-grained rocks range from cream-yellow to blue-grey and purple; and are fissile, laminated, or thin-bedded. Some massive thick-bedded shale and mudstone is also present. In some areas, fine-grained sandstone and silty sandstone contain halite and pseudomorphs and crystal-shaped voids after gypsum. Halite pseudomorphs, showing hopper structures up to 2.5 cm in size, have been found 12 km east-southeast of 12 Mile Pool on the Savory Creek (Figs 32, 33). At least four other halite-bearing sandstones have been located between the Dean Hills and the Gemini Rock Holes, a distance of more than 110 km. Gypsum casts in medium- to fine-grained sandstone have been found in the vicinity of the 12 Mile Pool halite locality and 4 km southwest of Akubra Hill. Massive evaporite beds have not been found in outcrop.

Medium-grained sandstone, 17 km east of the Boondawari–Savory Creek junction, has been found to contain abundant (up to 40%) barite in the matrix. Petrologic work indicates that the barite has probably replaced carbonate, and is of late-diagenetic origin (Fander, 1981).

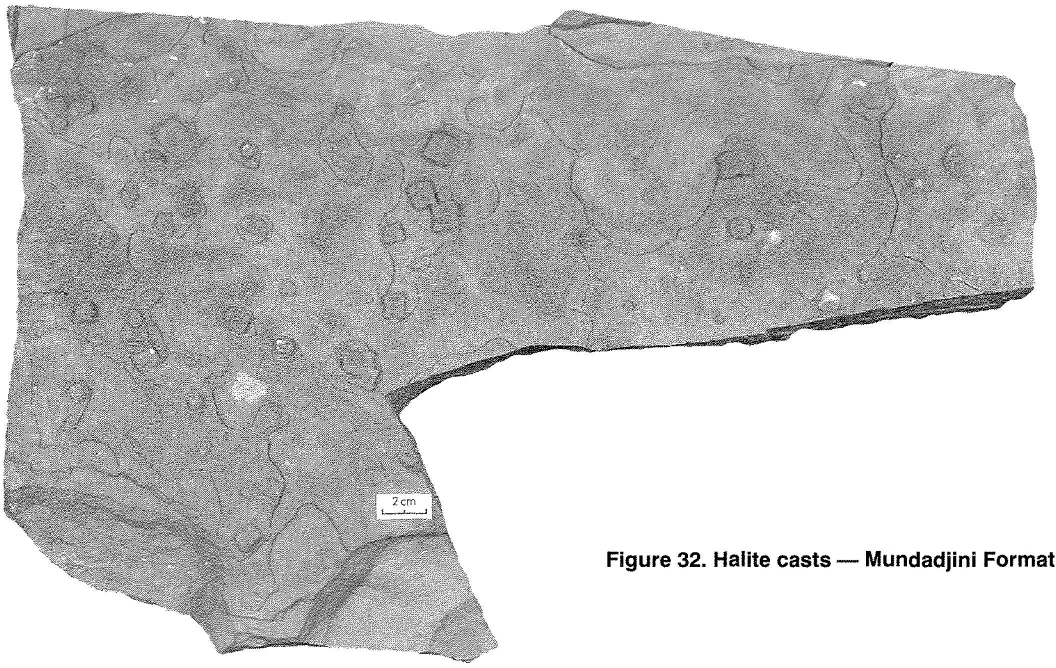

Figure 32. Halite casts — Mundadjini Formation

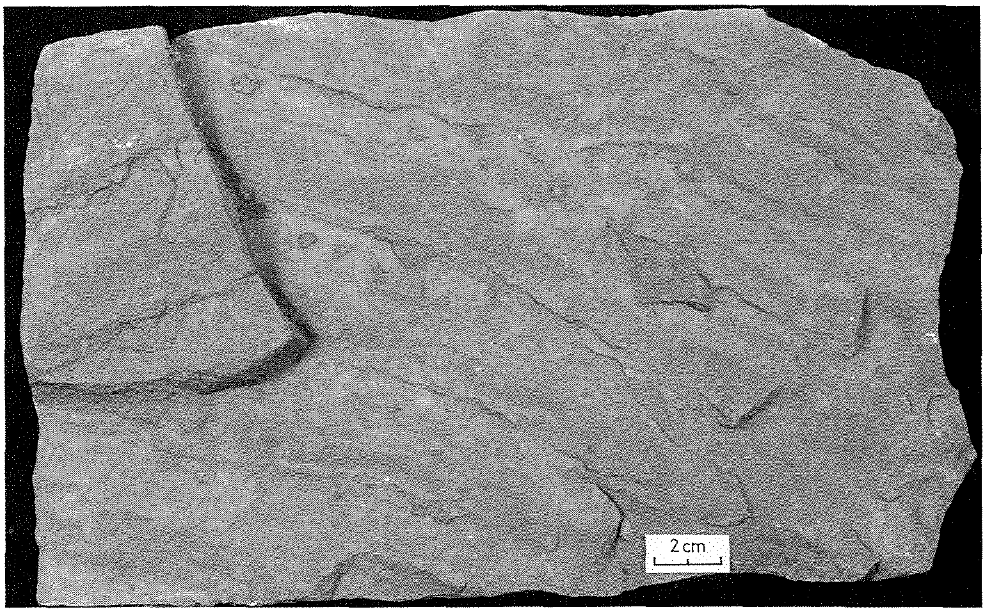

Figure 33. Halite casts in fine-grained, rippled sandstone — Mundadjini Formation

Calcareous shale, dolomite, and minor stromatolitic dolomite, are interbedded with the shale, mudstone, and siltstone. The calcareous rocks are blue-grey, white, cream to pink and, generally, thin bedded. Unidentified cumulate-style, and single-nodular stromatolites have been found at Ripple Hill and 18 km north-northwest of Ripple Hill.

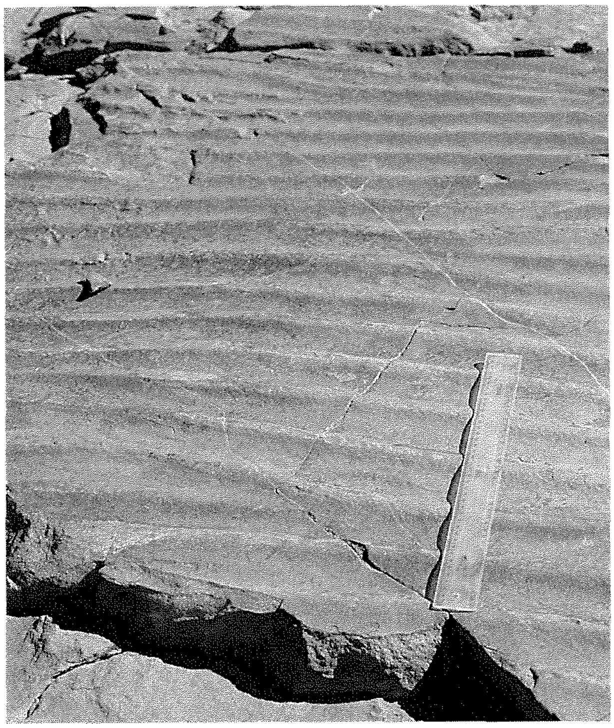

Figure 34. Symmetric (wave) ripples — Mundadjini Formation

Red-brown to purple-red, coarse-grained sandstone and pebbly sandstone, together with interbedded pebble and cobble conglomerate lenses, are abundant in some areas of the Mundadjini Formation. Such sandstone is massive and thick-bedded, and closely resembles similar rocks in the underlying Spearhole and Coondra Formations. Some matrix-supported boulder conglomerate fills penecontemporaneous channels in sandstone at Ripple Hill. Coarse-grained sandstone and conglomerate are prominent where Mundadjini Formation forms the basal unit of the Savory Group, as on the Ward Inlier, and west of the Woora Woora Hills. A good exposure of the angular unconformity between Mundadjini Formation and Cornelia Formation can be seen 9 km north of No. 14 Well (Canning Stock Route), where the basal pebbly sandstone contains shale and siltstone clasts derived from underlying Cornelia Formation (Fig. 31). All conglomerate clasts, a mature assemblage of quartzite, sandstone, vein quartz, various cherts, and minor jasper, are subangular to subrounded.

A wide variety of sedimentary structures is exhibited by the Mundadjini Formation. Ripple forms, in particular, are widespread throughout. Symmetric (Fig. 34) and asymmetric ripples (Fig. 35) are equally common, and indicate a range of water depths from the very shallow to the moderate (metre-scale). Linguoid (Fig. 36), catenary (Fig. 37), and interference or ladderback ripples (Fig. 38), have been recorded. Some ripple surfaces have been bevelled — a feature of tidal-flat conditions. Many of these ripple forms are found with mud cracks (Fig. 39), wind-blown wet-sand structures (Fig. 40), obstacle scours (Fig. 41), and rib-and-furrow structures. Halite pseudomorphs have also been found on ripple surfaces (Fig .33).

Some of the fine-grained sandstone that is interbedded with siltstone and shale has graded bedding. Some other sandstone exhibits bottom structures, such as load and flute

Figure 35. Asymmetric (current) ripples — Mundadjini Formation

casts; or tool marks, such as prod, skip, and groove marks. Synaeresis cracks and hummocky cross-bedding have also been observed in these sequences. Groups of planar and trough cross-beds of small to medium size are also found in the interbedded sandstone and siltstone units.

Coarse-grained sandstone, and pebbly sandstone, are characterized by large trough, and single planar cross-beds (Fig. 42). Flat-bedded sandstone with current lineations, and asymmetric ripple-marked sandstone, are sometimes sandwiched between cross-bedded units. Overall, cross-bedding is more common than ripple bedding in the coarse-grained sandstone.

Upward-coarsening sequences are characteristic of the Mundadjini Formation. A typical sequence commences with calcareous shale, dolomite, and mudstone, followed by interbedded siltstone and fine-grained sandstone; and the sequence is capped by thick-bedded fine- to medium-grained sandstone. Exposures at Mystery Hill and Ripple Hill show this type of sequence. However, east of the Boondawari–Savory Creek junction, some upward-fining sequences from medium-grained sandstone to siltstone have been recorded.

Skates Hills Formation

(Brakel and Leech, 1980)

Derivation of name: Skates Hills (lat. 24°34'S, long. 123°04'E).

Type area: A type section was given in Muhling and Brakel (1985) at lat. 24°33'15"S, long. 122°42'15"E. This

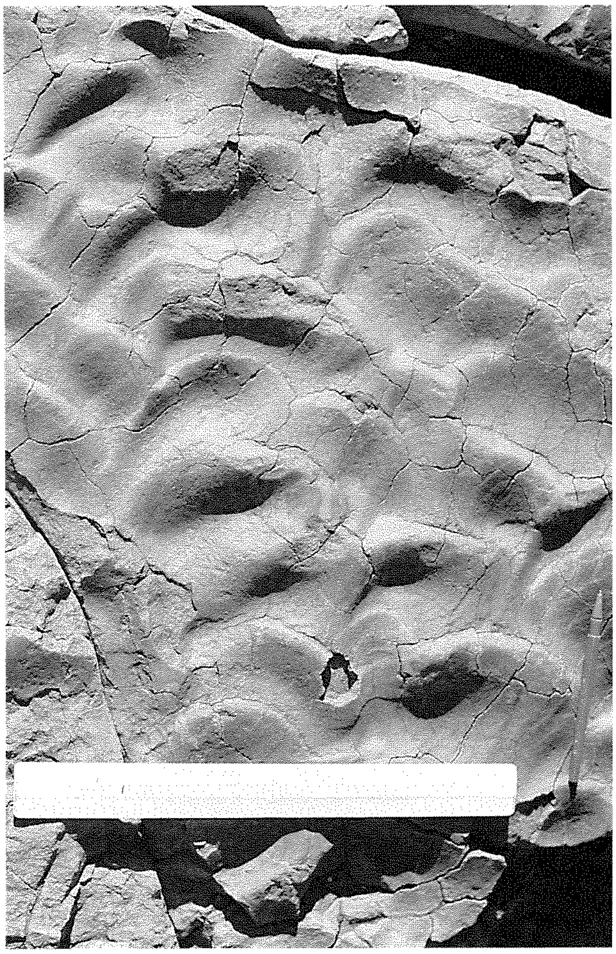

Figure 36. Linguoid ripples — Mundadjini Formation

Figure 37. Catenary ripples (in phase) — Mundadjini Formation

locality lies about 6 km north-northeast of Phenoclast Hill. Type areas for stromatolite occurrences are the northern margin of the Skates Hills, lat. 24°32'58"S, long. 123°04'26"E, and 36 km southeast of Phenoclast Hill, lat. 24°48'34"S, long. 122°57'50"E.

Lithology: Dolomite; stromatolitic dolomite; medium- to fine-grained sandstone; siltstone; shale; local thick conglomerate; and minor chert and evaporite.

Thickness: Maximum thickness, derived from airphotos appears to be about 200 m. The type section is estimated to be about 50 m.

Stratigraphic relationships and possible age: The Skates Hills Formation is restricted to the southeast quadrant of the Savory Basin, where it forms the basal unit of the Savory Group, and unconformably overlies the northern

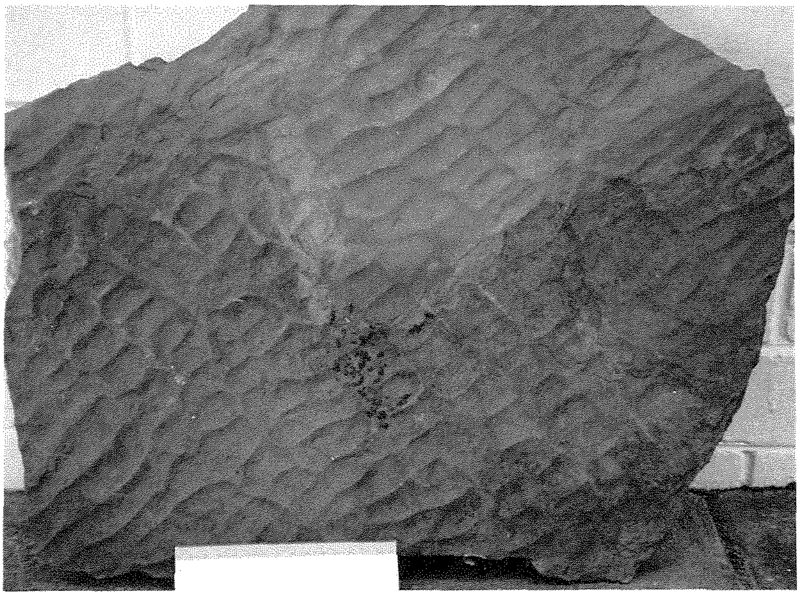

Figure 38. Interference or ladder ripples — Mundadjini Formation. (Scale bar 150 mm).

Figure 39. Mud cracks — Mundadjini Formation

and eastern margins of the Oldham Inlier (Fig. 43). The inlier contains folded Middle Proterozoic Cornelia Formation. The absence of Skates Hills Formation from the southern margin of the inlier suggests that, either the formation is restricted to the area north of the inlier, or that it may have been removed by faulting.

To the west, the formation is faulted against Boondawari Formation. Eastwards, it is unconformably overlain by Permian rocks of the Officer Basin. Within the Savory Basin, Skates Hills Formation is disconformably overlain by McFadden Formation. It is tentatively correlated with the Mundadjini Formation, which lies to the northwest, and with which it has a number of lithological similarities.

Recent work by Grey (1989), following earlier reports (Grey, 1976, 1978, 1981, 1985), on stromatolites from the Skates Hills Formation confirmed the identification of *Acaciella australica* (Fig. 44). The recognition of this stromatolite has important biostratigraphic significance. It enables the Skates Hills Formation to be correlated, as regards both age and environment, with the lower two units of the Late Proterozoic Loves Creek Member of the Bitter Springs Formation of the Amadeus Basin and the Yackah Beds of the Georgina Basin. As pointed out by Grey (1989), this places the age of the Skates Hills Formation somewhere between 900 and 750 Ma. A more precise date, between 820 and 815 Ma, was reported by

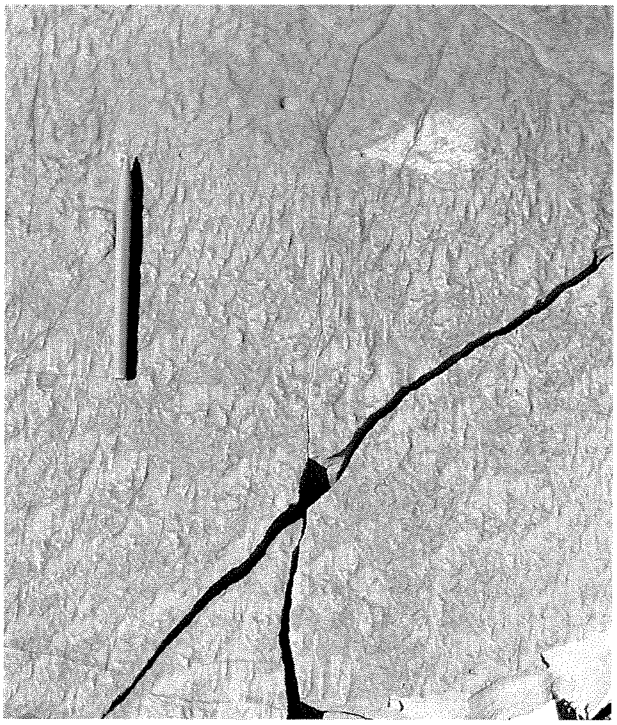

Figure 40. Wind-blown wet-sand structures (top structure) — Mundadjini Formation

Figure 41. Obstacle scours (top structure) — Mundadjini Formation

Lindsay and Korsch (1991) for the Bitter Springs Formation.

Description: The Skates Hills Formation contains three distinct lithologic units. The basal unit comprises restricted, but locally thick, units of polymictic cobble to boulder conglomerate with a fine-grained sandy matrix. The conglomerate is thought to be the filling of a channel incised into Cornelia Formation, upon which it rests unconformably. Subrounded boulders up to 0.5 m occur at Phenoclast Hill (Fig. 45). Brakel and Leech (1980) reported at least 30 m of conglomerate at this locality. Imbricate structure has been noted in vertical sections of the conglomerate in this region. The clasts are of sandstone, quartzite, vein quartz, silicified shale, and chert, and have been mainly derived from the underlying

Figure 42. Large-scale planar cross-beds — Mundadjini Formation

Figure 43. Distribution of the Skates Hills Formation

Cornelia Formation. Similar boulder conglomerates occur 20 km northwest of Phenoclast Hill. Where the boulder conglomerate is absent, the basal sequence of the Skates Hills Formation consists of red-brown, coarse-grained sandstone, granule sandstone, and some pebbly units. Maroon, purple, cream, and grey, fine-grained sandstone, micaceous siltstone, and shale, overlie the basal units. Some quartz wacke lenses and chert have also been noted. However, the presence of glauconitic laminites in the wacke, as reported by Brakel and Leech (1980), was not confirmed by this survey.

The middle unit of the Skates Hills Formation is dominated by carbonate. Grey, blue, buff, cream, and pink, finely-crystalline, laminated to thick-bedded dolomite crops out over a wide area. Individual beds up to 10 m thick were described (Brakel and Leech, 1980); and four beds ranging up to 3 m thick occur 5.5 km north-northwest of Phenoclast Hill. Seven kilometres northeast of Phenoclast Hill, the dolomite unit, together with interbedded sandstone, siltstone, shale, and chert, total 21 m. Twelve kilometres southeast of the Cornelia Range, a thick, white-weathering, black chert occurs near the base of the basal dolomite unit. The chert, which is faintly laminated and podded, exhibits desiccation cracks. The dolomite also contains numerous, discontinuous, blue chert pods and lenses and a few interbeds of shale, siltstone, and fine-grained sandstone (Fig. 46). Cauliflower chert, a silica

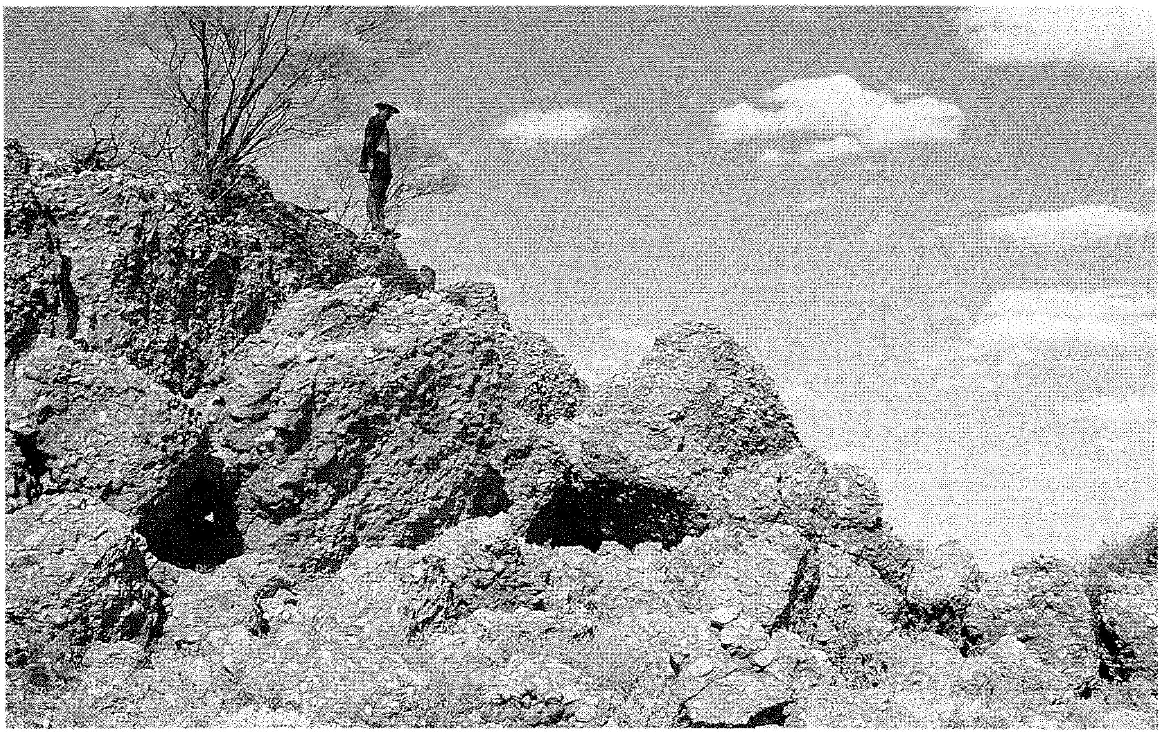

Figure 44. Stromatolites, *Acaciella australica* — Skates Hills Formation

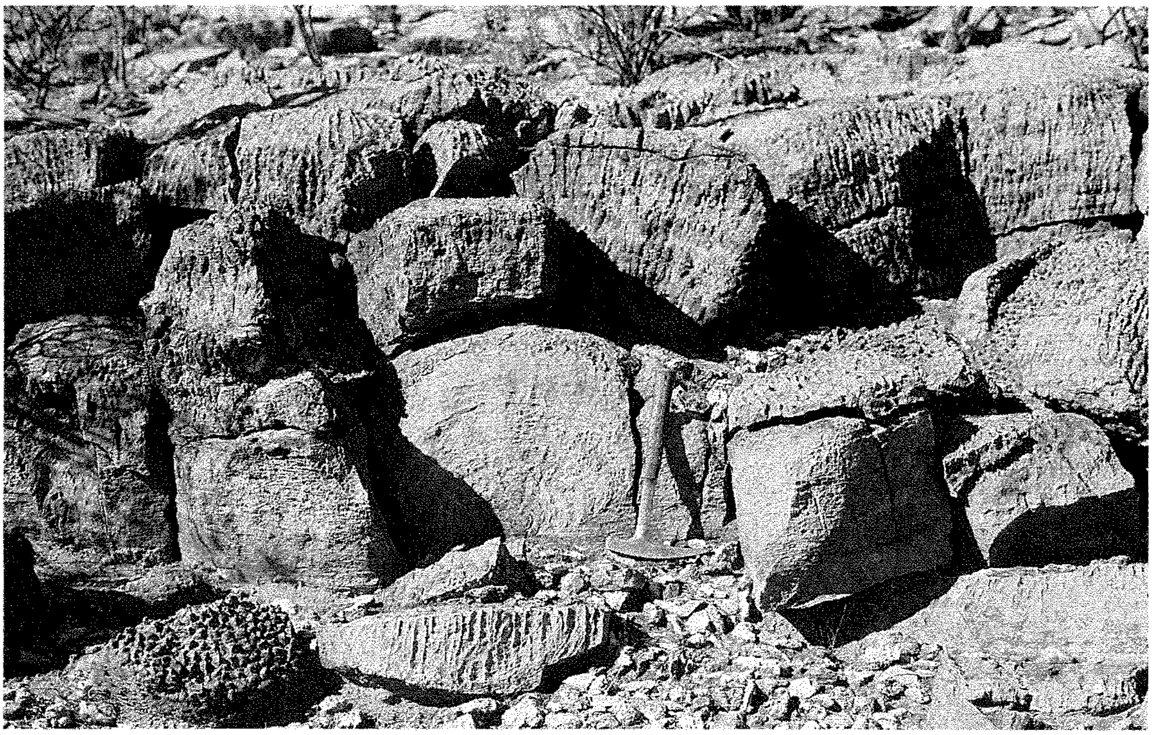

Figure 45. Conglomerate in channels at base of Skates Hills Formation, Phenoclast Hill

Figure 46. Blue chert pods in dolomite — Skates Hills Formation

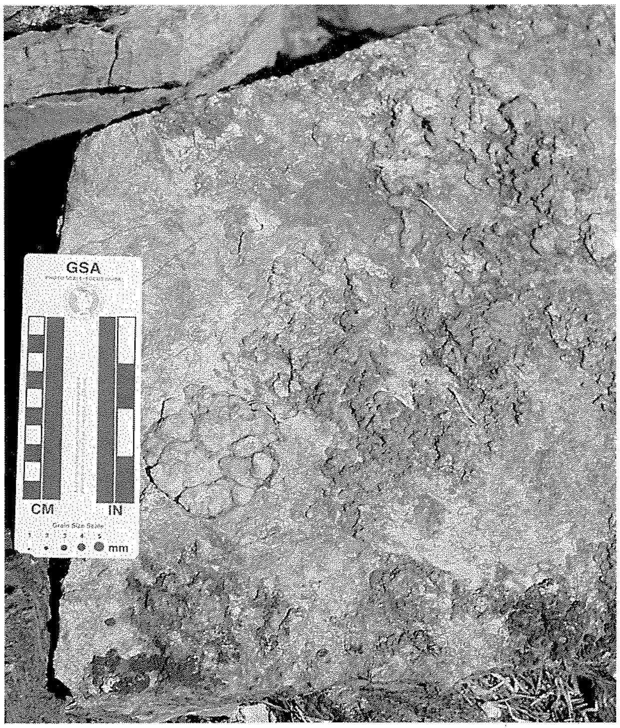

Figure 47. Cauliflower chert after anhydrite — Skates Hills Formation

replacement of anhydrite nodules, indicates evaporitic conditions (Chown and Elkins, 1974) (Fig. 47). Voids shaped like gypsum crystals are found in the fine grained sandstone.

Stromatolite occurrences are widespread in the dolomite. Large, domed or tabular bioherms, as much as 5 m long and 1.5 m high, are found in some beds. Elsewhere, siliceous cones and mounds (silica replacements of stromatolites) are scattered amongst dolomite and shale rubble. Fourteen stromatolite localities have been documented (Grey, 1989). The occurrence of *Acaciella australica* has been confirmed (Fig. 44); and specimens of ?*Basisphaera irregularis* Walter 1972 were tentatively identified (Fig. 48) (Grey, 1989). As previously stated, the presence of these fossils has important biostratigraphic implications for the formation. Excellent stromatolite exposures can be seen in dolomite north of Phenoclast Hill and northeast of the Skates Hills.

The middle unit is overlain by a thin succession of pink to red shale, siltstone, and flaggy, fine- to medium-grained ferruginous sandstone. The abrupt appearance of coarse-grained, cross-bedded, dark red-brown sandstone marks the base of the overlying McFadden Formation. The sandstone and coarse siltstone units of the Skates Hills Formation generally exhibit small, planar cross-beds and symmetrical, ripple bedding. Bottom structures, such as

Figure 48. Stromatolite, ?*Basisphaera irregularis* Walter 1972 — Skates Hills Formation.

flute casts, have been found in the interbedded sandstone and siltstone. Intraclastic sandstone also occurs in these units.

Boondawari Formation

(Williams and Tyler, 1991)

Derivation of name: Boondawari Soak, (lat. 23°35'10"S, long. 121°27'40"E), ROBERTSON.

Type Area: Three type areas are given:

(a) 7.5 km bearing 030° from Boondawari Soak, (lat. 23°31'32"S, long. 121°29'57"E) for basal glacigenic diamictite association.

(b) 29 km east-southeast of No. 13 Well (Canning Stock Route), (lat. 24°17'46"S, long. 122°16'19"E) for diamictite and coarse-grained sandstone sequence.

(c) Boondawari Creek area, (lat. 23°34'56"S, long. 121°28'25"E) for upper lutite and carbonate sequence.

Lithology: Diamictite (glacigenic); rhythmite; fine- to coarse-grained sandstone; wacke; pebbly sandstone; conglomerate; ferruginous sandy siltstone; siltstone; shale; mudstone; dolomite; dolomitic siltstone; oolitic dolomite; stromatolitic dolomite.

Thickness: The formation ranges up to 800 m thick, estimated from airphotos.

Stratigraphic relationships: The Boondawari Formation crops out discontinuously through the central and northern parts of the Savory Basin (Fig. 49). The formation can be traced discontinuously from southeast of the Ward Hills, northwards to just south of the Talawana–Windy Corner track.

The Boondawari Formation is best exposed in the Boondawari Creek drainage basin. Although previously described as part of a conformable sequence (Williams and Tyler, 1991), the regional distribution of the Boondawari Formation suggests that it has disconformable to unconformable contacts with the underlying Mundadjini and the overlying McFadden Formation. It is faulted against the Tchukardine Formation north of the Emu Range.

The southernmost exposures of the Boondawari Formation, which are in the Trainor Hills, are very poor. It seems to unconformably overlie the Cornelia Formation in the Ward Inlier, and is faulted against the Cornelia Formation in the Oldham Inlier. It is also faulted against the Spearhole Formation. Near No. 15 Well (Canning Stock Route), it disconformably overlies Mundadjini Formation, and is, in turn, disconformably overlain by (or ?faulted against) McFadden Formation.

A thin diamictite unit, which is exposed at the base of Boorabee Hill, and in a series of small tablelands extending northwards to near Marloo Marloo Rock Hole, is a possible correlate of the Boondawari Formation. This diamictite is disconformably overlain by Tchukardine

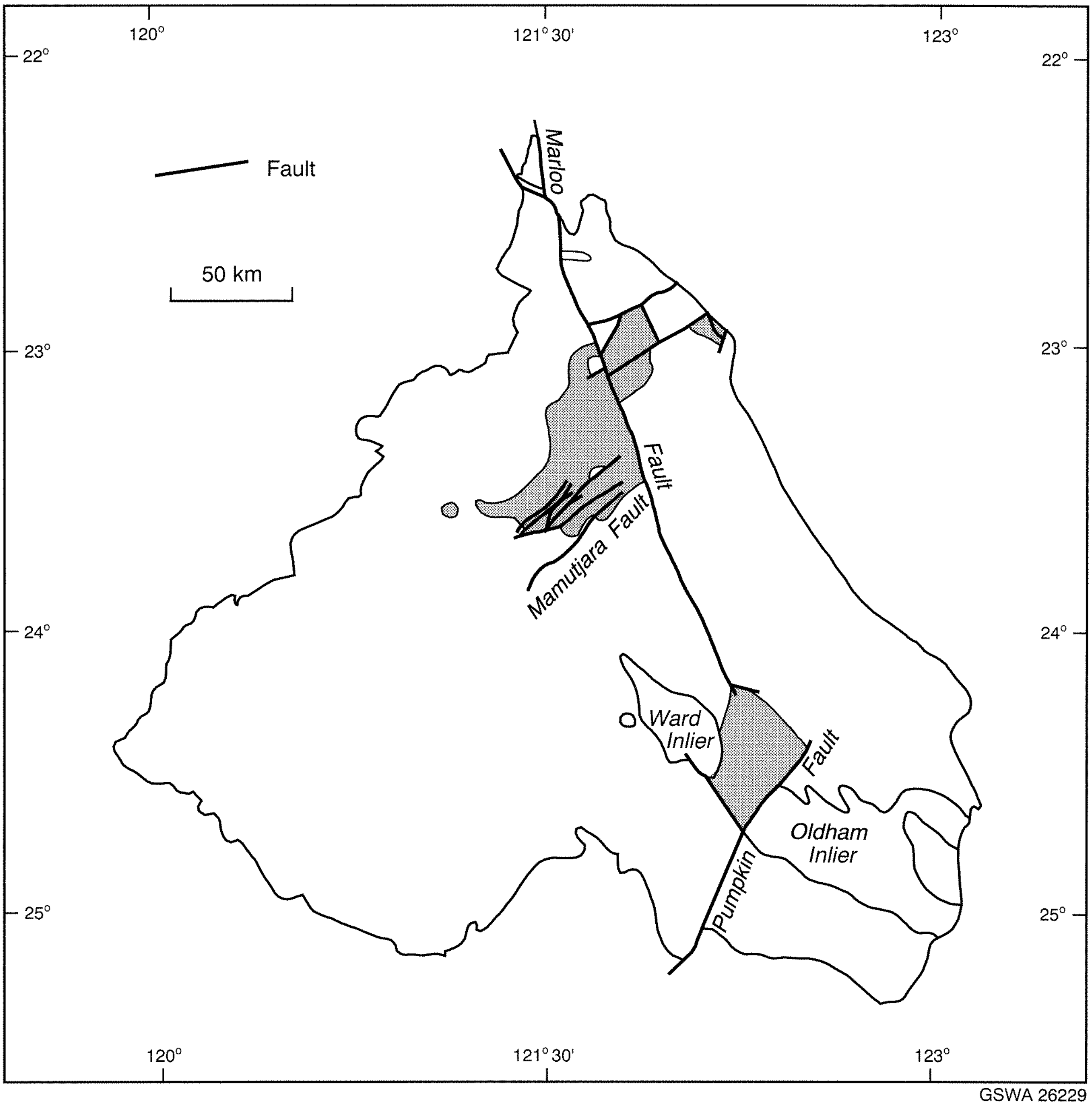

Figure 49. Distribution of the Boondawari Formation

Formation. A thin, medium- to coarse-grained sandstone and conglomerate sequence which separates the diamictite from the unconformably underlying Yeneena Group may be a correlate of the Mundadjini Formation. This diamictite unit, which is too thin to show on the 1:500 000-scale map accompanying this bulletin, was included in Watch Point Formation on BALFOUR DOWNS (I. R. Williams, 1989). However, that correlation is now believed to be incorrect. These units are discussed further in the section on the Tchukardine Formation.

Description: The Boondawari Formation differs from other formations of the Savory Group in that coarser grained sandstone and conglomerate units are subordinate to argillaceous and finer grained sandstone components. This is expressed visually by the sparsity, or lack, of sand dunes overlying the formation. Also, the formation is commonly covered by an ironstone-pebble veneer derived from low mounds of laterite. Where recent erosion has stripped the laterite, thick (as much as 20 m), deeply weathered profiles are exposed. The deeply weathered rocks, often capped by laterite, form breakaways — as in the Boondawari Creek drainage basin.

The Boondawari Formation is best exposed in the Boondawari Creek area, where the three main lithologic associations have been identified. However, because of scattered outcrop and the widespread disruption of the

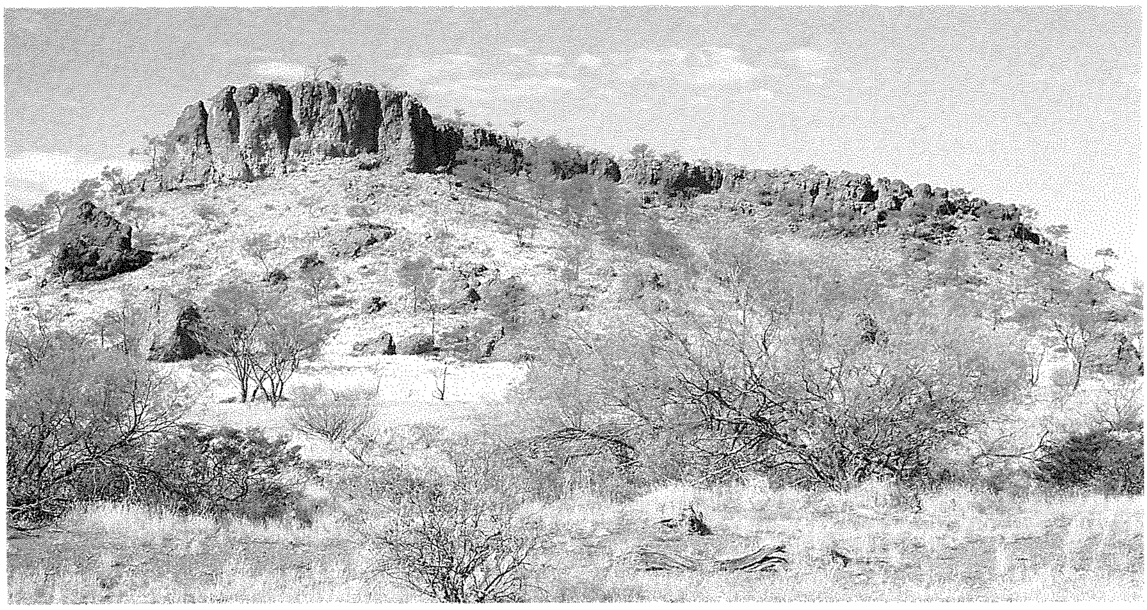

Figure 50. Laterite-capped diamictite — Boondawari Formation

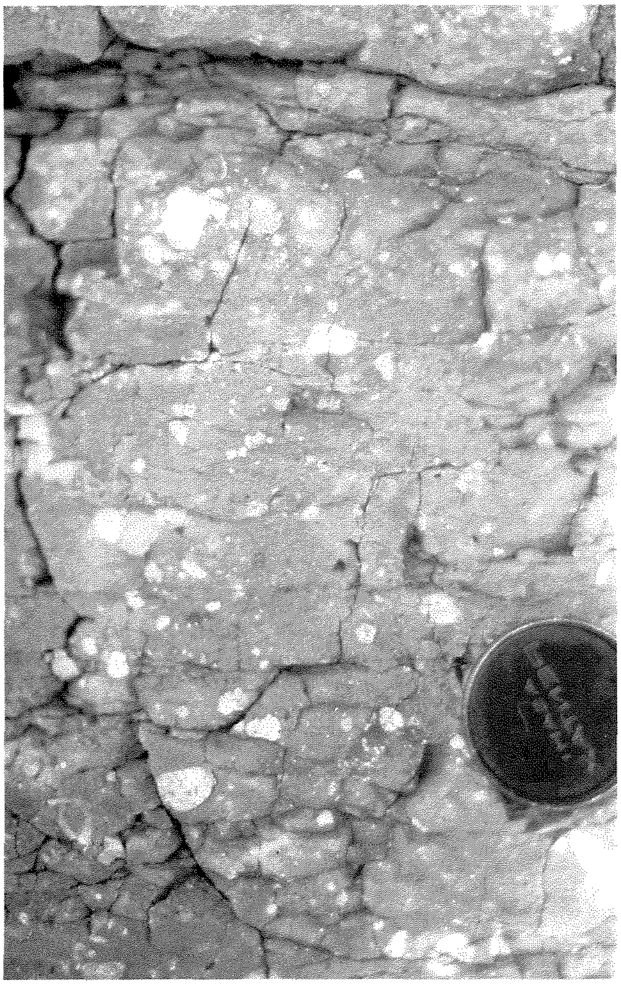

Figure 51. Diamictite — Boondawari Formation (lens cap 50 mm)sa

Boondawari area by northeast-trending faults, further refinement into members or new formations was not attempted in this bulletin. The base of the Boondawari Formation in the Boondawari Creek area is defined by the appearance of the first diamictite unit. An exposure of the contact can be seen east of Savory Creek, 11 km northeast of the Boondawari–Savory Creek junction. At that locality, diamictite rests with apparent conformity on sandstones of the Mundadjini Formation.

The diamictites of the Boondawari Creek area were first described by Williams (1987), who argued for a glacigenic origin. The lowest lithological association in the area is characterized by diamictite, mudstone, rhythmite, minor sandstone, and conglomerate. A massive diamictite (Fig. 50), 30 m thick, occurs beneath laterite-capped breakaways 8 km north of Boondawari Soak (Williams and Tyler, 1991). In other areas, at least two diamictite beds, separated by coarse-grained, red-brown sandstone, and lenses of polymictic conglomerate, have been noted. In many areas, the presence of diamictite is inferred from surface accumulations of a wide variety of boulders and cobbles derived from the underlying bedrock by weathering.

The diamictite comprises a range of deep purple-red, dark chocolate-brown to dark-grey mudstone, which, in some areas, may be silty, or even sandy. The mudstone constitutes the matrix for an unevenly distributed assortment of pebbles, cobbles, and boulders, that range up to 3.5 m (Fig. 51). The clasts range from angular to subrounded, but some are wedge-shaped. A significant number show striations, faceting and variable degrees of polishing (Figs 52, 53). Large boulders have commonly been shattered and split open *in situ* by recent weathering. Many clasts are remarkably fresh; and it is not unusual to see large boulders of friable, but fresh, shale and mudstone

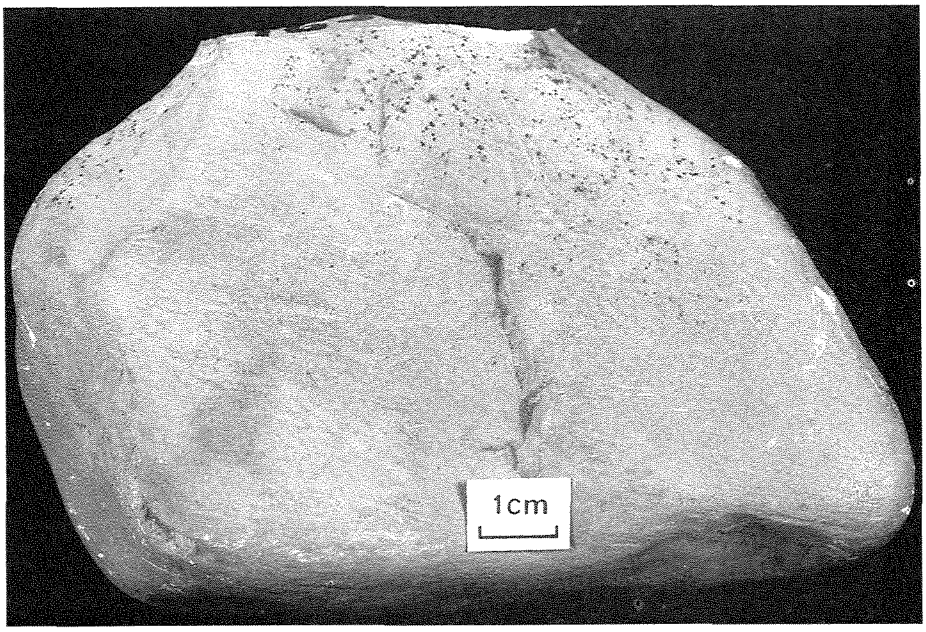

Figure 52. Ice-faceted, striated cobble from Boondawari Formation, Boondawari Creek

lying next to faceted and polished granite boulders (Fig. 54). Clasts of more than twenty different lithologies have been identified in the Boondawari Creek area. These include sandstone, siltstone, shale, mudstone, dolomite, conglomerate, breccia, chert, quartzite, basalt, amygdaloidal basalt, dolerite, gabbro, felsic volcanic rocks, and various kinds of schist, gneiss, and granitoid. Amongst the more unusual are stromatolitic dolomite, dolomitic edgewise breccia, and ferruginous peloidal chert.

A statistical count of cobbles and boulders in an area 8 km north-northeast of Boondawari Soak showed that 54% of the clasts were sedimentary, 28% metamorphic, and 18% igneous — the latter mostly granite. However, this ratio was found to vary from outcrop to outcrop, even within the Boondawari Creek area. The greatest numbers of varieties of clasts were recorded from three localities: 3 km east; 10 km northeast; and 8 km north-northeast of Boondawari Soak. In contrast, diamictite 2 km west of the

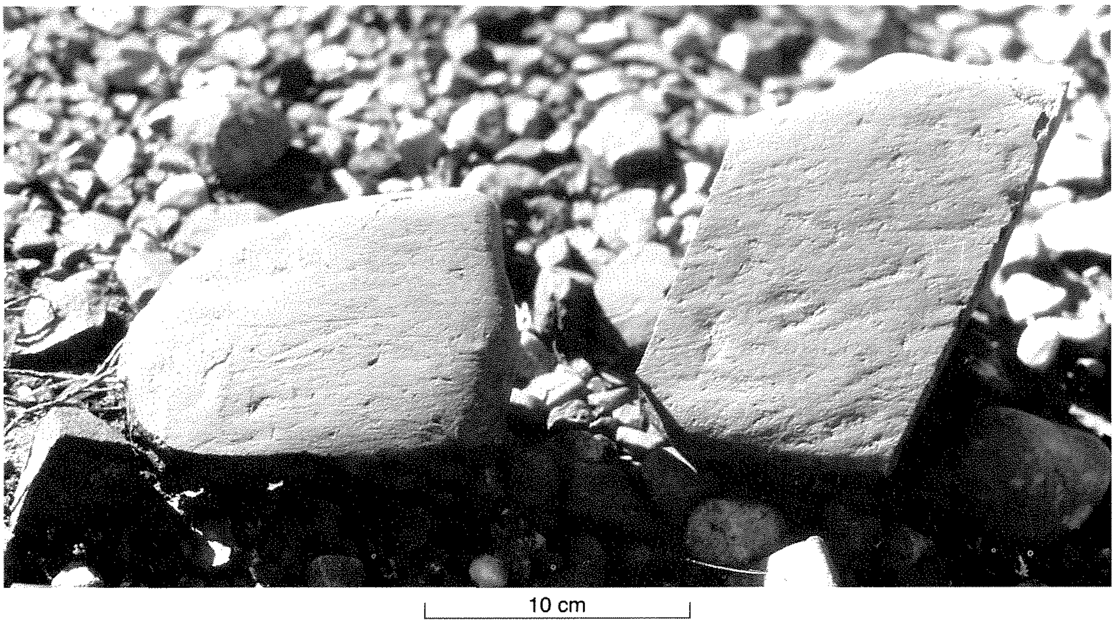

Figure 53. Polished, striated cobbles from Boondawari Formation

Figure 54. Boulder (banded gneiss intruded by granite) from diamictite — Boondawari Formation

soak carries up to 70% igneous clasts; the remaining 30% are sedimentary. Most of the igneous clasts were either basalt, amygdaloidal basalt, or dolerite; only a few were granitoid.

One kilometre west of Boondawari Soak, sedimentary rhythmite conformably overlies diamictite (Fig. 55). This single exposure of grey-blue rhythmite comprises alternate light and dark bands that vary from 1 to 10 mm thick. The light bands are thicker and composed of siltstone, whilst the dark, clay-rich bands are generally less than 1 mm thick. The siltstone consists mainly of angular to subrounded quartz grains, but some feldspar and mica grains are also present. Light-coloured siltstone grades upward into dark clay-rich layers; but the contacts between dark clay-rich layers and overlying light-coloured siltstone are sharp. Overall, the thickness of the banding varies greatly, and it does not show the regularity of banding attributed to varves. As well as graded bedding, small-scale cross-bedding, scours, and flame structures (resulting from load compaction of siltstone on the clay-rich bands), have been noted. The Boondawari Formation rhythmite closely resembles the rhythmite described from the Late Proterozoic (800–650 Ma) glacigenic sequences (Elatina Formation) in South Australia (G. E. Williams, 1989).

Figure 55. Sedimentary rhythmite — Boondawari Formation

The middle lithologic association of the Boondawari Formation in the Boondawari Creek area comprises grey, buff, red-brown, and maroon, coarse- to fine-grained sandstone containing widely scattered pebbles, cobbles, and occasional boulders. The sandstone is interbedded with nodular sandstone, feldspathic sandstone, quartz wacke, siltstones, and lenses of polymictic conglomerate. Many of the cobbles and boulders in the sandstone, which appear identical to clasts found in the underlying diamictite, appear to be dropstones. The quartz wacke contains up to 15% lithic fragments, microcline, and plagioclase. Tourmaline is an important accessory in all these rocks. The massive, thick-bedded sandstone and wacke units are commonly weathered and roughly pitted. In some areas, north of Kari Soak, for example, a pseudo tower-karst topography has formed in the thick sandstone units. The pattern reflects and is controlled by strong orthogonal jointing. Both planar and trough cross-bedding are present. Current directions, derived from cross-bedding, in both overlying sandstone and sandstone interbeds within the diamictite units indicate currents predominantly from the

Figure 56. Conglomerate filling penecontemporaneous channel in sandstone — Boondawari Formation

west, southwest, and south-southeast. Polymictic conglomerate appears to infill penecontemporaneously scoured channels in the sandstones (Fig. 56). Much of it is matrix supported and poorly sorted for size. As the clasts are the same as those seen in the diamictite beneath, some reworking of these sediments may have occurred. A good example of this type of conglomerate is exposed beside the track 11 km northeast of the Boondawari–Savory Creek junction. This middle, coarse, arenaceous association varies from a few to more then 200 m thick.

The argillaceous–carbonate-rich upper association is largely restricted to the Boondawari Creek area. The base of the unit, which is marked by thin-bedded, pink dolomite overlying coarse, buff-coloured sandstone of the middle association, is exposed 5 km north-northeast of Boondawari Soak. The upper association consists of a series of upward-coarsening units that range from shale and siltstone to fine- and coarse-grained sandstone. Overall, however, the sandstone content decreases upwards, and the percentage of mudstone and carbonate units increases.

The sandstone units are maroon, red to pink, thin to thick bedded, and are commonly flaggy. Some sandstones are better described as quartz wackes. They are sometimes cross-bedded; but more frequently, wave and current rippled. Graded bedding with occasional mud-cracked

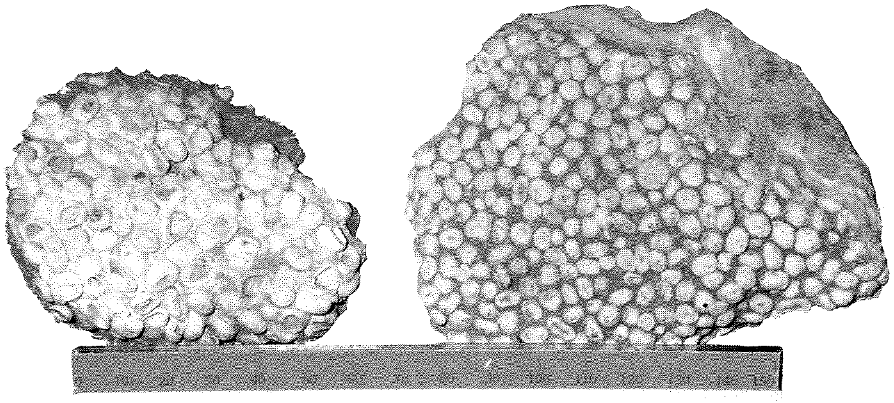

Figure 57. Limestone pisoliths (up to 7 mm), upper section of Boondawari Formation

Figure 58. Stromatolite, unassigned — Boondawari Formation

horizons is present in some sandstone and siltstone units. Where thin-bedded sandstone is interbedded with siltstone and shale, the sandstone shows load and flute casts. The siltstones, some of which are micaceous and ferruginous, range from dark red and purple through to cream and grey. The sandstone interbedded with the siltstone commonly contains siltstone intraclasts.

Five kilometres north of Boondawari Soak, ferruginous shale, siltstone, and sandstone, form an upward-coarsening sequence. Some of the siltstone contains layers of heavy minerals and superficially resembles poor-quality iron-formation. The heavy minerals are iron-rich opaques, after magnetite and hematite, and ilmenite. A yellow, speckled sandstone was found to contain nontronite, a break-down product of iron-rich minerals.

Shale and mudstone of the upper association are not well exposed except in an area 2 km east of Boondawari Soak, where thick-bedded, green, purple, and black shale and mudstone are interbedded with siltstone and mixed carbonate rocks. The carbonate rocks include thin- to thick-bedded grey and pink dolomite, oolitic dolomite, light-brown dolo-arenite, thin-bedded white limestone, unusual grey pisolitic carbonate, and pink, silicified, oolite rock (Fig. 57). Unassigned stromatolitic bioherms and biostromes occur in dolomite and finely laminated dolomite and limestone 2 km northeast and 8 km east of Boondawari Soak (Fig. 58). At the former locality, dolomite and shale are interbedded with thin-bedded, pink, fine-grained sandstone, some of which carries halite casts.

Away from the Boondawari creek area, the Boondawari Formation is less well exposed. However, scattered exposures of diamictite and associated sandstone, conglomerate, shale, and siltstone, can be traced intermittently for 80 km northwards to near the Horsetrack Range. A study of clasts in a well-exposed diamictite, 20 km southwest of the Horse Track Range, showed that 70% were sedimentary, 20% igneous, and 10% metamorphic.

Two chocolate-brown diamictite beds containing scattered cobbles and boulders of sedimentary and metamorphic rocks up to 1 m occur 7 km north of the Emu Range close to the northeastern boundary of the Savory Basin. They are interbedded with red-brown, coarse-grained sandstone and pink siltstone. The upper diamictite is overlain by a well-bedded shale, which, in places, resembles the rhythmite near Boondawari Soak. Matrix-supported conglomerate lenses and coarse-grained sandstone with scattered large (dropped?) cobbles are exposed nearby. Cross-bedding in the sandstone indicates a general current direction from the northeast.

The thin, dark-brown diamictite found in the Boorabee Hill–Marloo Marloo Rock Hole area contains scattered sedimentary and granitic pebbles and cobbles; it is overlain by lithic sandstone and quartz wacke at Boorabee Hill. Five kilometres south of Marloo Marloo Rock Hole, the sequence comprises mudstone, shale, sandy siltstone, and fine-grained glauconitic sandstone.

The diamictites in the Trainor Hills and southeast of the Ward Hills were originally mapped as Permian (Brakel and Leech, 1980). However, the shale, mudstone, siltstone, and medium- to coarse-grained sandstone that occur interbedded with, and overlie the diamictite are lithologically identical with rocks of the Boondawari Creek area. A large intrusion of coarse-grained dolerite, similar to the Boondawari Dolerite, has intruded the sequence in the Trainor Hills area. The matrix of the diamictite here is generally sandier than that found further north. The clasts are largely derived from sedimentary rocks: only a minor contribution comes from igneous (granitoid) and metamorphic terrains. Large orthoquartzite boulders resemble orthoquartzite in the nearby Ward and Oldham Inliers.

McFadden Formation

Previously called McFadden Sandstone
(Williams and Williams, 1980)

Derivation of name: McFadden Range (lat. 23°21'30"S, long. 122°18'30"E), GUNANYA.

Type area: In the McFadden Range, a series of flat-lying mesas up to 100 m high; good exposures can also be found in the Durba and Diebil Hills beneath a thin capping of Durba Sandstone.

Lithology: Fine- to coarse-grained sandstone, feldspathic sandstone, quartz and feldspathic wacke, minor pebble and granule conglomerate, siltstone.

Figure 59. Distribution of the McFadden Formation

Thickness: Maximum thickness, estimated from airphotos, may reach 1500 m. However, the original thickness is unknown because the upper surface has been removed by erosion.

Stratigraphic relationships: The poorly outcropping McFadden Formation is confined to the northeast margin of the Savory Basin, mainly east of the Marloo Fault (Fig. 59). The formation, as now defined, occupies slightly less area than as originally described by Williams and Williams (1980).

It disconformably overlies Skates Hills Formation in the south, Boondawari Formation in the west and northwest, and Mundadjini Formation in the north near the Horse Track Range. It is faulted against Mundadjini Formation northeast of Ripple Hill. Although McFadden Formation is faulted against Tchukardine Formation west of the Emu Range, the regional setting suggests that the two formations are probably coeval. Durba Sandstone unconformably overlies McFadden Formation. Poor outcrop and widespread sand cover have made it difficult to determine the contact relationship between the McFadden Formation and both the Yeneena Group and the Karara Formation of the Paterson Orogen . However, the straightness of the contact between McFadden Formation and the units of the Paterson Orogen suggest it may be largely fault controlled. Southeast of the Calvert Range, the McFadden Formation is unconformably overlain by Permian sediments of the Officer Basin.

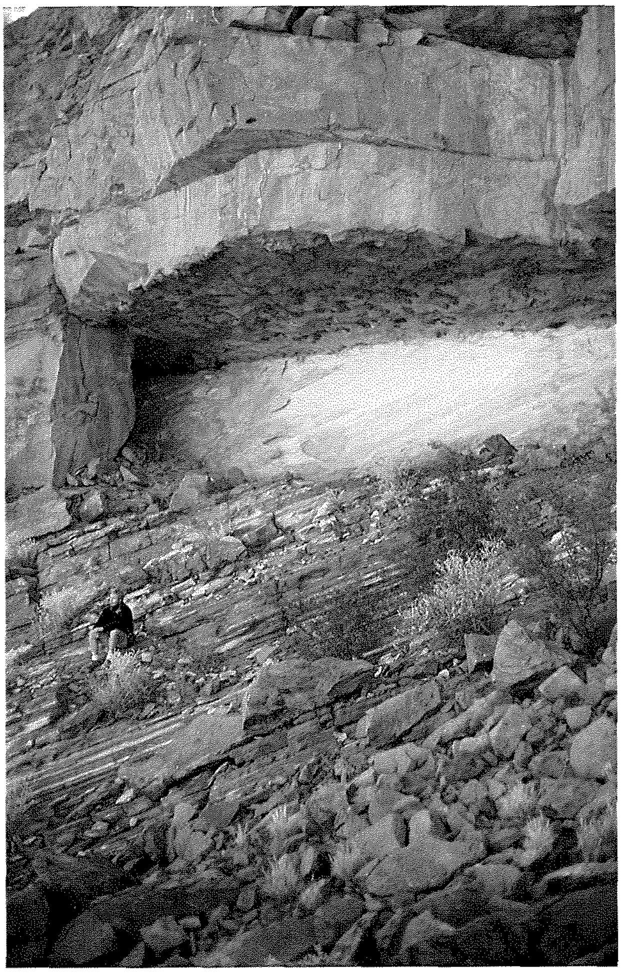

Figure 60. Large planar heterogeneous cross-beds in McFadden Formation; unconformable contact with overlying Durba Sandstone, Diebil Hills

Description: The McFadden Formation is predominantly a coarse-grained arenaceous sequence. It is characterized by laminated to thick-bedded, commonly flaggy, fine- to coarse-grained sandstone, interbedded with similarly bedded feldspathic sandstone and quartz and feldspathic wacke. The latter rocks are not well sorted for size or composition and may consist of up to 20% matrix. Feldspar (both microcline and plagioclase), chert grains, siltstone intraclasts, and occasional flakes of mica, typify the wacke assemblages. The weathered surfaces of sandstone and wacke range from purple and purple-brown to red and grey-brown. The rock is commonly friable and presents a rough, honeycombed surface. A variable clay matrix probably accounts for the crumbly weathered surface. Purple, thick-bedded siltstone and flaggy micaceous siltstone, and intraclastic sandstone, are interbedded with sandstone and wacke. Brakel and Leech (1980) referred to a possible volcanic ash component in some wackes from TRAINOR. The McFadden Formation becomes coarser grained towards the north and east. In the McFadden Range area, the formation is characterized by granule and pebble sandstone and beds of polymictic pebble to cobble conglomerate. The conglomerate occurs as thin interbeds or penecontemporaneous fills in channels scoured in the sandstones. The generally rounded clasts are chert, quartzite, sandstone, siltstone, and vein quartz. The matrix tends to be sandy. Upward-fining cycles from conglomerate to fine-grained sandstone have been noted in a number of localities.

The McFadden Formation is characterized by large heterogeneous cross-bed sets up to 10 m thick (Fig. 60). The cross-beds are typically flaggy, and many individual units within the cross-beds are graded from granule sandstone to fine-grained sandstone. The large size of the cross-beds often makes it difficult to estimate regional bedding dip in areas of poor outcrop. Planar cross-beds may be traced for several kilometres, whilst some large, asymptotic trough cross-beds are over 250 m wide and up to 10 m thick. Good examples can be seen in the McFadden and Calvert ranges and the Diebil and Durba Hills. The tops of large cross-beds in the last three localities have been eroded and unconformably overlain by Durba Sandstone.

Current lineations on flat-bedded sandstone, and occasional current ripple marks, have been found on sandstone units between large cross-bedded units. Dewatering structures that result from load compaction have been observed in fine-grained sandstones in the Calvert Ranges.

Tchukardine Formation

(new name)

Derivation of name: Tchukardine Pool (lat. 22°32'38"S, long. 121°36'21"E).

Type area: Two type areas are proposed. The first is a region of low, dissected tablelands which rises 60 to 70 m above the plains that extend 10 km south from Hanging Rock (lat. 22°30'28"S, long. 121°40'36"E). The second is the Wells Range, a low, sandstone range lying south of the Talawana–Windy Corner track (lat. 22°54'03"E, long. 121°56'62"E).

Lithology: Dominantly medium-grained sandstone; lesser fine- and coarse-grained sandstone, some with widely scattered pebbles; minor quartz and lithic wacke; sandy siltstone; siltstone; shale; pebble and cobble conglomerate.

Thickness: Thickness estimated from airphotos is about 700 m. The original thickness is unknown because the upper surface has been removed by erosion.

Stratigraphic relationships: The Tchukardine Formation is confined to the northern margin of the Savory Basin, between the Talawana–Windy Corner track, north of the Emu Range in the east and the Marloo Marloo Rock Hole area in the northwest (Fig. 61). However, it is not clear if the rocks that lie with angular unconformity on the Yeneena Group along the northern boundary of the Savory Basin, and which are lithologically different from the bulk

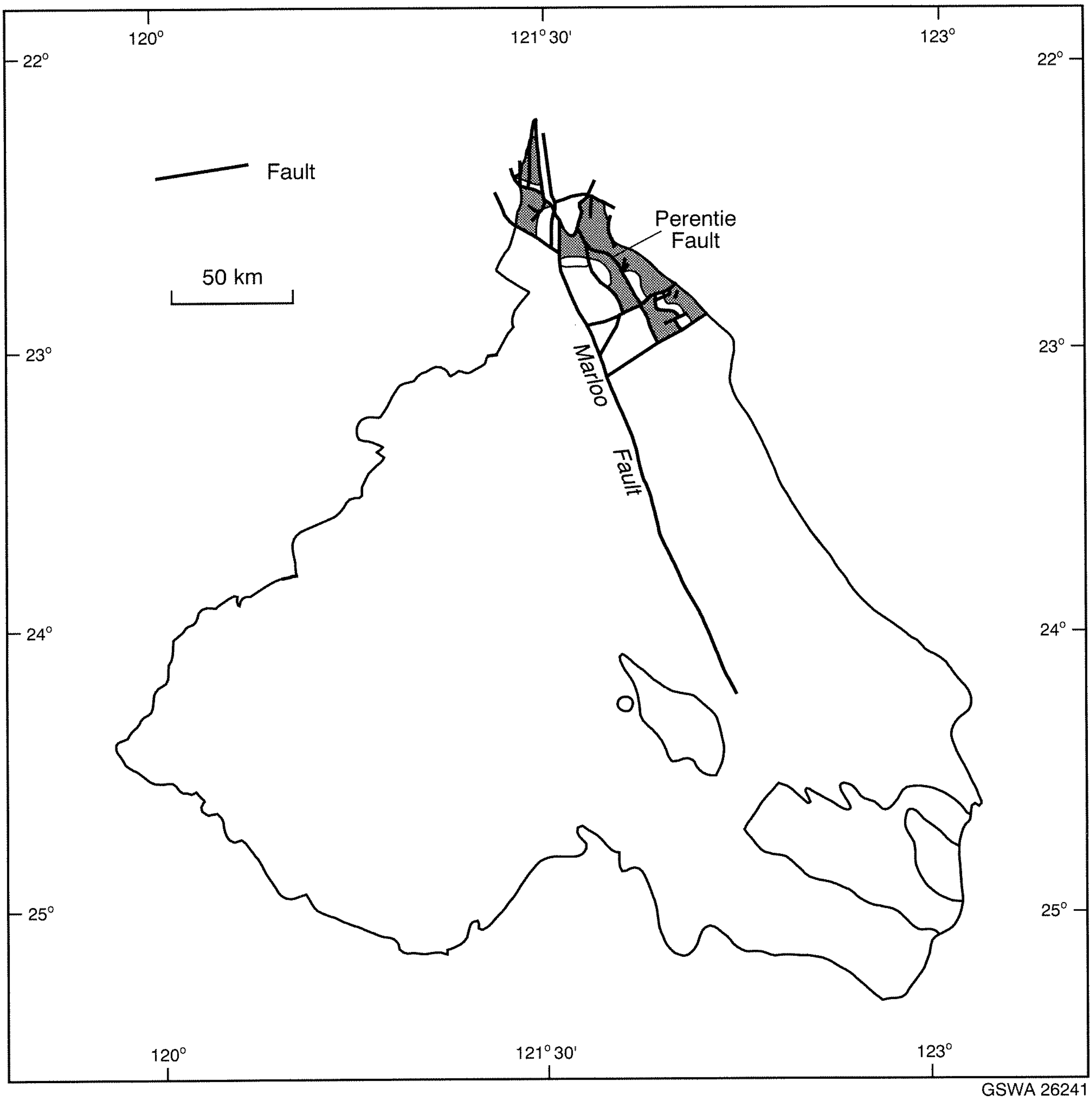

Figure 61. Distribution of the Tchukardine Formation

of the Tchukardine Formation, should be included in the Tchukardine Formation. The unconformity between rocks of the Savory Group and rocks of the Yeneena Group of the Paterson Orogen is well exposed 7 km north of Boorabee Hill, and 12 km and 23 km south of Hanging Rock. In all cases, the sequence overlying the unconformity comprises a basal conglomerate, between 0.5 m and 2 m thick, followed by medium- to coarse-grained sandstone; this sequence may be as much as 30 m thick. The arenaceous rocks are overlain by as much as 25 m of interbedded chocolate-brown diamictite, mudstone, shale, siltstone, and fine-grained sandstone. The largely lutite sequence is, in turn, abruptly terminated by large-scale, cross-bedded, medium- to coarse-grained sandstone typical of the Tchukardine Formation. On a regional scale, this contact, which is well exposed in cliff sections northeast of Boorabee Hill, is disconformable. A considered possibility is that the basal conglomerate and overlying sandstones may be stratigraphic equivalents of the Mundadjini Formation, whereas the interbedded diamictite–lutite sequence may be equivalent to the Boondawari Formation. However, because the exposures are small and largely restricted to cliff sections, it has not been possible to show the distribution of these two sequences on the accompanying 1:500 000 scale map (*see* sections on Mundadjini and Boondawari Formations).

Figure 62. Large trough cross-beds, curvilinear outcrop — Tchukardine Formation

It should be noted that earlier work, carried out in isolation from the rest of the Savory Basin, assigned rocks, now mapped as Tchukardine Formation to the Coondra Formation, and the underlying, arenite–lutite sequence to the Watch Point Formation (I. R. Williams, 1989). Subsequent mapping of the Savory Basin has shown this correlation to be incorrect. An added complication to the understanding of the stratigraphy along the northern margin of the Savory Basin is the extensive disruption of this unconformity by steep reverse and strike-slip faults.

Tchukardine Formation disconformably overlies Mundadjini and Boondawari Formations in the Wells Range area. It is faulted against rocks of the coeval McFadden Formation, with which it may also be partly a stratigraphic equivalent. The Tchukardine Formation is, in turn, disconformably overlain by Woora Woora Formation in the Woora Woora Hills area.

Description: The Tchukardine Formation is predominantly medium-grained sandstone. It is distinguished

Figure 63. Low-angle, planar cross-beds — Tchukardine Formation

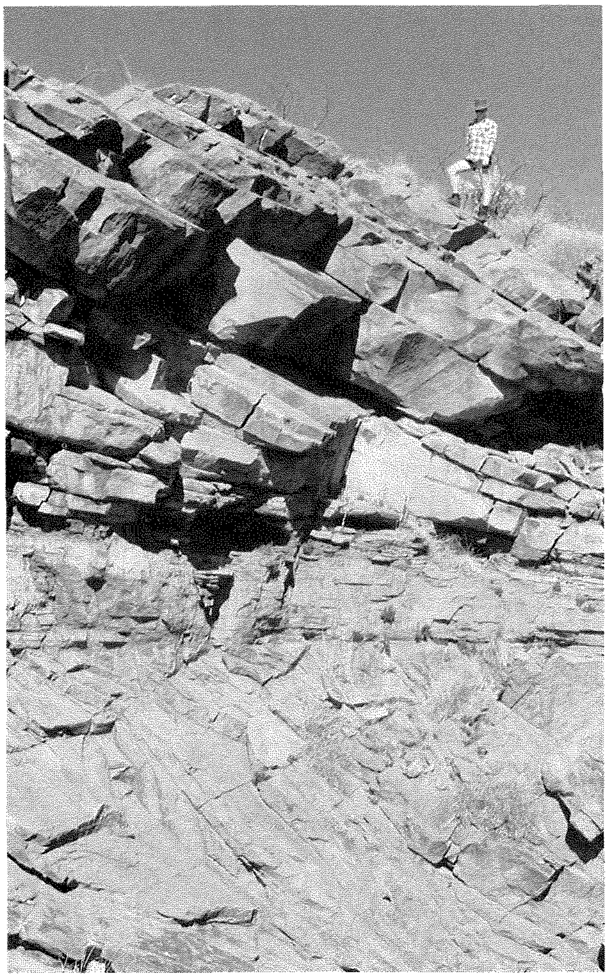

Figure 64. Asymptotic cross-beds, part of large trough cross-beds, eroded tops — Tchukardine Formation

by well-rounded quartz grains, clay cement, and a variable clay matrix. Feldspar and mica are very uncommon, and tourmaline is present in accessory amounts only. Glauconite has been recorded from one locality northwest of the Emu Range. Small fragments of chert, chalcedony, and siltstone, are nearly always present; but true wackes are only a minor component of the formation. Most sandstone occurs as flaggy-to-massive units, ranging from light-brown to dark red-brown. The clay matrix may account for the characteristically friable weathering surface. The rocks are also well jointed and show numerous silicified microfaults.

Fine- and coarse-grained sandstone, thin beds of pebble and cobble conglomerate, thick-bedded purple siltstone, and thin-bedded shales are less prominent components of the formation. Intraclastic sandstone containing siltstone and mudstone pellets occurs in some areas. Some conglomerates contain locally derived sandstone clasts and appear to be penecontemporaneous. Others consist of allogenic, rounded and mature clasts of quartzite, chert, and vein quartz, all set in a sandy matrix. Small upward-fining cycles have been recorded from the conglomerate and sandstone sequences.

As in the adjacent McFadden Formation, very large cross-beds are a feature of the Tchukardine Formation. These take the form of both single and grouped tabular sets and large grouped trough cross-bed sets (Figs 62, 63, 64). The tabular sets may have either planar or asymptotic foresets, but the trough cross-beds are always asymptotic. Tabular cross-beds up to 6 m thick and trough cross-beds up to 10 m thick and 200 m wide have been recorded. In contrast to the adjoining McFadden Formation, heterogeneous epsilon-style cross-beds appear to be absent.

Ripples are infrequent, and are most likely to occur in the fine-grained sandstone units. Current lineations have been seen on some flat-bedded sandstone.

Woora Woora Formation

(new name)

Derivation of name: Woora Woora Hills (lat. 22°40'42"S, long. 121°28'09"E), BALFOUR DOWNS.

Type area: Woora Woora Hills.

Lithology: Medium-grained ferruginous sandstone; lesser amounts of fine- and coarse-grained sandstone; lithic wacke; quartz wacke; siltstone.

Thickness: The thickness, estimated from airphotos, is at least 400 m, but the original thickness is unknown because the upper surface has been eroded.

Stratigraphic relationships: The Woora Woora Formation is restricted to a small area around the Woora Woora Hills in the northern part of the Savory Basin (Fig. 65) where it disconformably overlies Mundadjini and Tchukardine Formations. It is possibly a western outlier of the upper part of the McFadden Formation, which it closely resembles in lithological content. The distinctive rocks of this sequence were recognized in earlier mapping but, at that time, were not assigned to a separate formation (I. R. Williams, 1989).

Description: The sandstone of the Woora Woora Formation is distinguished by the high (up to 15%) content of clay matrix, and the prevalent, ferruginous, weathered surface. It weathers to a distinctive, white-flecked, purple to purple-brown. The sandstone is mostly medium-grained, but there are subordinate fine- and coarse-grained beds. Bedding ranges from thin, flaggy units, to thick, massive units. In addition to the abundant clay just mentioned, lithic clasts, and grains, such as chert, siltstone, and clay fragments (possibly after feldspar), may constitute another 15% of the rock. These sandstones are best described as lithic and quartz wackes. Feldspar and mica are scarce, and tourmaline is an accessory.

Interbeds of purple-red to greyish-white, massive siltstone, micaceous siltstone, and silty sandstone, are common in some areas. Many of the latter carry siltstone intraclasts.

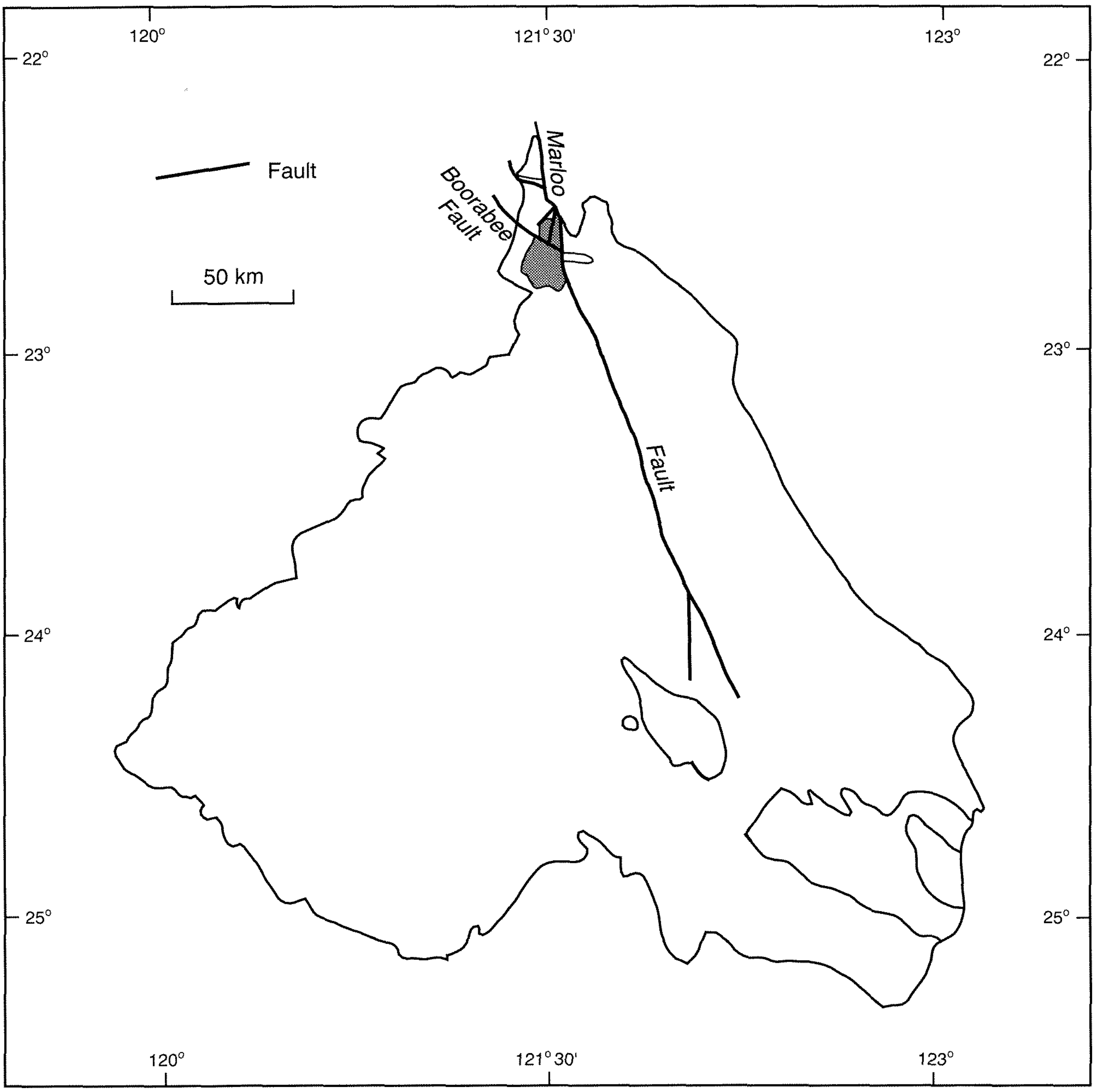

Figure 65. Distribution of the Woora Woora Formation

Large sets of tabular cross-bed are common. They may be planar or asymptotic and may range up to 5 m thick. Some trough cross-beds have also been recorded. Many of the large cross-beds are heterogeneous in grain size and show graded bedding within individual flaggy foresets, a feature previously described from the McFadden Formation. Current lineations occur on interbedded, flat-bedded units. Ripple marks appear to be absent.

Durba Sandstone

(Williams and Williams, 1980)

Derivation of name: Durba Hills (lat. 23°47'25"S, long. 122°28'01"E), GUNANYA.

Type area: Type areas include the northern end of the Durba Hills (lat. 23°43'S, long. 122°29'30"E) (Williams and Williams, 1980), the gorge upstream from Durba Springs (lat. 23°45'31"S, long. 122°30'57"E), and Mudjon Gorge at the western end of the Calvert Range (lat. 23°57'14"S, long. 122°43'41"E).

Lithology: Basal, matrix-supported pebble and cobble conglomerate; medium- to coarse-grained sandstone containing scattered pebbles and cobbles; medium- to fine-grained sandstone.

Thickness: Estimated thickness from airphotos is at least 100 m. However, the original thickness is unknown due to erosion of the upper surface.

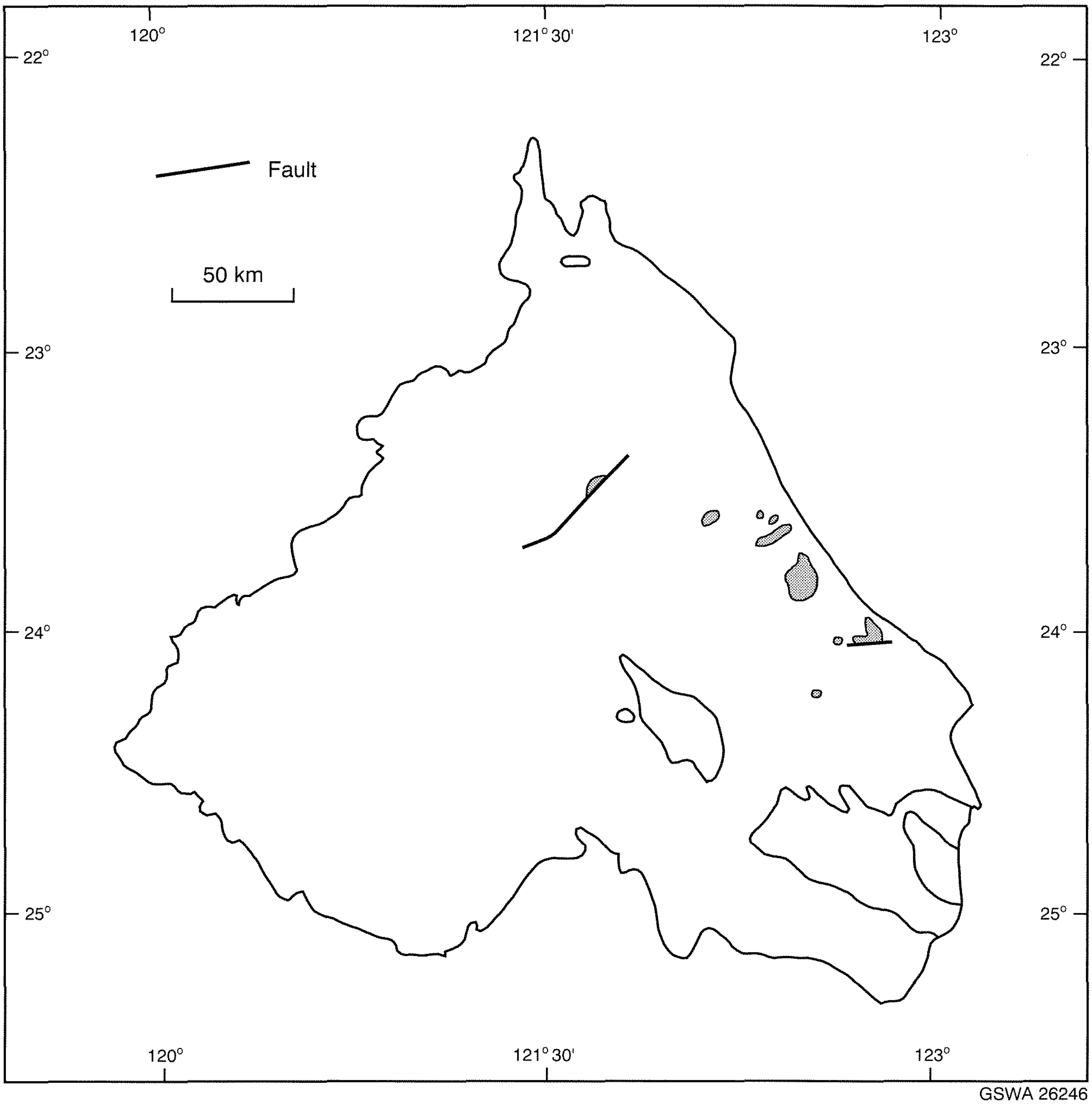

Figure 66. Distribution of the Durba Sandstone

Stratigraphic relationships: The Durba Sandstone is exposed in a series of small, widely separated outcrops that are roughly parallel to the northeast margin of the Savory Basin (Fig. 66). At Budgie Springs in the northwest, it unconformably overlies gently folded Boondawari Formation; southeastwards, in the Diebil and Durba Hills, it unconformably overlies eroded McFadden Formation; and in the Calvert Range, it rests, largely disconformably, on McFadden Formation (Figs 67, 68).

Description: The base of the Durba Sandstone is marked by discontinuous, matrix-supported, poorly sorted polymictic conglomerate up to 3 m thick (Fig. 69). This conglomerate is overlain by thick-bedded, medium- to coarse-grained sandstone that carries scattered pebbles and cobbles. This sandstone, in turn, passes upwards into medium- and fine-grained sandstone.

The conglomerate comprises mature, rounded and discoidal pebbles, cobbles, and small boulders, set in a sandy matrix. Where flattened cobbles occur in thick units, an imbricate structure has been observed. The clasts, which appear to be allogenic, are mainly quartzite, sandstone, vein quartz, coloured and banded chert, and occasional red jasper. The conglomerate is thickest where it fills erosion channels in the underlying rocks. In places, the conglomerate grades upwards into coarse-grained sandstone that features single-pebble layers as well as very sparsely scattered pebbles and cobbles.

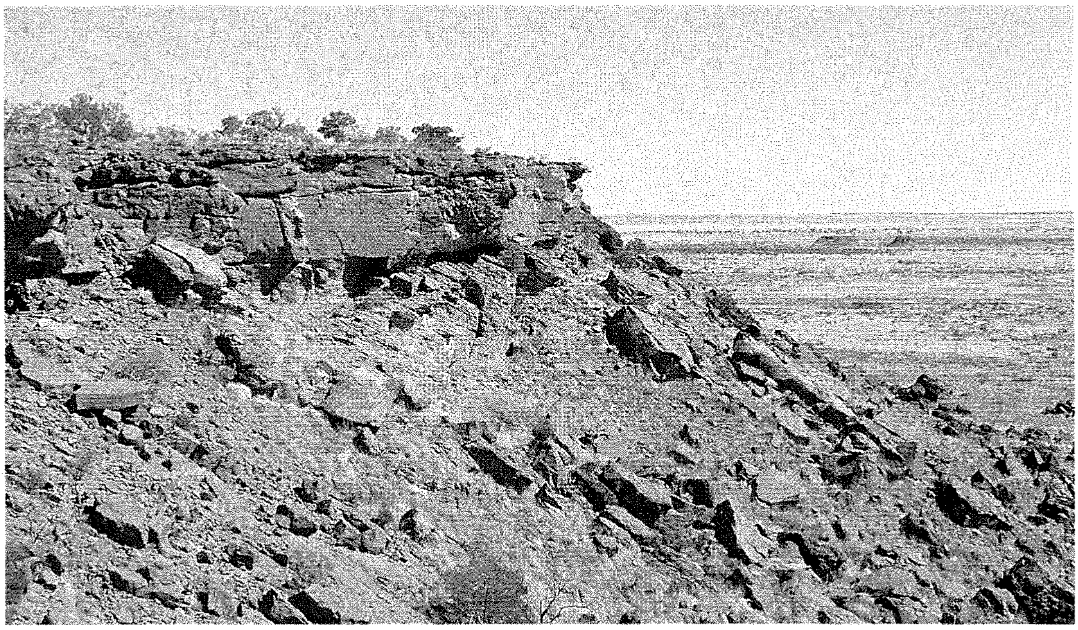

Figure 67. Flat-lying Durba Sandstone unconformably overlying northwesterly dipping McFadden Formation, Durba Hills

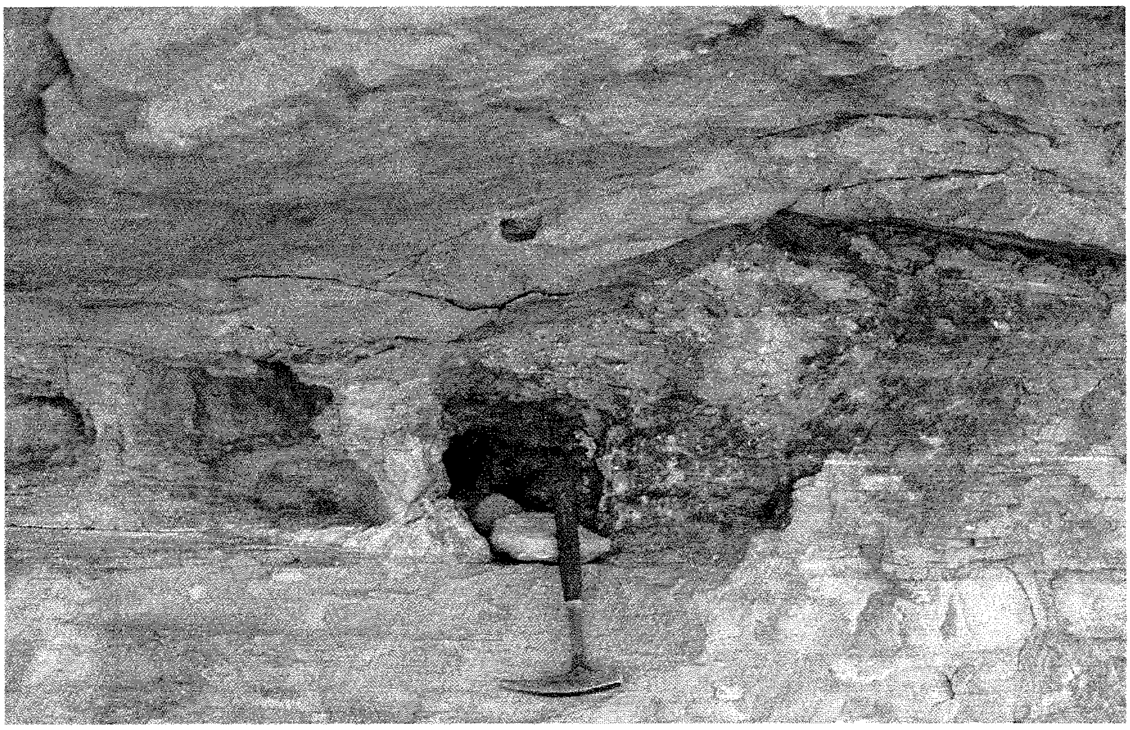

Figure 68. Cobbles of sandstone in Durba Sandstone disconformably overlying eroded, flat-lying McFadden Formation, Calvert Range

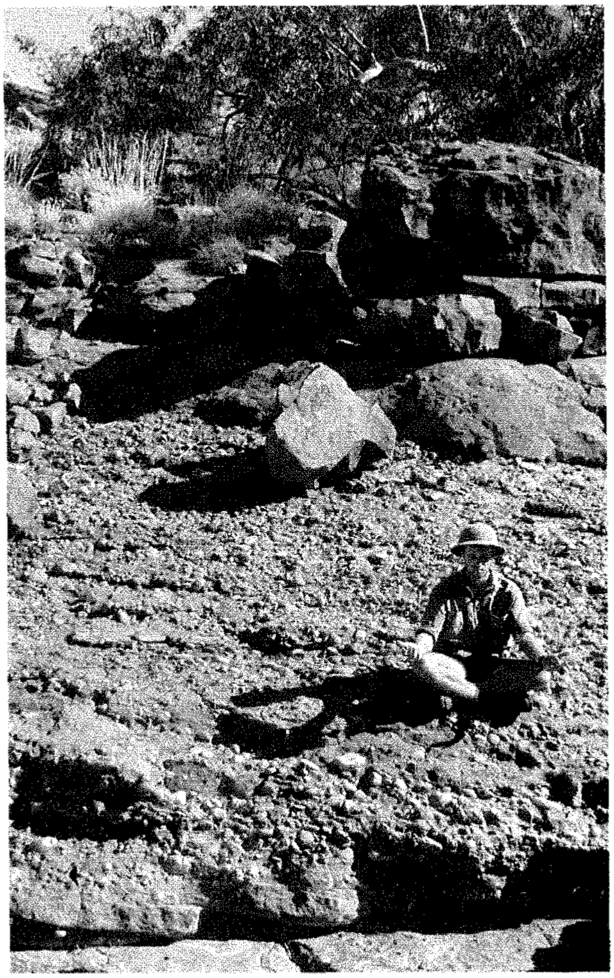

Figure 69. Channel conglomerate—Durba Sandstone, Calvert Range

The generally clean, well-sorted quartz arenite contains accessory amounts of tourmaline and zircon as well as small amounts of detrital feldspar and chert. Near the base of the formation, the sandstone is thick bedded and medium to coarse grained. Higher in the sequence, as may be seen in the Calvert Range exposures, the sandstone becomes medium to fine grained, more flaggy, and has a larger amount of clay matrix. Occasional thin, white claystone interbeds appear in the sandstone, particularly towards the base of the formation.

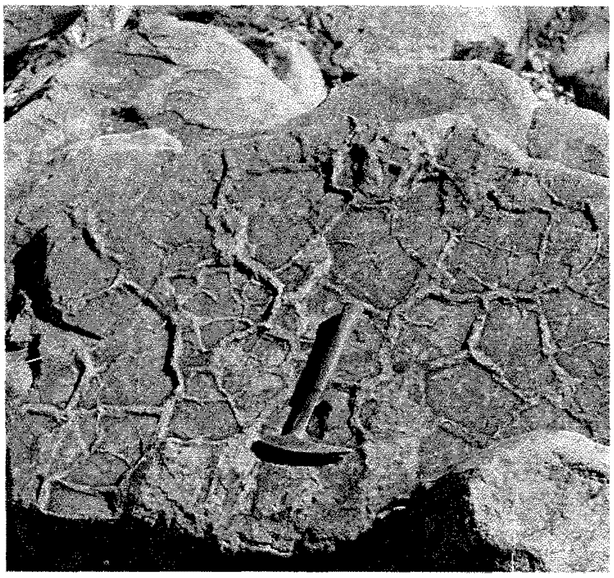

Figure 70. Mud cracks in upper part of Durba Sandstone, Calvert Range

Small, or occasionally large, tabular and trough cross-bed sets are present in the medium- and coarse-grained sandstone. The fine- to medium-grained sandstone exhibits asymmetric ripple marks, interference and ladderback ripples, rib and furrow structures, and mud cracks (Fig. 70). Overall, the Durba Sandstone appears to be a large upward-fining sequence.

Chapter 4

Igneous rocks

Introduction

Although igneous rocks are widely scattered throughout most of the Savory Basin, they probably occupy less than 2% of the area. The bulk of the igneous material is represented by fine- to coarse-grained mafic rock of basaltic composition. It occurs in sills, dykes, and irregularly shaped intrusive bodies.

Extrusive rocks

The Savory Basin appears to be devoid of unequivocally extrusive rocks, either mafic or felsic. Brakel and Leech (1980) record a verbal communication with field geologists of the Broken Hill Propriety Co., who claimed that some sandstones in the McFadden Formation contained embayed, corroded, and broken quartz grains with distinct, scalloped edges, reminiscent of air-fall tuff. They envisaged a distant volcanic source for this material. This observation has not been confirmed by subsequent field work. However, unusual concentrations of clay in some otherwise clean, well-sorted, quartz arenite in the McFadden, Tchukardine, and Woora Woora Formations, may be evidence for the addition of a very fine-grained tuff component. Hence, the possibility of a minor tuff component in some sandstones cannot be entirely discounted.

Leech and Brakel (1980) recorded the occurrence of an unusual, altered, partly trachytic-textured, partly amygdaloidal, basalt on BULLEN (lat. 24°12'20"S, long. 120°04'30"E), which they interpreted as a flow. An inspection of this area during the current survey could not confirm this conclusion. However, a thin dyke of material like that described was found to intrude sandstone in the same area. There are similar occurrences of amygdaloidal basalt in the Robertson Range to the north; but these can be seen to be near-surface sills and dykes. The possibility that some magma may have reached the surface cannot be discounted. However, all basaltic rocks examined during the current survey appear to be intrusive.

Intrusive rocks

Scattered sills, dykes, and irregular bodies of fine- to coarse-grained mafic rocks are widely distributed throughout the northwestern, southern, and central parts of the basin. In contrast, the northeastern margin is free of large intrusions. The only igneous rocks identified in this area were thin (less than 5 m), discontinuous, mafic dykes.

Three broad categories of mafic intrusion were recognized in the Savory Basin. These are near-surface mafic intrusions; large, coarse-grained dolerite intrusions; and late, mainly north-northeasterly trending, mafic dykes (Fig. 71).

Near-surface mafic intrusions

De la Hunty (1969) and Williams and Tyler (1991) gave detailed descriptions of unusual vesicular and amygdaloidal basalt and fine-grained dolerite from sills and dykes in the Robertson Range area along the northwestern margin of the basin. These rocks are particularly well exposed east and south of Coondra Coondra Springs and near the Nyianinya Rock Hole. During the present investigation, similar intrusions were found in an area extending from Tardanya Rock Hole in the northern Robertson Range south to Ilgarari Creek, a distance of 170 km. More than fourteen separate bodies have been identified, all within 30 km of the northwestern margin of the Savory Basin. The intrusions also appear to be confined to the lower 1800 m of the Savory Group, where they intrude Watch Point, Coondra, Glass Spring, Jilyili, and possibly basal Mundadjini Formations (Fig. 72).

The intrusions are red- to purple-weathering, dark-green basalt and fine-grained dolerite that carry, particularly on the tops of sills and at the edges of dykes, patches and bands of vesicles and amygdales. Some basalt contains plagioclase phenocrysts, and some is trachytic textured. All contain plagioclase (mainly labradorite that is generally saussuritized), clinopyroxene, and ubiquitous magnetite. Secondary amphibole partly replaces the clinopyroxene. The amygdales contain crystalline quartz, chalcedonic silica (particularly carnelian-bearing agate), and bright-green chlorite. Much of the amygdaloidal basalt has a large content of clay, a feature suggesting hydrothermal alteration.

Where a contact between basalt and sandstone can be seen, the overlying sandstone is invariably recrystallized, and generally shows prominent columnar (prismatic) jointing up to 8 m high. Good examples of columnar-jointed sandstone overlying amygdaloidal basalt can be seen west of Nyianinya Rock Hole (Fig. 73). The contact-metamorphic effects shown by the sandstones overlying the basalt confirm an intrusive origin for the fine-grained mafic rocks.

Basalt and fine-grained dolerite are also found in the Brassey Range Formation near the southern boundary of the Savory Basin. More than 150 m of basalt and fine-grained dolerite intrude fine-grained sandstone and siltstone 10 km north of Sunday Well. In several areas northeast of Mt Normanhurst, thin dykelets and veins of basalt form anastomosing, joint-controlled, net-vein complexes in the sandstone. The sandstones show contact-metamorphic recrystallization. These basalts and fine-grained dolerites are subophitic and glomeroporphyritic. Although vesicles and amygdales appear to be absent in this area, the mineral assemblage is the same as in the basalt and dolerite lying along the northwest margin of the Savory Basin.

The occurrence of intrusive basalt and fine-grained dolerite along the northwest and southern margins of the Savory Basin, where the oldest formations of the Savory Group are exposed, suggests that these intrusive rocks may have been emplaced penecontemporaneously with, or soon after, the growth of the sedimentary pile. The presence of amygdales and vesicles, and the generally fine-grained nature of these rocks, supports low-pressure, rapid-cooling, and near-surface emplacement. As mentioned earlier, such near-surface emplacement might also be expected to produce some extrusive rocks. However, none could be verified during the present survey.

There is a close spatial relationship between the distribution of these fine-grained intrusive rocks and a zone of extensive faulting that roughly parallels the northwest margin of the Savory Basin. Most of these faults, now steep reverse faults, are attributed to an episode of basin inversion which occurred later in the evolution of the basin (Williams and Tyler, 1991).

The episode of basin inversion is thought to have reactivated pre-existing (extensional) normal (?growth) faults, the product of an earlier regime, which initiated and controlled deposition during the early stages of basin development. It was during the early tensional stage of development, when emplacement of basic magma is not uncommon (Kingston et al., 1983), that the basalt and dolerite are believed to have been emplaced. A similar genesis is envisaged for basalts and fine-grained dolerites that occur on the southern margin of the Savory Basin.

The age of the fine-grained mafic intrusions is not known, but they predate the deposition of the Boondawari Formation (670 Ma).

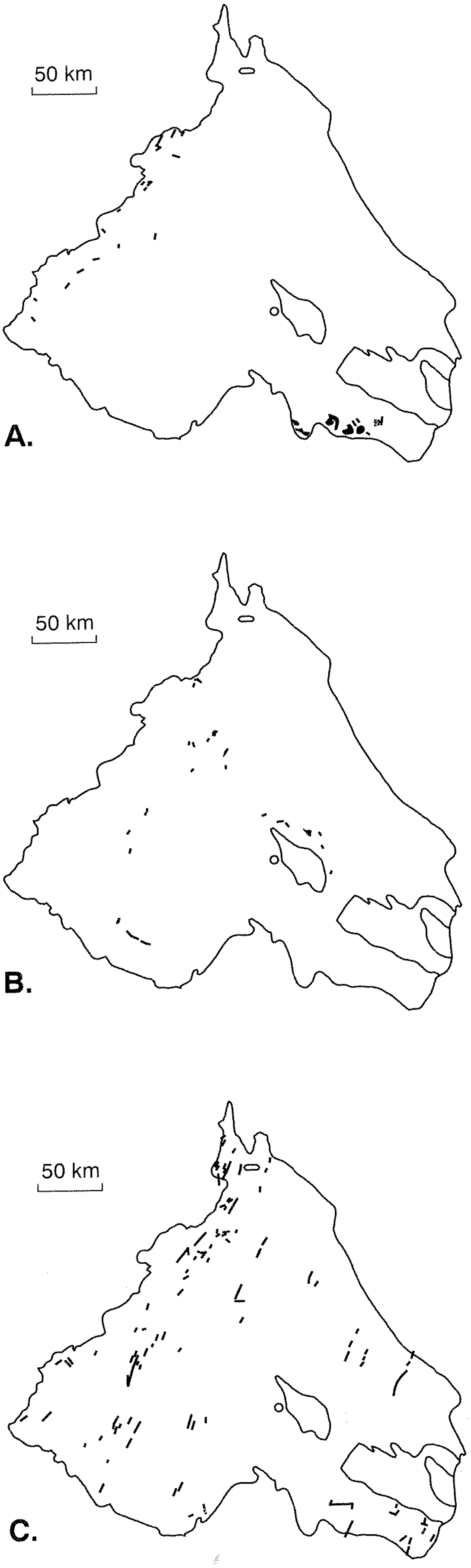

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Figure 71. Distribution of mafic rock outcrop in Savory Basin.
A — near surface.
B — large dolerite intrusions.
C — mafic dyke suite.

Figure 72. Dolerite and basalt sills (scree area) — Glass Spring Formation

Large dolerite intrusions

Widely scattered, large to very large, medium- to coarse-grained dolerite sills and irregular bodies occur in the central, western, and southwestern parts of the Savory Basin, where they intrude the Jilyili, Spearhole, Mundadjini and Boondawari Formations, and the upper parts of the Coolbro Formation.

A good example is a sill, over 30 km long and up to 200 m thick, that intrudes Jilyili Formation in the Jilyili Hills area. A second, poorly exposed, but larger body intrudes Mundadjini Formation west and southwest of Canning Stock Route Well No. 15. On the basis of scattered outcrops, this body appears to be at least 28 km long and as much as 800 m thick.

The best exposed of the irregularly shaped and steeply dipping dolerite bodies is the Boondawari Dolerite. This body, 11 km long and up to 1500 m wide, intrudes the Boondawari Formation near Boondawari Soak (Williams and Tyler, 1991). Other similar intrusions are found in Mundadjini Formation near Akubra Hill and in Spearhole Formation in the Dean Hills.

The dolerite is a medium- to coarse-grained, grey-green rock with ophitic to subophitic textures. It consists mainly of labradorite, clinopyroxene, and accessory, coarse-grained (sometimes skeletal) magnetite. Variable, but generally minor amounts of primary orthopyroxene, brown hornblende, quartz, and occasional olivine, have been noted. The plagioclase is partly saussuritized, and the pyroxenes are partly replaced by secondary green

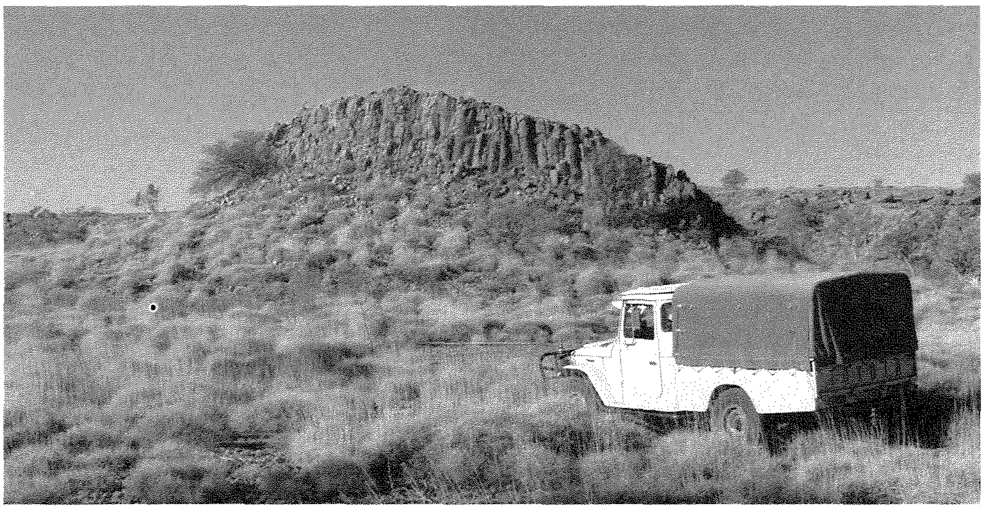

Figure 73. Prismatically jointed Coondra Sandstone overlying amygdaloidal basalt sill near Nyianinya Rock Hole, Robertson Range

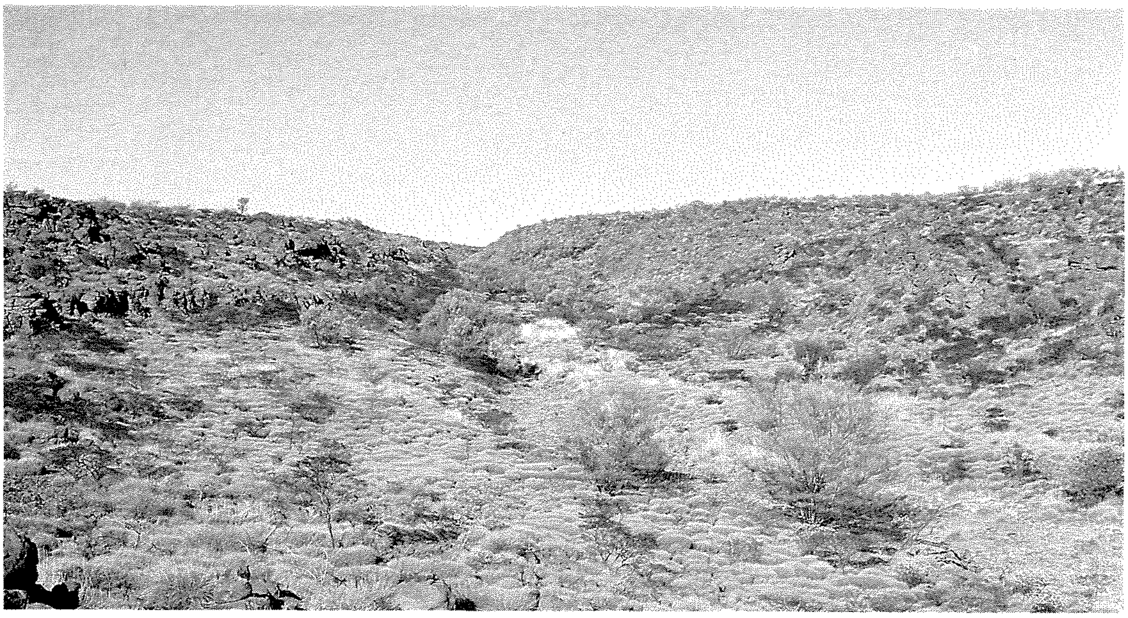

Figure 74. Linear valley occupied by northeasterly trending weathered mafic dykes — Coondra Formation

amphiboles. Minor amounts of biotite, chlorite, and serpentine after olivine, have also been recorded. Pyrite and rutile are sometimes present.

The dolerite appears to be tholeiitic, but has an unusual feature — the widespread occurrence of irregularly shaped, quartz-rich, granophyric patches. It is justifiable, in many cases, to describe these rocks as granophyric quartz dolerite. The co-existence of quartz and granophyric patches with olivine suggests that the former may be due to partial assimilation of quartz-rich wallrock during intrusion of the basic magma into the thick sedimentary pile.

The Boondawari Dolerite is intruded by small cross-cutting leucocratic dykes of various compositions. Some consist of albitic feldspar, minor amounts of green amphibole, accessory magnetite and sphere, and an isotopic mineral with the composition of andradite garnet; others consist of a more calcic plagioclase, dark-brown amphibole, quartz (10%), and prominent magnetite. The latter rock could be described as a microdiorite. Such dykes have only been found in the Boondawari Dolerite.

All the dolerite is partly altered, but the occurrence of the dolerite in an unmetamorphosed sedimentary sequence suggests that the alteration is deuteric rather than metamorphic. Hornfelsic spotting in shale and mudstone, a result of contact metamorphism, and recrystallization of sandstone, occur adjacent to the large dolerite intrusions.

Chemical analyses of fifteen basalts and dolerites from the Savory Basin are given in Appendix 2.

A preliminary Rb–Sr isotopic age has been obtained from samples collected from the Boondawari Dolerite. A four-point isochron gave an age of approximately 640 Ma (J. de Laeter, 1991, pers. comm., initial ratio of 0.7074). The young age agrees with the field observation that the Boondawari Dolerite intrudes the glacigenic Boondawari Formation which, it is postulated, falls in the age range (c. 670 Ma) of the Late Proterozoic glacial event.

Mafic dyke suite

A suite of, generally, northerly to northeasterly trending mafic dykes crops out throughout the Savory Basin. However, a few northwesterly trending dykes probably also belong to this suite. These dykes have been assigned to the d_7 suite of the southeastern part of the Pilbara region (Williams and Tyler, 1991).

Individual dykes range up to 30 km long and 10 m wide. Most are smaller, but discontinuous lines of outcropping dykes can be traced along strike for over 100 km. Although occurring throughout the Savory Basin, the dykes tend to form clusters, most of which lie near the northwestern margin of the Savory Basin, between the Dean Hills and Woora Woora Hills. Similar dykes have been found in the Bangemall Basin to the west, the Nabberu Basin to the south, and the Paterson Orogen to the north. These dykes are unconformably overlain by Permian sedimentary rocks of the Officer Basin.

Most dykes are strongly kaolinized, but the dolerite textures are locally preserved in the weathered rocks. They generally occupy the floors of narrow linear valleys eroded into the sandstone hills (Fig. 74). Where fresh material can be found, the dykes are fine- to medium-grained dolerite.

The emplacement of these dolerite dykes was the last magmatic event to influence the Savory Basin.

Chapter 5

Sequence stratigraphy and sedimentology

Introduction

The conclusion that the sedimentary rocks occupying the Savory Basin were different in depositional and tectonic history from those in surrounding basins was the outcome of a detailed reappraisal of previously collected data and additional field work conducted between 1983 and 1989 (I. R. Williams, 1987, 1989; Williams and Tyler, 1991). This work culminated in the recognition of a Late Proterozoic basin in an area previously mapped as part of the Middle Proterozoic Bangemall Basin (Muhling and Brakel, 1985). The historical background to this work is discussed in Chapter 1.

Initial sedimentological studies assigned the region to the eastern facies of the Bangemall Basin (Brakel and Muhling, 1976; Williams et al., 1976). Later, Muhling and Brakel (1985) refined their facies subdivision and placed more emphasis on the formal lithostratigraphic subdivision of the basin. The relationship between the stratigraphy of the newly established Savory Group and published facies and lithostratigraphic subdivisions of the Bangemall Basin that were formerly applied to Savory Basin is given in Table 1.

Depositional framework

The thirteen formations that constitute the Savory Group reflect a wide range of depositional environments, provenance, and climatic conditions. A key factor in the interpretation of this stratigraphy has been the recognition of five unconformity-bounded depositional sequences, each consisting of an assemblage of genetically related strata that extend beyond strict formation boundaries. The five depositional sequences and their constituent formations are listed below in descending stratigraphic order:

Table 1. Correlation between Savory Group stratigraphy and published Bangemall Group stratigraphy previously applied to Savory Basin area

Savory Group nomenclature	*Bangemall Group nomenclature (a)*		
Formalized lithostratigraphy	*Formalized lithostratigraphy*	*Facies subdivision*	*Facies*
Watch Point Formation	Parts of the Backdoor Formation and Balfour Shale in the Watch Point–Robertson Range area	Eastern shelf mud facies	Eastern Facies
Glass Spring Formation Jilyili Formation Coondra Formation Spearhole Formation Mundadjini Formation Boondawari Formation	Calyie Sandstone	Eastern sand facies	Eastern Facies
Skates Hills Formation	Skates Hills Formation	Eastern basal facies	Eastern Facies
McFadden Formation Tchukardine Formation Woora Woora Formation Northern exposures of Mundadjini and Boondawari Formations	McFadden Sandstone Northeastern exposures of Calyie Sandstone	Tidal sand-tongue and channel facies	Eastern Facies
Brassey Range Formation	Calyie Sandstone	Southeastern deltaic facies	Southeastern Facies
Durba Sandstone	Durba Sandstone	Fluvial	Not assigned; relationship to Bangemall Group uncertain

(a) Muhling and Brakel, 1985

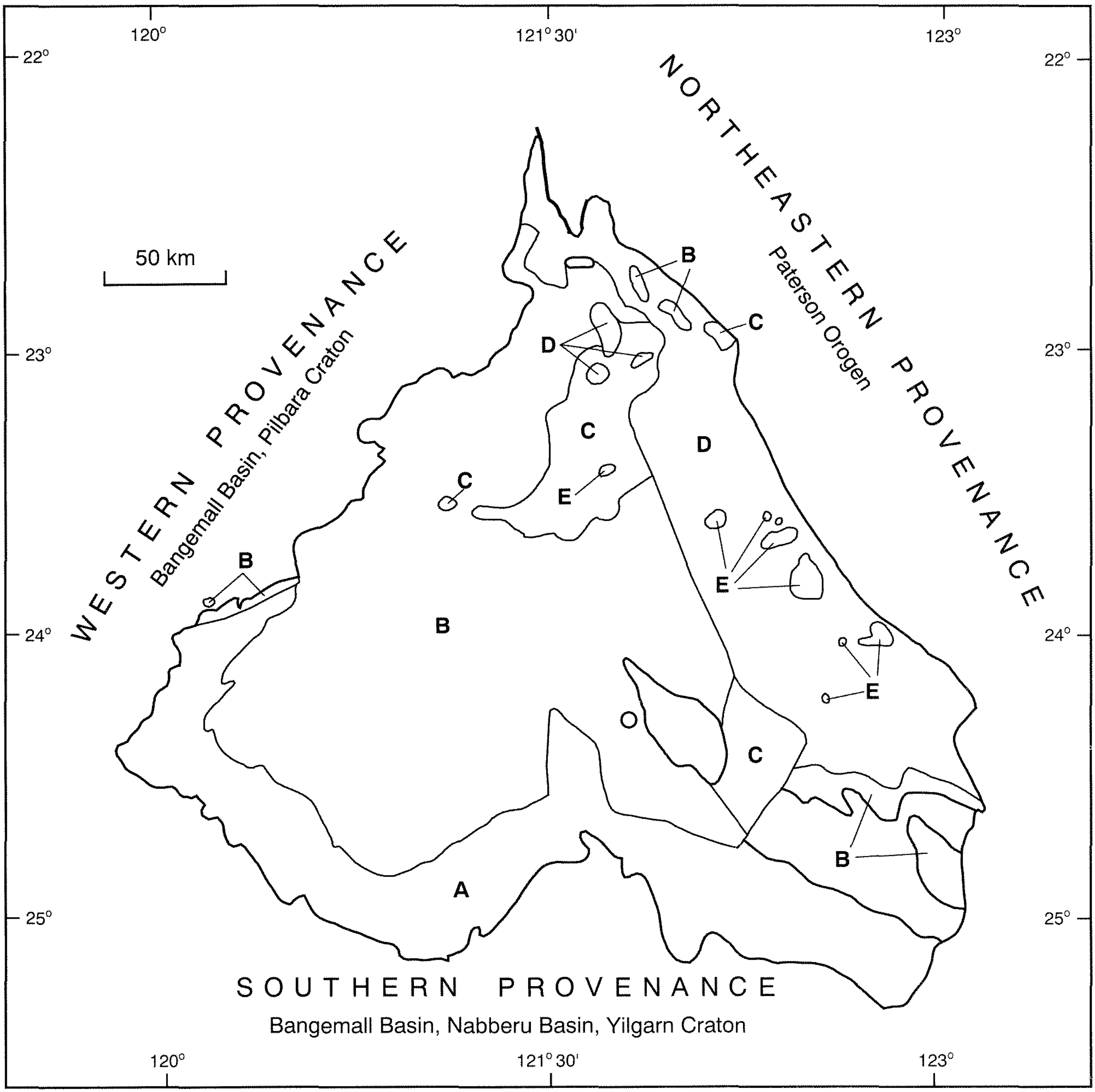

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Figure 75. Regional distribution of Depositional Sequences A to E. (Refer to Figure 76 for key).

Depositional sequence	*Component formations*
E	Durba Sandstone
D	McFadden, Tchukardine, and Woora Woora Formations
C	Boondawari Formation
B	Watch Point, Coondra, Spearhole, Mundadjini, and Skates Hill Formations
A	Glass Spring, Jilyili, and Brassey Range Formations

Palaeocurrent data recorded from Depositional Sequences A, B, D, and E are broadly unidirectional. When these data are combined with details of provenance, it is possible to identify three source areas that sequentially supplied clastic material to the Savory Basin.

Depositional Sequence C, comprising the glacigenic Boondawari Formation, differs from the others in having been derived from widespread source areas lying mainly to the west and south of the basin margins.

The unconformity-bounded sequences listed above form the basis for the stratigraphic interpretation of the Savory Basin. It should be noted, however, that the depositional sequences described here are an order of magnitude thicker than those described from Phanerozoic passive-margin settings (Vail et al., 1977; Posamentier et

PROVENANCE		DEPOSITIONAL SEQUENCE												
		A			B					C	D			E
		Glass Spring Fm.	Jilyili Fm.	Brassey Range Fm.	Watchpoint Fm.	Coondra Fm.	Spearhole Fm.	Mundadjini Fm.	Skates Hills Fm.	Boondawari Fm.	McFadden Fm.	Tchukardine Fm.	Woora Woora Fm.	Durba Sandstone
PATERSON OROGEN	KARARA FORMATION										▨			
	YENEENA GROUP									▨ ?	▨	▨	▨	
	RUDALL COMPLEX									▨ ?	▨	▨	▨	
BANGEMALL BASIN	MANGANESE SUBGROUP				▨	▨	▨	▨		▨				
	COLLIER SUBGROUP						▨	▨		▨				
	KAHRBAN SUBGROUP	▨	▨							▨				▨ ?
	CORNELIA FORMATION	▨	▨				▨	▨	▨	▨				▨
CAPRICORN BASIN	NABBERU BASIN	▨	▨	▨						▨				
	GASCOYNE COMPLEX									▨				
PILBARA CRATON	HAMERSLEY BASIN													
	SYLVANIA INLIER				▨									
	YILGARN CRATON			▨						▨ ?				

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Figure 76. Provenances of sedimentary material

al., 1988). They are broadly comparable in scale to the second-order cycles of Vail et al. (1977) or the megasequences of Hubbard et al. (1985).

It should also be pointed out that, at present, there are no subsurface data available to support specific basin models, and published geophysical information is restricted to regional gravity (Bouguer anomaly) and total magnetic intensity surveys, both produced at 1:250 000 scale by the Bureau of Mineral Resources, Canberra.

The relationship between the major depositional sequences, designated A to E, and their probable provenance is shown in Figure 75. More specific relationships between the source of the detrital material and individual formations are outlined in Figure 76. These depositional sequences form the basis for a more detailed review of the sedimentary environment of the Savory Basin.

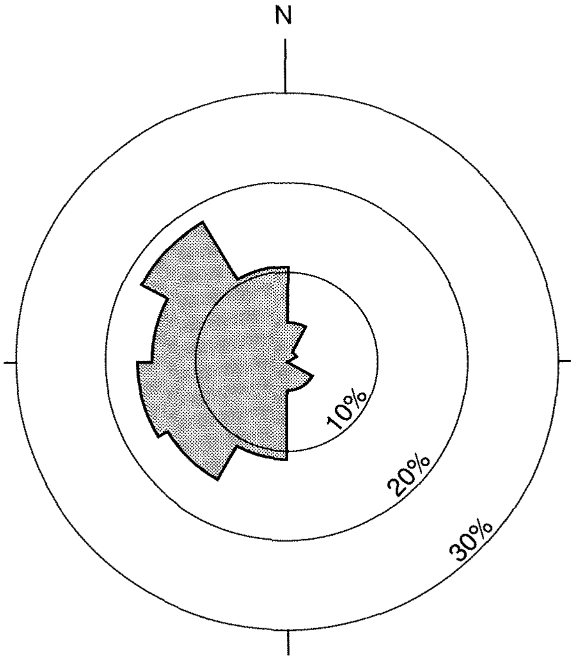
Depositional Sequence A

Depositional Sequence A contains the oldest rocks in the Savory Basin. It is confined to the southern margin of the basin, where it unconformably overlies rocks of the Kahrban and Collier Subgroups of the Bangemall Basin. Depositional Sequence A also unconformably overlies Cornelia Formation (Oldham Inlier), which is correlated with the Collier Subgroup (Bangemall Basin).

Depositional Sequence A contains three defined formations: the Brassey Range Formation in the east; and the Glass Spring and overlying Jilyili Formations in the west. The Brassey Range Formation is separated from the Glass Spring and Jilyili Formations by the northerly trending Kelly Fault, which is downthrown to the west. Glass Spring Formation has been faulted against Watch Point Formation by the Kimberley Well Fault, a dextral transpressive fault. Depositional Sequence A is disconformably overlain by Spearhole Formation (Depositional Sequence B), which overlaps Jilyili Formation at both its northern and eastern ends.

Glass Spring Formation: Although all three formations are arenaceous, they can be distinguished by grain size, bedding characteristics, and compositions of the interbedded lithologies. The basal Glass Spring Formation is characterized by the overall coarse-grained nature of its sandstone. Its pebble and cobble conglomerate is generally matrix supported and contains mature clasts of sandstone, quartzite, vein quartz, and chert, including jasper. Where a thin basal conglomerate is present at the unconformity, the clasts appear to have been derived from the underlying Bangemall Group.

The diagnostic feature of the formation is the widespread cross-bedding that ranges from solitary, large-scale alpha cross-bedding (Allen, 1963) to grouped, tabular and trough cross-bedding. A high-energy environment of deposition is indicated by asymptotic foresets and current lineations. Ripples, where found, are usually current formed.



No of measurements 212

Class interval 30°

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Figure 77. Palaeocurrent data for Glass Spring Formation

Two hundred and twelve palaeocurrent directions were measured from cross-bedded units (tabular cross-beds and axes of trough cross-beds). These were plotted on a rose diagram (Fig. 77). The readings showed a strong (more than 87% of readings) flow to the west; the maximum was around 315° — roughly parallel to the southwest margin of the Savory Basin. Northwest of Glass Spring, the palaeocurrent direction is at right angles to, and directed towards, the faulted northwest margin of the basin as now defined. This suggests that the basin may have extended somewhat further to the northwest. In contrast, palaeocurrent directions measured in the easternmost exposures of the formation in the area southwest of Kelly fault, lie transverse to the margin of the basin. The region south and southeast of the Savory Basin was probably the source of these coarse-grained sediments (Fig. 81).

The generally coarse-grained, poorly sorted, nature of the sandstone, the abundant cross-bedding, and the minimal amount of fine-grained material, point to high-energy conditions during deposition. These features, coupled with the strong unidirectional palaeocurrent measurements recorded for the formation, could be interpreted as indicating a sandy, near-shore, marine shelf with sand bars and a strong long-shore current. Some of the basal units may be braided-stream deposits. The absence of upward-coarsening and upward-fining units suggests that the formation is not deltaic; but the coarse grain size indicates proximity to a primary erosion source. Water depth can be estimated from cross-bedding height (Allen, 1970). Calculations from cross-bedding in the

Glass Spring Formation yield depths of as much as 30 m for the thick (5 m), tabular cross-beds.

The high content of quartz, the low content of feldspar (although the variable amount of clay matrix may have been derived from weathered feldspar), and the frequent occurrence of chert and chalcedony grains, all point to a weathered, sedimentary provenance for these sediments. This interpretation is supported by the kinds of large clasts in the conglomerate; they are exclusively quartz sandstone, quartzite, vein quartz, and variously coloured and banded cherts. The adjacent Bangemall and Nabberu Basins are the most likely source for the detrital material in this part of the Savory Basin.

Jilyili Formation: The conformably overlying Jilyili Formation is a lithologically heterogeneous unit. Although sandstone is still the main rock type, it shows greater variability in grain size than does the Glass Spring Formation; but fine- to medium-grained sediments predominate. Cross-bedded sandstone is overlain by flat-bedded and current- and wave-rippled sandstone. Water depths of as much as 20 m have been estimated from measurements of cross-bedding. Persistent beds of well-sorted and rounded cobbles, which resemble beach deposits, have been found in several localities at or near the base of the formation. Elsewhere in the formation, conglomerate beds appear to be confined to pene-contemporaneous channels. However, the diagnostic feature of the formation, particularly in the Jilyili Hills area, is the upward-fining sequences of conglomerate, sandstone with graded bedding, siltstone, and shale. Synaeresis cracks have been noted in the fine-grained sandstones in this area. The conglomerate clasts, both in clast-supported and in the less well-sorted, matrix-supported types, are of the same composition as those in the underlying Glass Spring Formation: this points to a common provenance. In some areas, siltstone and pebbly mudstone form thick lenses.

Based on measurements of cross-bedding, the Jilyili Formation shows a strong preferred palaeocurrent direction. Over 90% of the readings reveal a strong east to west flow — similar to that in the underlying Glass Spring formation. There is, however, a marginally wider spread of directions and a slightly stronger northwest flow (Fig. 78).

The mixed lithologies of the Jilyili Formation indicate both high- and low-energy environments of deposition. Some areas have been subjected to strong currents, whilst others have been backwaters, marked by quiet conditions. The upward-fining sequences indicate waning currents. Overall, the formation becomes coarser grained towards the east. Matrix-supported boulder conglomerate, interbedded with coarse-grained sandstone, crops out 10 km northwest of Snells Well. The delta system appears to have had its source in the east-southeast.

Brassey Range Formation: The Brassey Range Formation lies east of the Kelly Fault, where it is unconformably overlain by Spearhole Formation. East of the Pumpkin Fault, the formation is confined to what is thought to be a broad palaeovalley between the Oldham Inlier to the north and the southern edge of the Savory Basin (Fig. 81). Both of these areas are underlain by rocks of the Bangemall Group that were exposed during the deposition of the Brassey Range Formation. North of Lake Burnside, the formation is unconformably overlain by sediments of the Officer Basin.

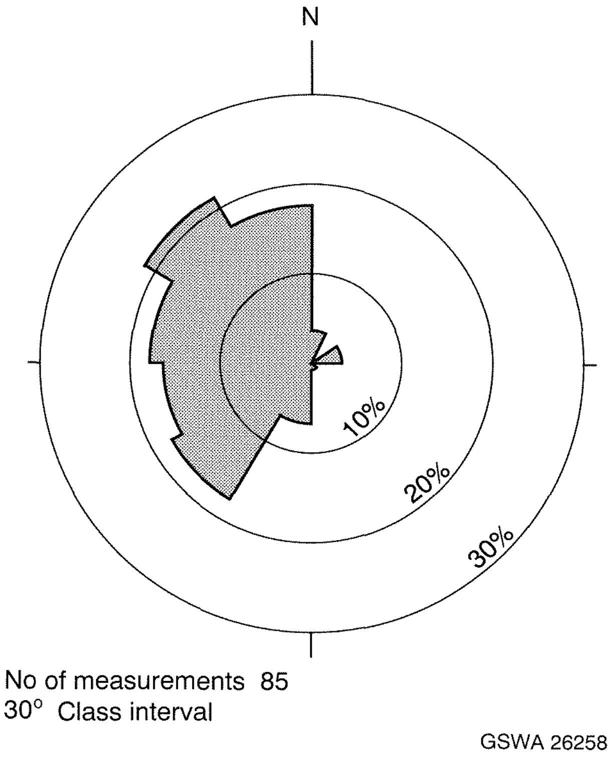

Figure 78. Palaeocurrent data for Jilyili Formation

The Brassey Range Formation is a mixed assemblage of fine- to coarse-grained sandstone, wacke, sandy siltstone, siltstone, and shale. Overall, the assemblage is less mature than the Glass Spring and Jilyili Formations. Fragments of sedimentary rock, feldspar, clay matrix (as much as 20%, possibly after weathered feldspar), and detrital muscovite, are prominent components in much of the sandstone and siltstone. This immaturity is coupled with upward-coarsening cycles (shale, siltstone, sandstone, and intraclastic sandstone) in the Kelly Range area; and upward-fining cycles (graded-bedded sandstone, sandy siltstone, siltstone, and shale) in the area north of Sunday Well. The paucity of rippled bedding, except for minor current ripples; and the frequency of cross-bedding, particularly trough and alpha cross-beds in the sandstone and siltstone; indicate an active environment. The sandstone and siltstone also exhibit slump structures, convolute bedding, and oversteepening of cross-beds. All the above features are commonly found in river-dominated deltaic deposits.

A plot of 61 cross-bedding measurements indicates a strong, unidirectional, northwesterly palaeocurrent flow (Fig. 79). Overall, the Brassey Range Formation has a stronger northerly component than the adjacent Jilyili and Glass Spring Formations, which have a more westerly component. However, the northerly component is the

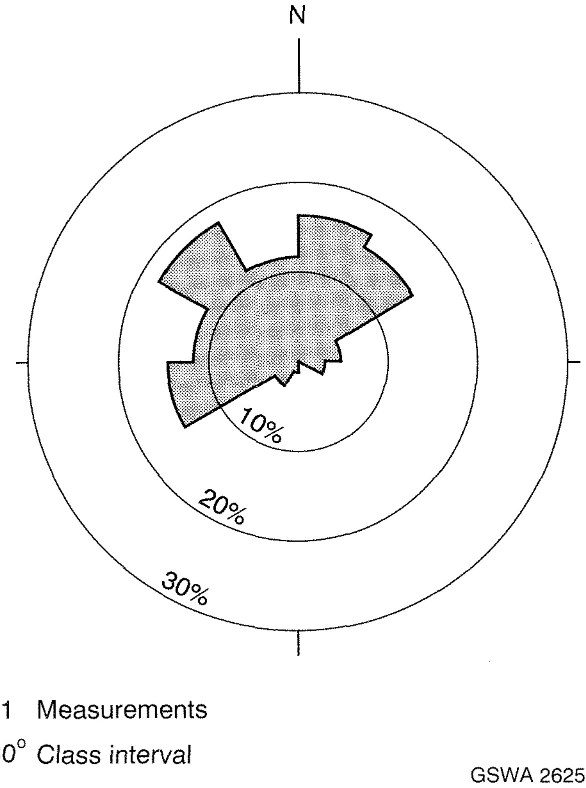

Figure 79. Palaeocurrent data for Brassey Range Formation

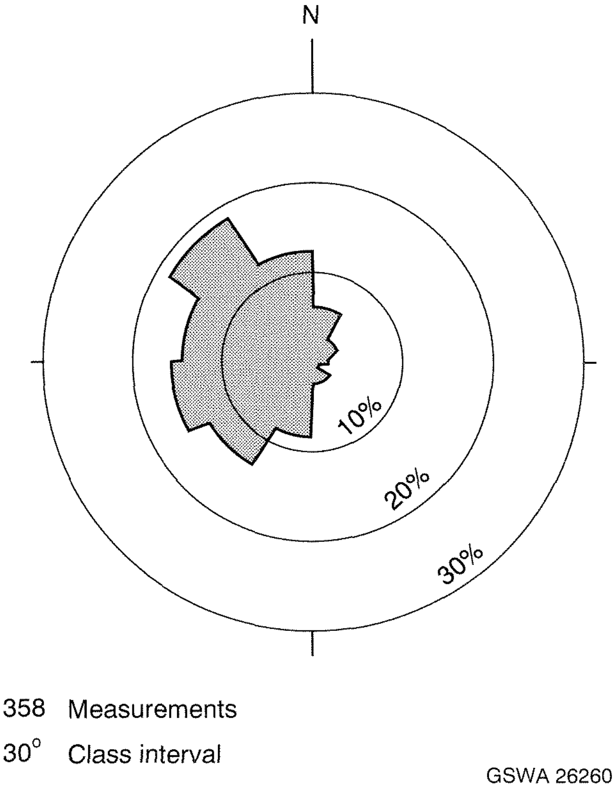

Figure 80. Palaeocurrent data for Depositional Sequence A, southern, southeastern, and eastern provenances

result of a constraint placed on the palaeocurrent direction by the exposed basement in the Oldham Inlier to the northeast and the Weld Spring area to the southwest.

The Brassey Range Formation is interpreted as having been a fluvial–deltaic deposit filling a broad, northwesterly sloping valley. Sediment was transported northwesterly towards the existing main depocentre of the Savory Basin by the river system. The exposed part of the Brassey Range Formation represents the medial to distal parts of this system. The main source of the detrital material lay south and southeast of the Savory Basin in the Bangemall and Nabberu Basins, but there was possibly a small contribution from the Oldham Inlier to the north.

As stated, the formations of Depositional Sequence A feature a general westward and northwestward palaeocurrent direction. The combined palaeocurrent measurements (358) show the predominance of the palaeocurrent direction, which appears to be a combination of fluvial, deltaic, and longshore shallow-shelf currents (Fig. 80). The palaeocurrent directions are schematically shown in Figure 81.

Depositional Sequence B

Depositional Sequence B occupies the central and northwestern parts of the Savory Basin, and makes up a large proportion of the sediments in the basin. The sequence also crops out in a narrow, southeasterly trending zone along the northern sides of the Ward and Oldham Inliers (Fig. 87).

Along the western margin of the basin, the sequence unconformably overlies rocks of the Manganese Subgroup in the Bangemall Basin; in the southeastern part of the basin, it overlies Cornelia Formation (also Bangemall Basin) in the Ward and Oldham Inliers. The unconformity in both areas is extensively faulted. The sequence is faulted against, or rests disconformably (locally unconformably) on rocks of Depositional Sequence A of the Savory Basin. Depositional Sequence B is disconformably, or unconformably, overlain by Boondawari Formation (Depositional Sequence C), and is faulted against or unconformably overlain by Depositional Sequence D (Fig. 21).

Depositional Sequence B comprises five defined formations. These are the Watch Point (oldest), Coondra, and Mundadjini Formations: the Spearhole Formation is coeval with the Coondra Formation; and the Skates Hills Formation is coeval with the Mundadjini Formation.

Watch Point Formation: In more detail, the basal Watch Point Formation unconformably overlies units of the Manganese Subgroup between Watch Point, which lies 10 km northeast of Jigalong, and a location 26 km southwest of Burranbar Well. The poorly exposed unconformity is disrupted in many places by compressional faulting related to the Robertson Fault System (Williams and Tyler, 1991). The southern exposures of the formation are terminated

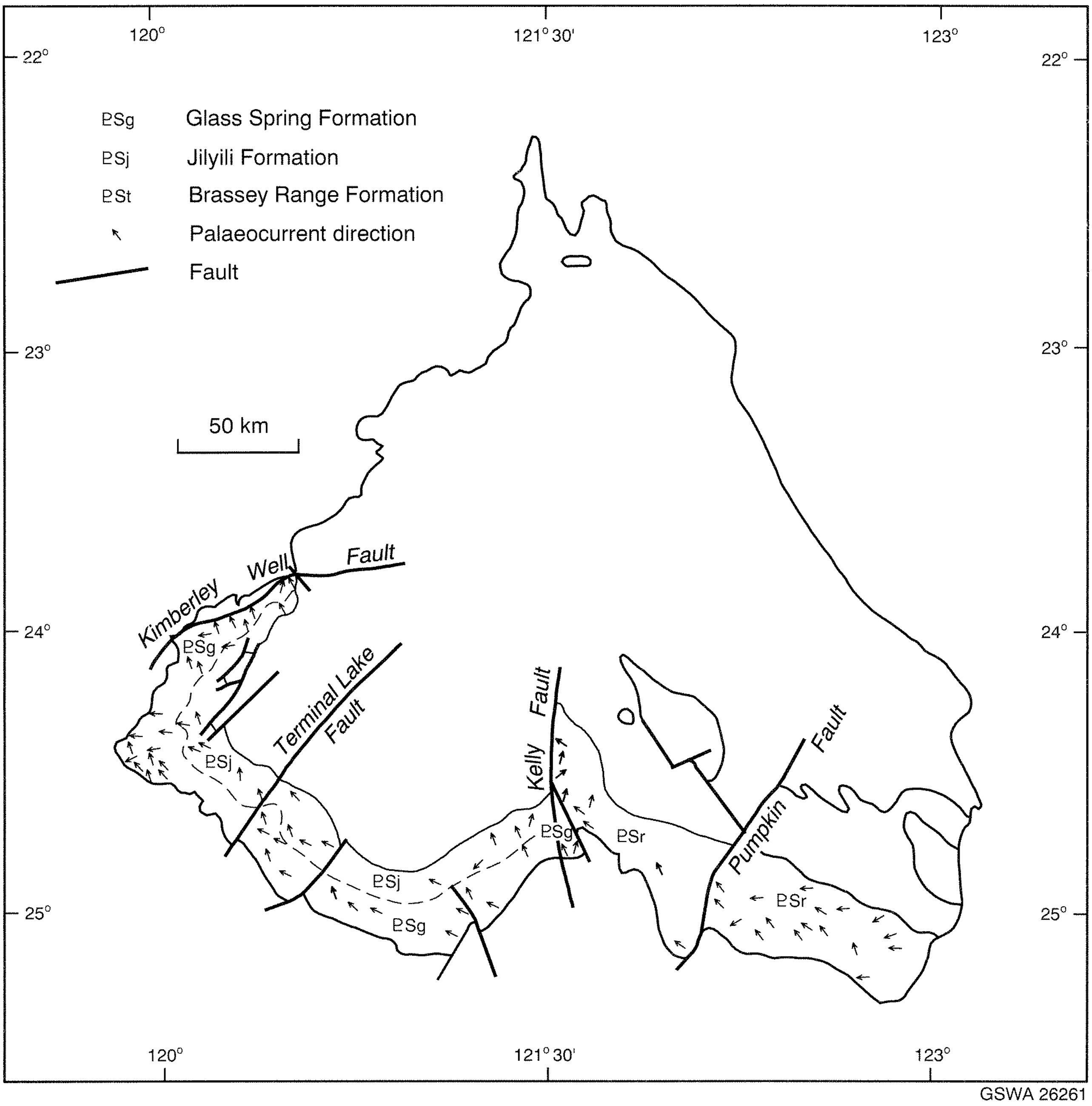

Figure 81. Palaeocurrent directions measured from cross-bedding of Depositional Sequence A, southern, southeastern, and eastern provenances.

against the Glass Spring Formation by the Kimberley Well Fault. North of Watch Point, the Coondra Formation has been thrust over the Watch Point Formation to rest with faulted contact on the rocks of the Manganese Subgroup. The contact between the Coondra Formation and the Watch Point Formation has been disrupted by faulting in several other localities east and southeast of Robertson Homestead. However, a section at Watch Point shows the contact between the Watch Point and Coondra Formations to be within a conformable, upward-coarsening sequence.

This sequence has been interpreted as a rapidly outbuilding, coarse-grained delta, deposited on prodelta muds (Muhling and Brakel, 1985, p. 96). The present survey broadly agrees with this interpretation, but not with the stratigraphic placement of these rocks in the Bangemall Basin (*see* Williams and Tyler, 1991). The Watch Point Formation represents initially quiet, near-shore, marine-shelf conditions that were brought to a close by the encroachment of a rapidly expanding, high-energy, alluvial-fan–delta system.

The mixed, interbedded lithologies, ranging from mudstone through medium to coarse sandstone (including glauconitic sandstone), and the wide range of sedimentary structures, including cross-bedding, ripple marks, various tool marks, and mud cracks, point to tidally influenced shallow-water conditions. A plot of palaeocurrent cross-

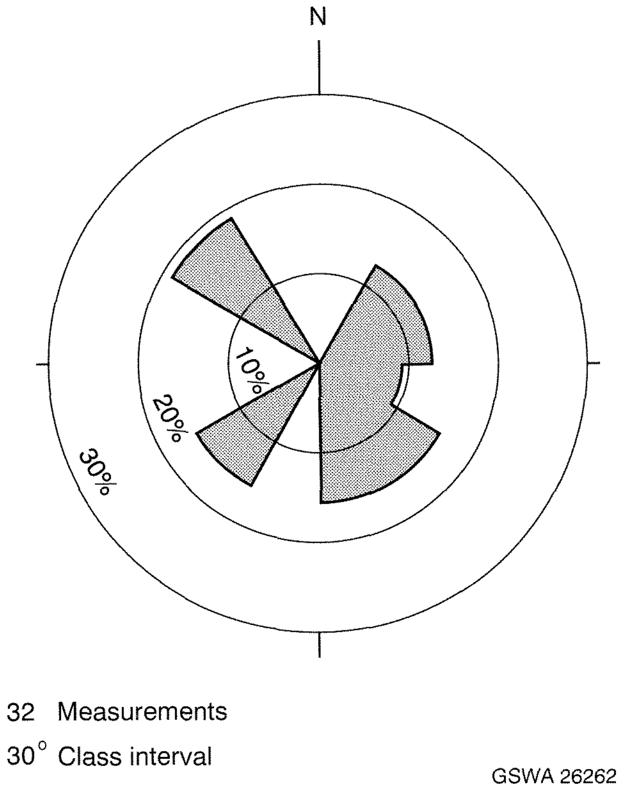

Figure 82. Palaeocurrent data for Watch Point Formation

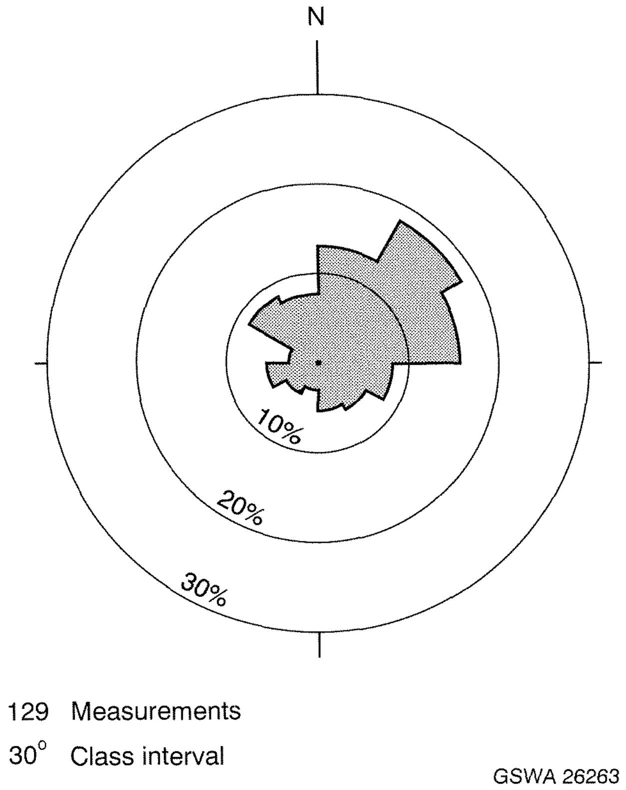

Figure 83. Palaeocurrent data for Coondra Formation

bedding measurements shows contrary current directions (Fig. 82). Measurements of palaeocurrent directions in the lower parts of the formation show a patchy, but generally westerly, flow; whereas those in the upper parts show a broader spread of easterly flowing currents, similar to those found in the overlying Coondra Formation (Fig. 83).

The westerly directed currents are reminiscent of those in Depositional Sequence A. It is tentatively suggested that the Watch Point Formation may have been prodelta shelf deposits, distant from the delta-edge deposits described for the Jilyili Formation of Depositional Sequence A. The juxtaposition of Watch Point Formation against the basal Glass Spring Formation (which lies beneath the Jilyili Formation) is the product of later thrusting. The Glass Spring Formation has been moved northwesterly up and over the Watch Point Formation.

The basal Watch Point Formation can be interpreted as a quiet, marine transgression of a low-relief shoreline in the initial stages of basin development along the western margin of the Savory Basin. This may be coeval with the younger units of Depositional Sequence A. However, this environment was radically changed by the rapid onset of Depositional Sequence B, which was brought about by strong basin subsidence or coastal uplift along the Robertson Fault System. The result was a rapid inflow of coarse-grained detrital material from the west. The Robertson Fault System is interpreted as initially an east-dipping, listric, normal fault system. It is the western, active part of the half-graben structure that marks the northwestern edge of the Blake Fault and Fold Belt (*see* Chapter 6). These faults were reactivated during a later basin inversion episode (Williams and Tyler, 1991).

The Watch Point Formation can also be regarded as a transitional formation bridging Depositional Sequences A and B. It is a palaeogeographic link between a waning south-southeasterly provenance and a newly activated westerly provenance.

Coondra Formation: The Coondra Formation crops out in a small area on the northwest margin of the Savory Basin. It conformably overlies Watch Point Formation at Watch Point; but elsewhere, is considerably disrupted by the Robertson Fault System. North of Watch Point, the formation is in faulted contact with the Manganese Subgroup of the Bangemall Basin. The contact with the overlying Mundadjini Formation ranges, on a regional scale, from conformable to disconformable. In some areas, Mundadjini Formation appears to intertongue with Coondra Formation. This indicates some coeval deposition.

The Coondra Formation is separated from the Spearhole Formation by the Kimberley Well Fault. However, lithologic similarity, stratigraphic position, and palaeocurrent concordance, argue for a coeval development of these two formations. This is thought to record the mutual encroachment of two sandy, fluvial systems, and subsequent modification of the contact zone by faulting.

The Coondra Formation can best be described as a fan delta — a transverse fan prograding directly on to a shallow-marine shelf from an active, fault-controlled coastline. The initial, high-energy, proximal phase is represented by structureless, thick-bedded boulder conglomerate and debris flows that are exposed adjacent to a faulted contact north of Coondra Coondra Springs. As described earlier (*see* Chapter 3), the composition of the larger clasts can be matched to horizons found (*in situ*) west of the Savory Basin in the Manganese Subgroup of the Bangemall Basin. To the east and southeast, these coarse-grained, proximal, fan-delta deposits pass into braided, medial, sandy-stream deposits and, finally, into distal sandy deposits.

Sedimentary structures include frequent trough, and tabular, cross-beds, flat-bedded current lineations, and cobble- and boulder-filled channels cut in sandstone. All these structures point to fluvial deposition. Palaeocurrent directions derived from cross-bedding show a strong northeast (045° maximum) direction (Fig. 83). These data, when combined with clast composition, support a western provenance. The northeasterly flow of the palaeocurrent contrasts strongly with the westward flow for Depositional Sequence A.

Spearhole Formation: Rocks of the Spearhole Formation, a partial correlate of the Coondra Formation, rest disconformably, or with local unconformity, on Glass Spring, Jilyili, or Brassey Range Formation, of Depositional Sequence A. The formation also unconformably overlies Cornelia Formation on the western side of the Ward Inlier.

The Spearhole Formation is a coarse-grained arenaceous and rudaceous sequence containing a minor siltstone and shale component. Conglomerate fills channels scoured in sandstone. Single-pebble and single-cobble layers, interpreted as lag gravels in distributary channels, occur at the bases of sandstone units; and patches of pebbles and small cobbles, and isolated clasts, can be seen in coarse-grained sandstone. Upward-coarsening and upward-fining units become more frequent in the upper parts of the formation. Single, tabular, alpha-style cross-beds and intervening flat-bedded, and current-rippled sandstone, are common. Grouped tabular and trough cross-beds also occur. Low-angle cross-beds in coarse sandstone and pebble and cobble conglomerate have also been recorded; these may indicate migrating channel deposits in a fluvial regime.

At the base of the formation, 9 km south-southwest of the abandoned Moffetah Well, very large cross-beds occur in medium- to coarse-grained sandstone. These are typically asymptotic, and resemble large, shallow scoops, 5–6 m thick and more than 20 m wide. The tops of some large cross-beds show slumping and overturning; this indicates high-energy conditions that have produced fluid drag (Allen, 1964). Deformed cross-bedding is common in fluvial and deltaic environments (Miall 1990, p. 50). This unit appears to be restricted to the southwest margin of the formation. Trough cross-beds in the rest of the formation are smaller and more typical of fluvial deposits.

Despite the wide range of cross-beds, a remarkably unidirectional palaeocurrent is evident from measurements (Fig. 84). This palaeocurrent direction (strong northeast maximum) is remarkably similar to that plotted for the Coondra Formation (Fig. 83). Again, a study of the compositions of large clasts indicates a west-southwest provenance for most of the detrital material. However, it is evident that, locally at least, there has been some contribution from the Cornelia Formation of the Ward Inlier. This can be seen 3 km northeast of No. 13 Well (Canning Stock Route), where an incised palaeochannel is full of large, poorly sorted, matrix-supported cobbles and boulders that have clearly been derived from the underlying Cornelia Formation.

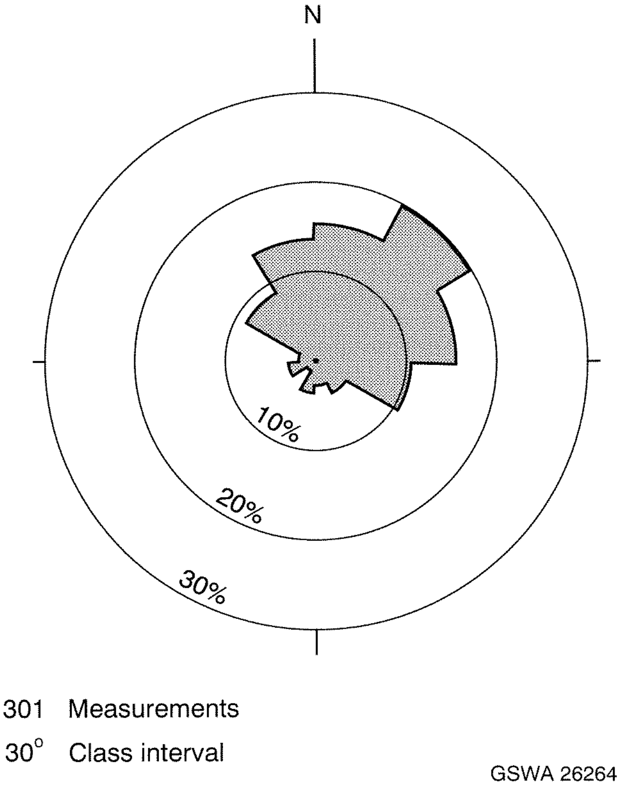

Figure 84. Palaeocurrent data for Spearhole Formation

Overall, the Spearhole Formation appears to be a medial to distal, fluvial, high-energy, braided-stream deposit passing upwards into sandy deltaic deposits at the top of the formation. The streams prograded generally northeastwards across a sandy shelf environment.

It would appear that at least two important river systems flowed into the Savory Basin from the west at this time. The larger, depositing the Spearhole Formation, came from the centre of what is now the Bangemall Basin, and probably entered the basin close to the present-day Yanneri Creek. The other, represented by the Coondra Formation, entered the basin north of Jigalong in the vicinity of Coondra Coondra Spring. The prograding fan delta of the Coondra Formation intersected the braided streams of the Spearhole Formation near the present day Savory Creek. Together, both formations passed eastwards and upwards into the deltaic, tidally influenced Mundadjini Formation.

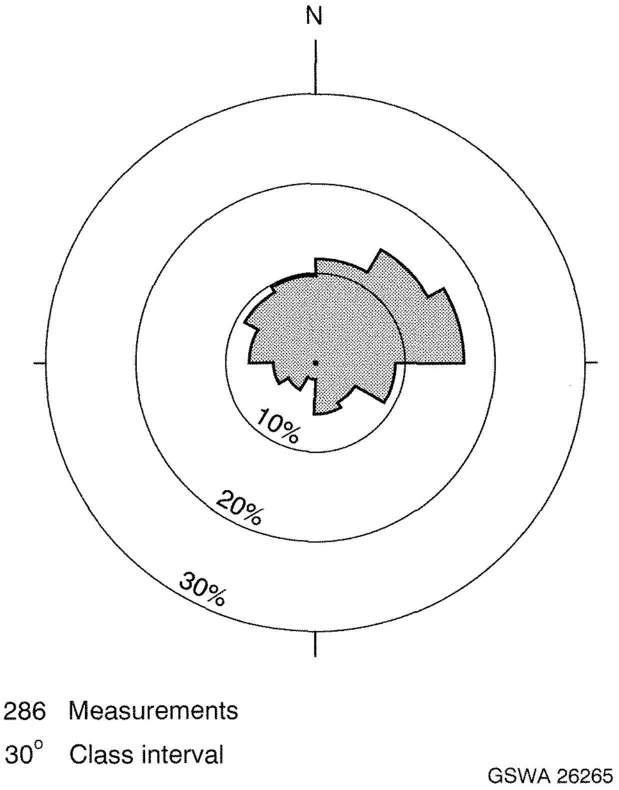

Figure 85. Palaeocurrent data for Mundadjini Formation

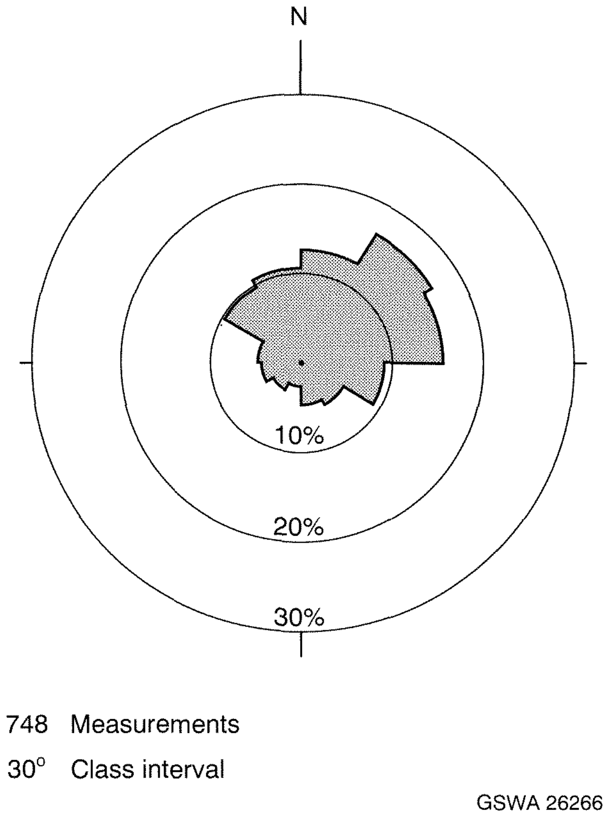

Figure 86. Palaeocurrent data for Depositional Sequence B, western and southwestern provenances

Mundadjini Formation: The Mundadjini Formation, which is widespread in the central and northern parts of the Savory Basin, is correlated with the Skates Hills Formation in the southeast part of the basin. Although the Mundadjini Formation was previously mapped as conformable on the Coondra Formation (Williams and Tyler, 1991), and there is some intertonguing, subsequent mapping in the rest of the Savory Basin has shown that it is probably mostly disconformable on the Coondra and Spearhole Formations. It is certainly unconformable on the Bangemall and Yeneena Groups in the north, and unconformable on the Cornelia Formation in the Ward Inlier to the southeast. The Mundadjini Formation is disconformably and, locally, unconformably overlain by Boondawari, Tchukardine, McFadden, and Woora Woora Formations of the Savory Group. It is also extensively faulted against McFadden Formation. In the southeast, on the Ward Inlier, the Boondawari Formation overlaps the Mundadjini Formation, thus separating it from the coeval Skates Hills Formation.

The Mundadjini Formation is a mixed lithologic association and is interpreted as representing a variety of depositional environments. Coarse-grained sandstone and minor conglomerate are more localized than in the underlying formations. They are interpreted as representing high-energy, fluvial incursions into a predominantly deltaic and marginal shallow-water tidal environment. Repetitive lithologies, typified by the series — mudstone (with or without dolomite), shale, siltstone, and fine- to medium-grained sandstone — form upward-coarsening sequences. These are interpreted as prograding deltaic sequences. Examples occur at Ripple and Mystery Hills. Some upward-fining sequences have been recorded from east of the Boondawari–Savory Creek junction. These are generally sandstone, siltstone, and sandy shale sequences. Some individual beds show normal graded bedding.

Nearshore, subaqueous deposits are represented by interbedded fine-grained sandstone and shale containing synaeresis cracks and small, hummocky cross-stratification. These rocks show bottom structures, such as bounce, skip, and groove casts that can probably be attributed to tidal currents. Shallow-water, tidal deposits include shale, mudstone, and mixed fine- to medium-grained, laminated sandstone which commonly has asymmetrical and symmetrical ripples of small to medium amplitude. Other structures include wave-flattened or bevelled ripples, ladderback, linguoid, and catenary ripples. Subaerial exposure of mud flats and sand banks is indicated by mud cracks, windblown wet-sand structures, and obstacle scours. The interbedded fine- to medium-grained sandstone sometimes carries pseudomorphs of halite and seed gypsum, but massive evaporites were not seen in outcrop. However, it is doubted that evaporites would be preserved at the surface under present weathering conditions. The presence of evaporite minerals suggests that salt pans and, possibly, sabkhas were associated with the delta distributaries and tidal mudflats.

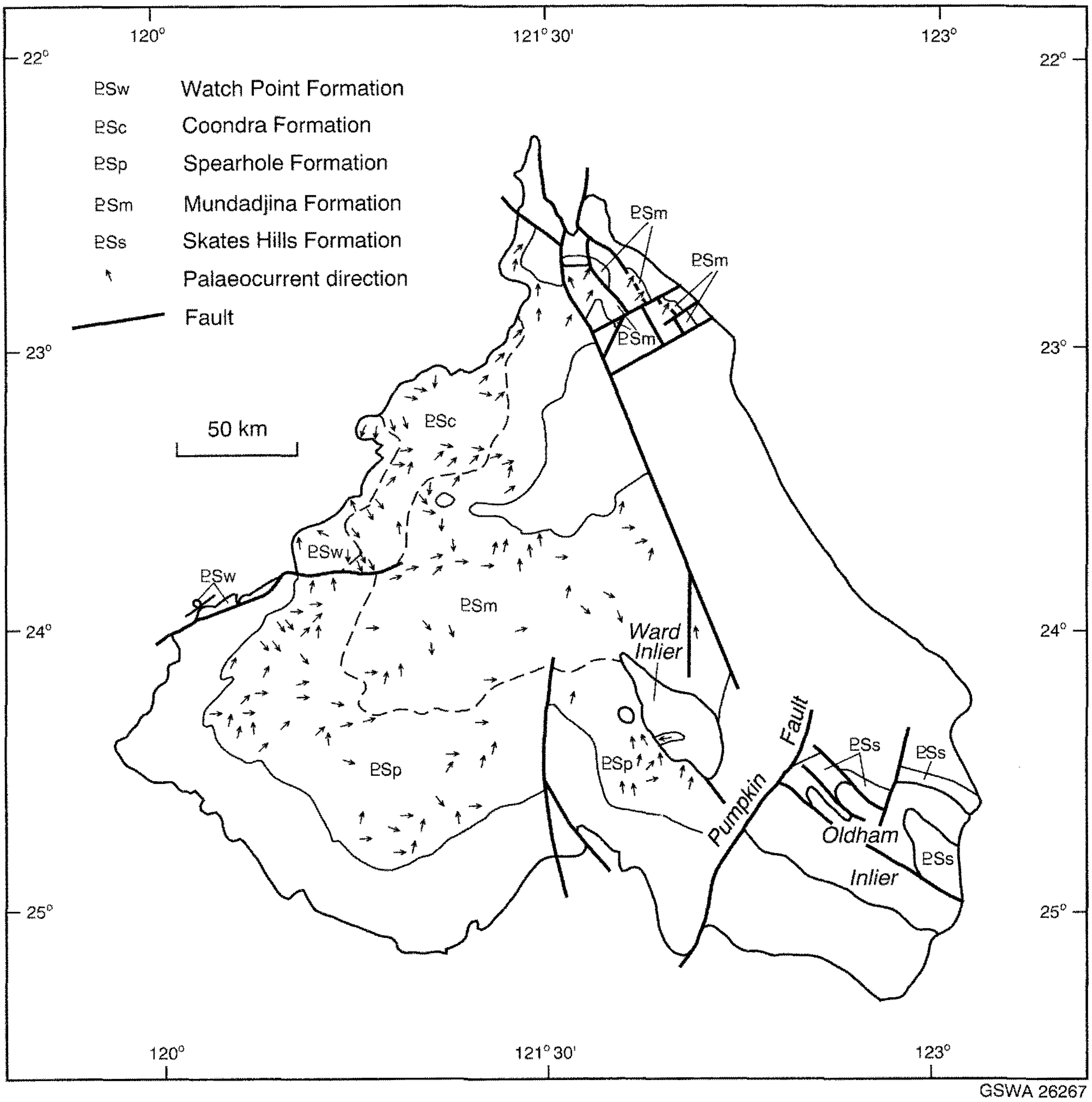

Figure 87. Palaeocurrent directions measured from cross-bedding in Depositional Sequence B, western and southwestern provenances

These features also indicate that the Mundadjini Formation was deposited in an arid or semi-arid environment. Scattered dolomite (some with poorly preserved stromatolites) and calcareous shale are probably lagoonal deposits.

Cross-bedding, together with rippled bedding, is a common sedimentary structure in the Mundadjini Formation. A plot of 286 measurements indicates a general east to northeasterly palaeocurrent direction (Fig. 85). A review of the data showed that most readings were obtained from coarse-grained material deposited in strongly directional, deltaic and fluvial components of the formation, and fewer from the finer-grained, probably tidally influenced, subaqueous rocks adjacent to the delta front. Overall, there is a marginally wider spread of current directions than in the underlying Coondra and Spearhole Formations. However, the obvious palaeogeographical connection between these three formations is supported by the overall similarity of the palaeocurrent direction (Fig. 86). The Coondra, Spearhole, and Mundadjini formations, which comprise the bulk of Depositional Sequence B, represent a strong, prograding fluvial–deltaic system that built out eastwards and northeastwards into the shallow Savory Basin. This system was activated by faulting (Robertson Fault System) along the northwestern margin of the basin. A schematic diagram of the palaeocurrent directions for Depositional Sequence B is given in Figure 87.

Skates Hills Formation: The Skates Hills Formation, which is restricted to the southeastern part of the Savory Basin north and east of the Oldham Inlier, has yielded important biostratigraphic and lithologic data. It is faulted against Boondawari Formation, which separates it from the Mundadjini Formation with which it is tentatively correlated. It is disconformably overlain by McFadden Formation of Depositional Sequence D.

A detailed description of depositional environments for the formation is given in Muhling and Brakel (1985). Further work by Grey (1989) on numerous stromatolite occurrences has established a good biostratigraphic correlation between the Skates Hills Formation and the Loves Creek Member of the Bitter Springs Formation, which occurs in the Amadeus Basin in central Australia. According to Muhling and Brakel (1985), the relatively thin (200 m) Skates Hills Formation reflects a wide range of depositional environments. Patchy basal boulder conglomerate and coarse-grained sandstone are interpreted as alluvial fans shed from a basement high of Cornelia Formation on what is now the Oldham Inlier. Imbrication in the conglomerate beds indicates palaeocurrent from the west-northwest. Overlying fine- to coarse-grained, laminated sandstone with current lineations but no cross-bedding, has been interpreted as beach deposits (Muhling and Brakel, 1985). The main part of the formation comprises dolomite, stromatolitic dolomite, calcareous shale, siltstone, and chert. This succession represents intertidal and subtidal mudflat to near-shore marine deposits. Edgewise dolomitic breccia and intraclastic sandstone suggest strong, possibly tidal, currents at times. Possible subaerial evaporative conditions are indicated by seed-gypsum voids in sandstone, and cauliflower chert in dolomite. The latter were formed by silica replacement of anhydrite nodules (Chown and Elkins, 1974). Black cherts in this sequence are probably surface-silicified mudstones. The dolomite sequence is overlain by pink to red shale, siltstone, and fine- to medium-grained sandstone. These red-bed units, together with the evaporitive minerals, point to semi-arid or arid climatic conditions during deposition of the Skates Hills Formation, conditions similar to those recorded by the Mundadjini Formation.

Cross-bedding is poorly developed in the Skates Hills Formation. Apart from the high-energy alluvial fans at the base of the formation, all other features, including stromatolitic build-up and the wave-rippled fine-grained sandstone, point to fairly quiet, low-energy conditions of deposition.

The correlation of the Skates Hills Formation with the Mundadjini Formation groups it with Depositional Sequence B of the Savory Basin. The formation shows that shallow-marine conditions extended eastwards from the central parts of the basin. The eastern boundary of the formation is unknown because these rocks pass beneath rocks of the Phanerozoic Officer Basin. However, evaporative sequences in the Madley and Woolnough Hills Diapirs (Wells and Kennewell, 1974; Iasky, 1990) suggest that these rocks may be coeval with the Mundadjini and Skates Hills Formation.

The Skates Hills Formation has provided the first good evidence that the Savory Basin may be coeval with deposition and development of at least part of the Amadeus Basin succession of central Australia, the Bitter Springs Formation.

Depositional Sequence C

Boondawari Formation: Depositional Sequence C comprises one lithostratigraphic unit, the glacigenic Boondawari Formation. Basin wide, the Boondawari Formation, which crops out in three separate areas, is bounded by disconformable (locally unconformable) contacts with both underlying and overlying formations. This distribution appears to be the result of a combination of faulting, natural thinning, and erosion of the uppermost beds before deposition of the overlying formations that make up Depositional Sequence D.

The main outcrop is in the north-central part of the basin, between Boondawari Creek and the Emu Range; the second, in the central southeastern part of the basin, lies between the Trainor Hills and the northwest edge of the Oldham Inlier; and the third, a thin diamictite succession, occurs on the northern margin of the basin, between Boorabee Hill and Marloo Marloo Rock Hole. This last outcrop is tentatively correlated with the main exposures of Boondawari Formation (Fig. 49).

The wide variety of rock types in the Boondawari Formation points to a range of depositional environments. A reassessment of the stratigraphy described by Williams and Tyler (1991), together with more recently collected information, allows the recognition of three main depositional environments. From base to top in gradational sequence, these environments were: glacial shallow-marine, distant from ice source; high-energy, sandy shelf; and upward-shoaling, quiet, near-shore, with local build-up of carbonate.

The glacigenic diamictite at the base of the Boondawari Formation is a distinctive chocolate-brown mudstone carrying polymictic ice-modified boulders and cobbles from a variety of sources. The clasts are randomly distributed throughout the diamictite. A review of the kinds of clasts in the diamictite, led to the conclusion that they are all from sources outside the Savory Basin. This is supported by the absence of glaciated pavement on Proterozoic rocks within the Savory Basin. Hence, large boulders (up to 3.5 m), found in diamictite near Boondawari Creek, would have had to have been transported at least 200 km to their present site. When these observations are coupled with the impressive preservation of both soft (sedimentary) and hard (igneous and metamorphic) rocks, the wide variety of rock types, and the morphological characteristics of clasts, the evidence strongly favours a glacigenic origin for the diamictite of the Boondawari Formation. Williams (1987) suggested that the characteristics of the diamictite were best explained by assuming that the clasts were glacial dropstones. Marine conditions are supported by the sporadic occurrence of glauconitic sandstone.

A study of the rock types revealed some unusual lithologies, but very few which could give diagnostic clues as to provenance. Probably the most distinctive clasts to

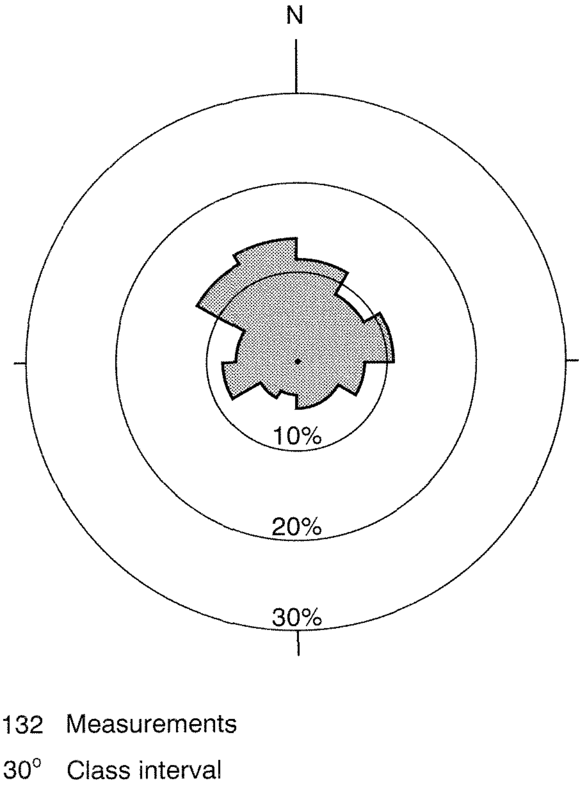

Figure 88. Palaeocurrent data for Boondawari Formation — Depositional Sequence C

be found were oolitic and pisolitic siliceous iron-formation. These cobbles, which closely resemble the unique granular iron-formations of the Frere Formation in the Earaheedy Group of the Nabberu Basin, were found near Boondawari Creek. Another group of distinctive cobbles and boulders are coarse-grained muscovite granite and two-mica monzogranite with S-type affinities. Such rocks are found in the northern Gascoyne Complex, but are not known in the Yilgarn or Pilbara Cratons. The large percentage of sedimentary clasts, such as sandstone, orthoquartzite, siltstone, shale, and mudstone, point to older sedimentary basins as large providers for the material. The sedimentary clasts are more indurated and recrystallized than are similar lithologies found in the Savory Basin. Both the adjacent Bangemall and Nabberu Basins fulfil these requirements. Likewise, the complete absence of clasts of banded iron-formation precludes the Hamersley Basin as a possible provenance.

Cross-bedded sandstones overlying and interbedded with the diamictite of the Boondawari Formation show palaeocurrent-direction maxima ranging from north-northwest to east, with subordinate maxima to the southwest (Fig. 88). Although the palaeocurrent directions measured from cross-bedding in sandstones may not be directly related to iceberg drift, the accumulated evidence indicates that the sources of the clasts lie mainly south and west of the Savory Basin. This is in general agreement with the measured palaeocurrent directions. Orthoquartzite boulders in the diamictite northwest of the Oldham Inlier resemble rocks of the nearby Cornelia Formation. It is possible that the gap between the Ward and Oldham Inliers is partly of glacial origin.

In conclusion, it can be stated that preliminary evidence shows that the Gascoyne Complex, Bangemall Basin, and Nabberu Basin, have been important provenances for the glacial-marine sequence of the Boondawari Formation.

The banded rhythmite, which developed locally in the Boondawari Creek and Emu Range areas, is not considered to be a true, varved deposit. The banding, although well marked, is too irregular, and is more likely the product of low-viscosity, density interflows and underflows generated by slumping (Miall, 1990).

The middle succession of the Boondawari Formation, which consists of coarse- to medium-grained sandstone, wacke, feldspathic sandstone, and conglomerate, also shows the influence of glacial conditions. Cobble and small-boulder dropstones are found scattered through these rocks in a number of localities. The polymictic conglomerate is both matrix and clast supported. It occurs as channel fills or as thin beds at the base of upward-fining, coarse sandstone. The polymictic clasts are similar to those found in the underlying diamictite; this may indicate some possible reworking of the diamictites. The coarse-grained nature of much sandstone, the interbedded wacke and feldspathic sandstone, and the general immaturity of the succession, suggest proximity to a high-energy fan delta. The ample feldspar content of these rocks, when compared to the almost supermature quartz arenites of the underlying sandstone in the Savory Basin, points to a more granitic provenance.

A possible explanation for the change in the sandstone composition may be that the river systems, which earlier supplied the detrital material to the Savory Basin below the Boondawari Formation, only eroded the adjacent Proterozoic sedimentary rocks of the Bangemall and Nabberu Basins. Following the glacial period, which saw icecaps to the south and west, the rejuvenated river systems extended further south and west into crystalline rocks of the Gascoyne Complex and the Yilgarn Craton (which underlie these basins). Such sources would have supplied the much more ample feldspar content of the sandstone and wacke of the middle and upper parts of the Boondawari Formation.

The uppermost units of the Boondawari Formation are only exposed in the Boondawari Creek area. Elsewhere, these rocks have been removed by erosion or are faulted out. The base of the uppermost units is marked by a thin, pink dolomite; this is overlain by brown shale, and a series of upward-coarsening units — from shale, to medium-, to coarse-grained sandstone. Laminated and iron-rich siltstone also occurs in this sequence. The enhanced iron content of these rocks may indicate an arid climate, conditions that are not unusual during glacial periods. Sedimentary structures, such as small-amplitude wave and current ripples, mud cracks, and graded bedding that predominates over cross-bedding in sandstone and siltstone, all point to quiet, shallow-marine, near-shore

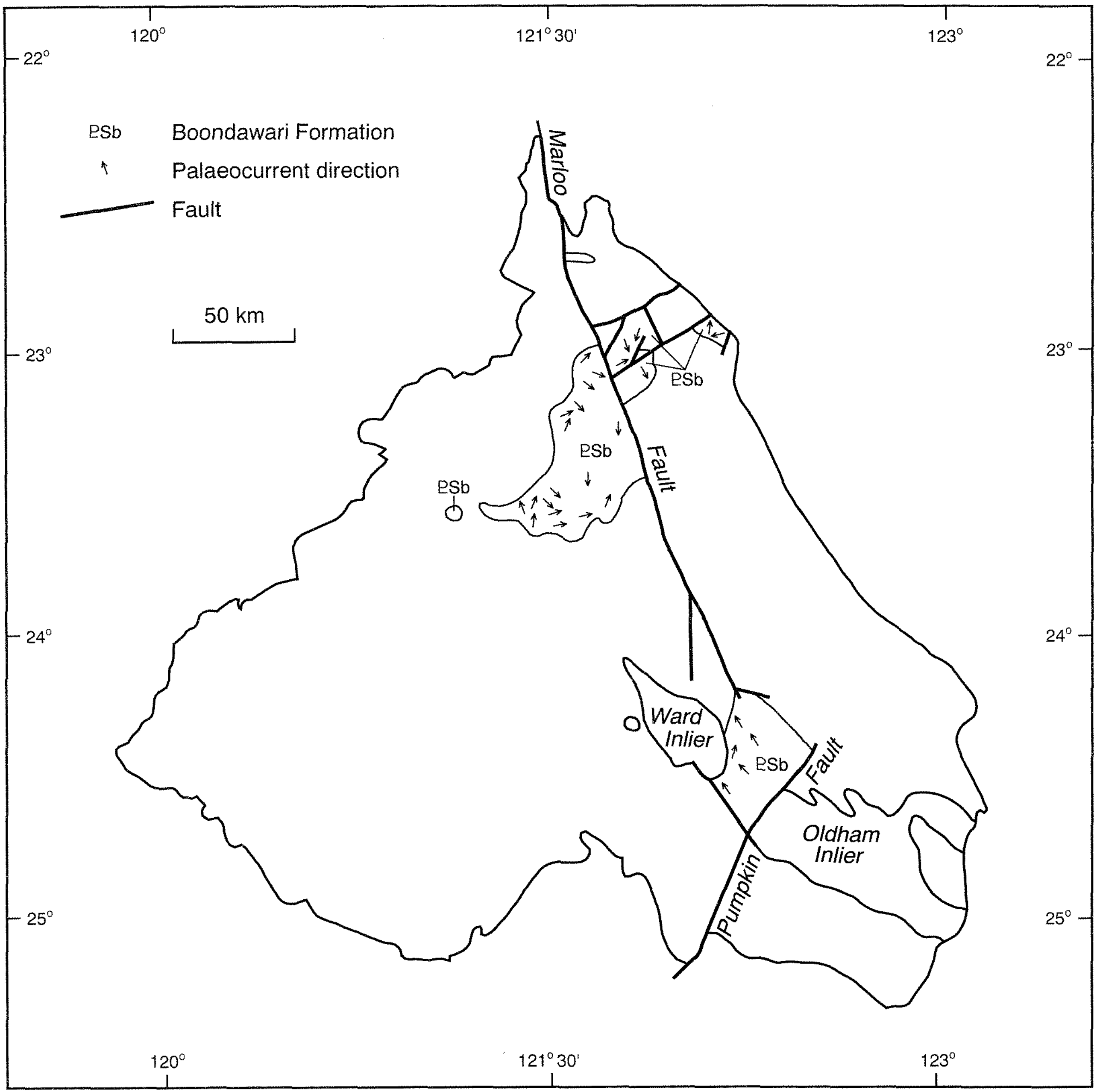

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Figure 89. Palaeocurrent direction, measured from cross-bedding — Depositional Sequence C — mixed provenances

conditions and probable remoteness from a delta mouth for this part of the succession.

Further shallowing of the basin is indicated by overlying carbonate, mudstone, shale, siltstone, and thin fine-grained sandstone units. Both dolomite and limestone are present, and in several areas, they contain small bioherms and biostromes of unidentified stromatolites. These stromatolites are sometimes overlain by oolitic and pisolitic (up to 7 mm) dolomite, which may represent shoals and strandlines. Halite pseudomorphs have been recorded from fine-grained sandstones near the Boondawari stockyards. The environment of deposition is envisaged as a shoaling area — with subtidal, shallow-water build-ups of stromatolites — adjacent to a shoreline with a low detrital input. Some beds, which show a development of evaporite minerals, have been interpreted as possible tidal flats or small sabkhas.

Palaeocurrent directions for the Boondawari Formation (Depositional Sequence C) are schematically shown in Figure 89.

Depositional Sequence D

This sequence is confined to the northeast margin of the basin between Marloo Marloo Rock Hole in the north and the Skates Hills in the southeast (Fig. 93). It unconformably overlies or is in faulted contact with the

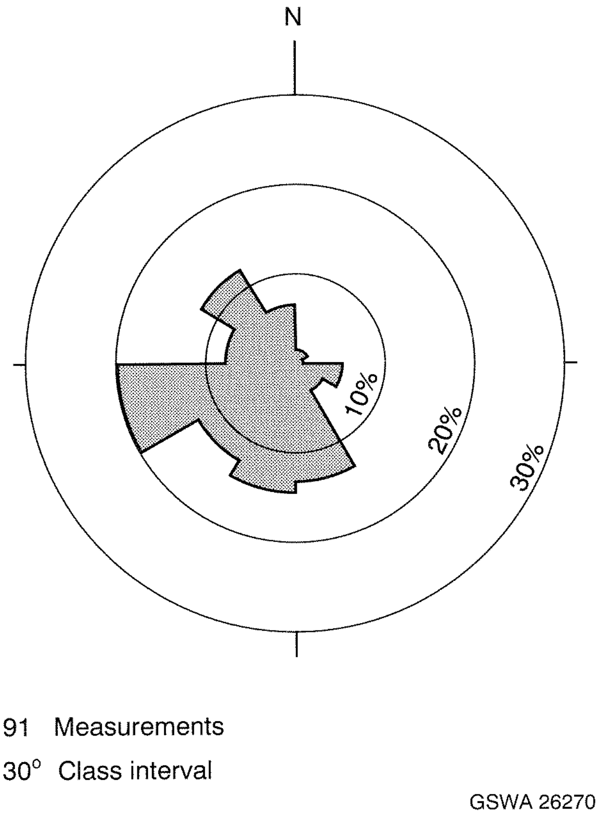


Figure 90. Palaeocurrent data for McFadden Formation

Yeneena and Karara Basins of the Paterson Orogen. It rests disconformably, or with local unconformity, on older units of the Savory Basin. This boundary has also been disrupted by faulting. The sequence is unconformably overlain by Depositional Sequence E; but sediments of the Phanerozoic Officer Basin unconformably overlie it southeast of the Calvert Range.

Depositional Sequence D comprises three formal lithostratigraphic units, the McFadden, Tchukardine, and Woora Woora Formations. The contact between the McFadden and Tchukardine Formations is not exposed, but is probably faulted. Woora Woora Formation disconformably overlies Tchukardine Formation in the Woora Woora Hills area. Both the Tchukardine and Woora Woora Formations appear to be, at least in part, coeval with the McFadden Formation.

McFadden Formation: The McFadden Formation is lithologically distinct from the formations occupying the western part of the Savory Basin; it comprises mostly flaggy to thick-bedded, poorly sorted, lithic and feldspathic sandstone and wacke. This contrasts strongly with the well-sorted, mature quartz sandstone that predominates in the western parts of the basin. The McFadden Formation becomes coarser grained northwards towards the margin of the basin. The formation also contains many very large tabular (omikron) and trough (pi) cross-beds up to 10 m thick. Single, large, alpha forms and heterogeneous, flaggy, epsilon forms have also been recorded. The flaggy, epsilon forms are commonly graded from small pebbles to fine-grained sandstone. The large-scale cross-beds sometimes have uniform dips for several kilometres and these may be mistaken for regional dips. Eroded tops of large cross-beds can be seen in the Diebil and Durba Hills, where Durba Sandstone has been stripped from an unconformity surface on McFadden Formation.

A plot of cross-bedding measurements for the McFadden Formation shows a strong west-southwesterly directed palaeocurrent (Fig. 90). These unidirectional currents and increasing grain size northwards indicate a northerly to northeasterly provenance. The immature coarse-grained sedimentary rocks (up to 20% feldspar, mica, and lithic fragments) typical of most of the McFadden Formation point to a mixed nearby bedrock source. The adjacent Paterson Orogen, with its mixture of sedimentary, metamorphic, and igneous rocks, is undoubtedly the main provenance of the detritus in the McFadden Formation. A local northwesterly directed palaeocurrent was indicate by measurements in the southern exposures of the McFadden Formation, where it overlies the Skates Hills Formation (Fig. 90). Here, the sandstone is cleaner and more mature; this suggests it may have been derived from the nearby Oldham Inlier.

The origin of the large cross-beds remains uncertain, but they may be the result of several different processes. Some large, heterogeneous cross-beds near the north-eastern boundary of the basin are suggestive of point-bar deposits that formed in large meandering channels in the delta build-up areas. Other uniformly dipping, heterogeneous, planar cross-beds may be delta fronts formed during the advance into quiet water. Further west and south, the large, trough cross-beds may be the product of migrating, sandy, offshore current-ridges, or giant ripples in channels. The McFadden Formation is thought to have been deposited in a prograding high-energy transverse sandy delta encroaching on a sandy shallow-marine shelf.

Tchukardine Formation: The Tchukardine Formation is confined to the northern margin of the Savory Basin, between Marloo Marloo Rock Hole and the Wells Range. Although the Tchukardine Formation rests unconformably on the adjoining Paterson Orogen, some problems in interpreting the relationship of the units where exposed at the unconformity, were discussed in Chapter 3.

There is a superficial resemblance between the Tchukardine Formation and adjacent components of the McFadden Formation, particularly with regard to the occurrence of large cross-bedded structures. However, the Tchukardine Formation is lithologically more mature. It is dominated by medium-sized, rounded, quartz grains set in a variable clay matrix. Feldspar grains and lithic fragments in sandstone and wacke are, in general, not common. Some upward-fining sequences have been recorded. The formation also lacks the large, immature, heterogeneous cross-beds found in the McFadden Formation. Overall, the Tchukardine Formation is further from source areas; and the patchy occurrence of glauconite points to a marine environment. Although the unusually abundant clay may have been derived from the breakdown of feldspar, its widespread distribution in this region (including to some extent, in the adjoining McFadden

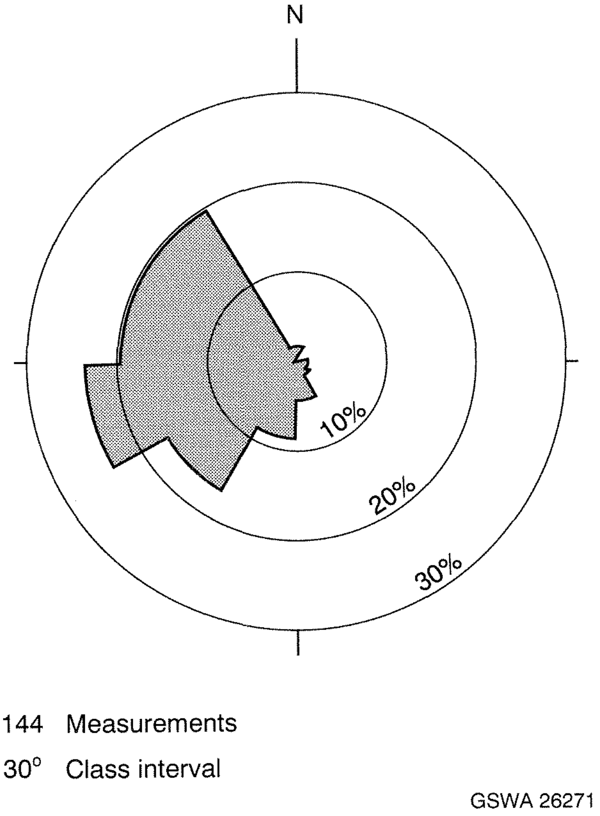


Figure 91. Palaeocurrent data for Tchukardine and Woora Woora Formations

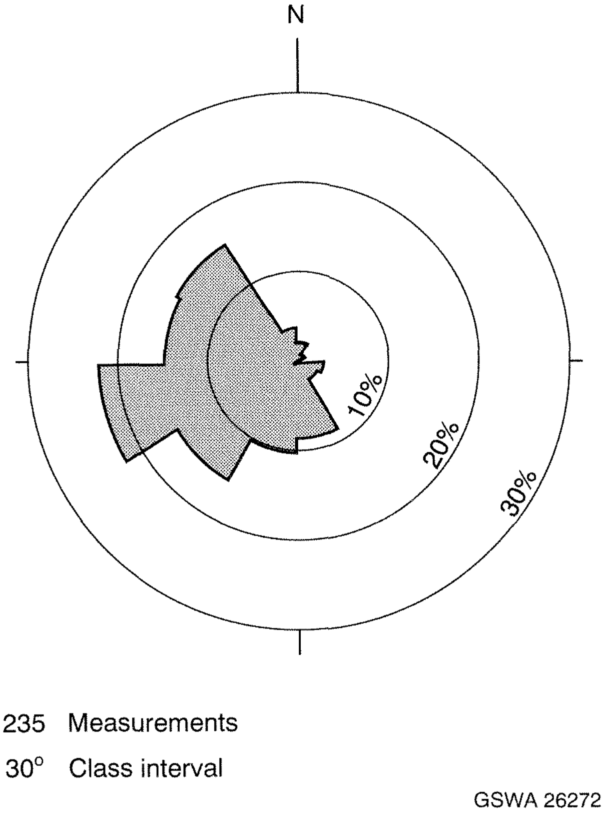


Figure 92. Palaeocurrent data for Depositional Sequence D, northeastern provenance

Formation) suggests that it may have been derived from air-fall tuffs that originated at some distance (*see* Chapter 4).

The Tchukardine Formation is thought to have been deposited on a sandy marine shelf. The large planar and trough cross-beds are believed to have been formed in migrating sand waves and tidal-current ridges on a sandy shelf, similar to those described by McCave (1971).

Woora Woora Formation: The Woora Woora Formation rests disconformably on Tchukardine Formation in a restricted area around the Woora Woora Hills. Lithologically, it closely resembles parts of the McFadden Formation to the southeast. It also contains similar large, heterogeneous planar cross-beds with graded, flaggy beds. It would appear that the Woora Woora Formation was deposited in a westerly extension of the high-energy deltaic environment suggested for the eastern part of the McFadden Formation. The Woora Woora Formation indicates that the shallow basin containing marine-shelf sediments (Tchukardine Formation) was gradually overrun by prograding deltaic sediments from the north-east. Cross-bedding attitudes from both Tchukardine and Woora Woora Formations have been combined on one rose diagram (Fig. 91). This shows that strong west-southwesterly palaeocurrents, similar to those in the adjacent McFadden Formation, prevailed during deposition .

To summarize, Depositional Sequence D was strongly controlled by westerly to southwesterly directed palaeocurrents (Fig. 92). This observation, coupled with the increase in grain size northeastwards, points to a source area northeast of the Savory Basin. There is change from shallow-marine shelf to deltaic conditions upwards in the sequence.

The Yeneena Basin and Rudall Complex of the Paterson Orogen have been moderately deformed by southwesterly directed folding and thrusting of the Paterson Orogeny (Clarke, 1991). It is evident from the broad asymmetric folds, steep reverse faults, and dextral slip faults in the Tchukardine Formation that the northeastern margin of the Savory Basin was also involved in the closing phases of this tectonism. During the deposition of Depositional Sequence D, this transpressional movement influenced, to some extent at least, the shape of its depositional basin: it is elongated parallel to the trend of the Paterson Orogen, and almost at right angles to the axis of the basin in which the older components of the Savory Group were deposited (Fig. 93).

This is interpreted as the result of an interplay between compressional tectonics and uplift, erosion, and deposition in a marginal downwarp, parallel to the Paterson Orogen. This parallel elongated basin is thought to have been an incipient foreland basin. The difference between the younger northeastern part of the Savory Basin and the older components is radically expressed by the almost 180° change in palaeocurrent directions (Fig. 92). Palaeocurrent directions for Depositional Sequence D are schematically shown in Figure 93.

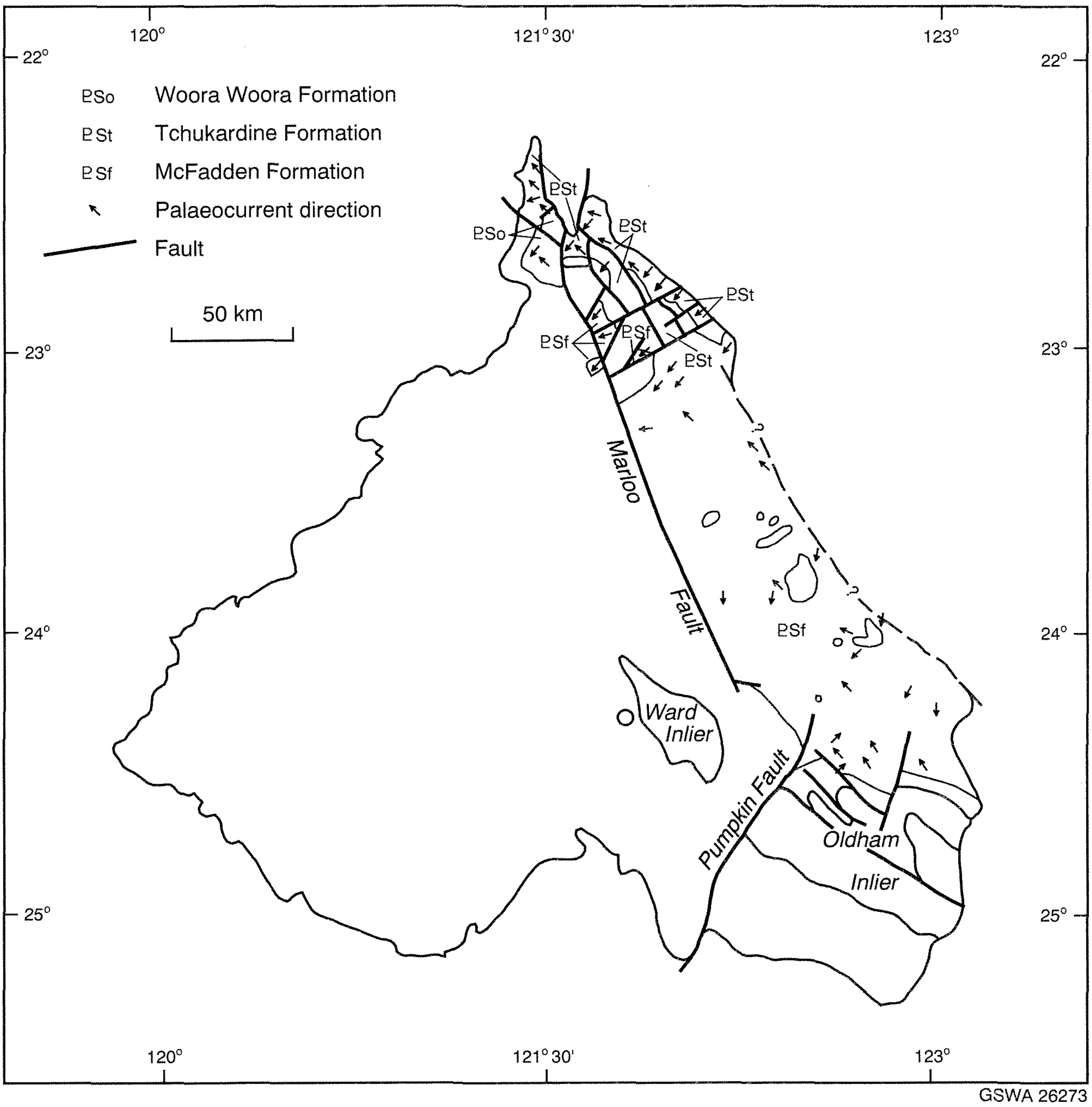


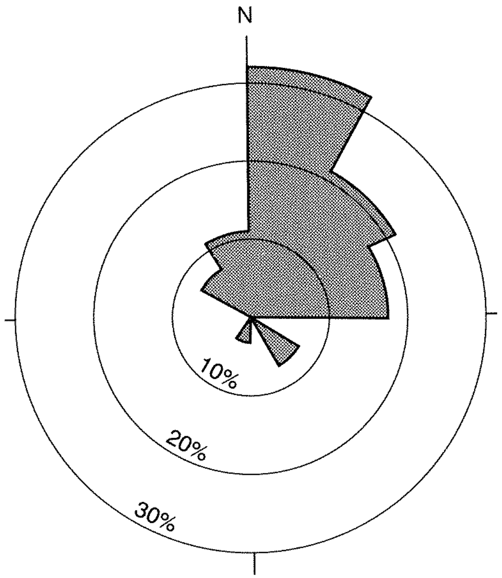
Figure 93. Palaeocurrent directions measured from cross-bedding — Depositional Sequence D — north-eastern provenance

Depositional Sequence E

Durba Sandstone: Depositional Sequence E comprises one formal lithostratigraphic unit, the Durba Sandstone. It is exposed in a number of small outcrops scattered roughly parallel to the northeastern margin of the Savory Basin, from Budgie Spring southeast to the Calvert Range. The formation rests unconformably on eroded McFadden Formation and gently folded Boondawari Formation. The sharp angular contact between the Durba Sandstone and the McFadden Formation, where it is exposed in the Durba and Diebil Hills, is primarily due to the erosion of very large cross-beds in the McFadden Formation. The true intensity of folding in the McFadden Formation in this area is difficult to ascertain.

The significance of the unconformity in relation to the time of deposition is unclear. Although a period of erosion separated the deposition of McFadden Formation from the deposition of Durba Sandstone, the common angular relationship between the two may be mainly due to the erosion of primary-dipping, very large tabular and trough cross-beds, rather than to a major tectonic event.

The Durba Sandstone appears to have been deposited in a shallow basin parallel to the Paterson Orogen. As the Savory Basin was involved in tectonic events generated within the Paterson Orogen, the Durba Sandstone is seen to be part of the closing stage of Late Proterozoic tectonism and sedimentation. It is the youngest unit of the Savory Group.



28 Measurements

30° Class interval

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Figure 94. Palaeocurrent data for Durba Sandstone — Depositional Sequence E

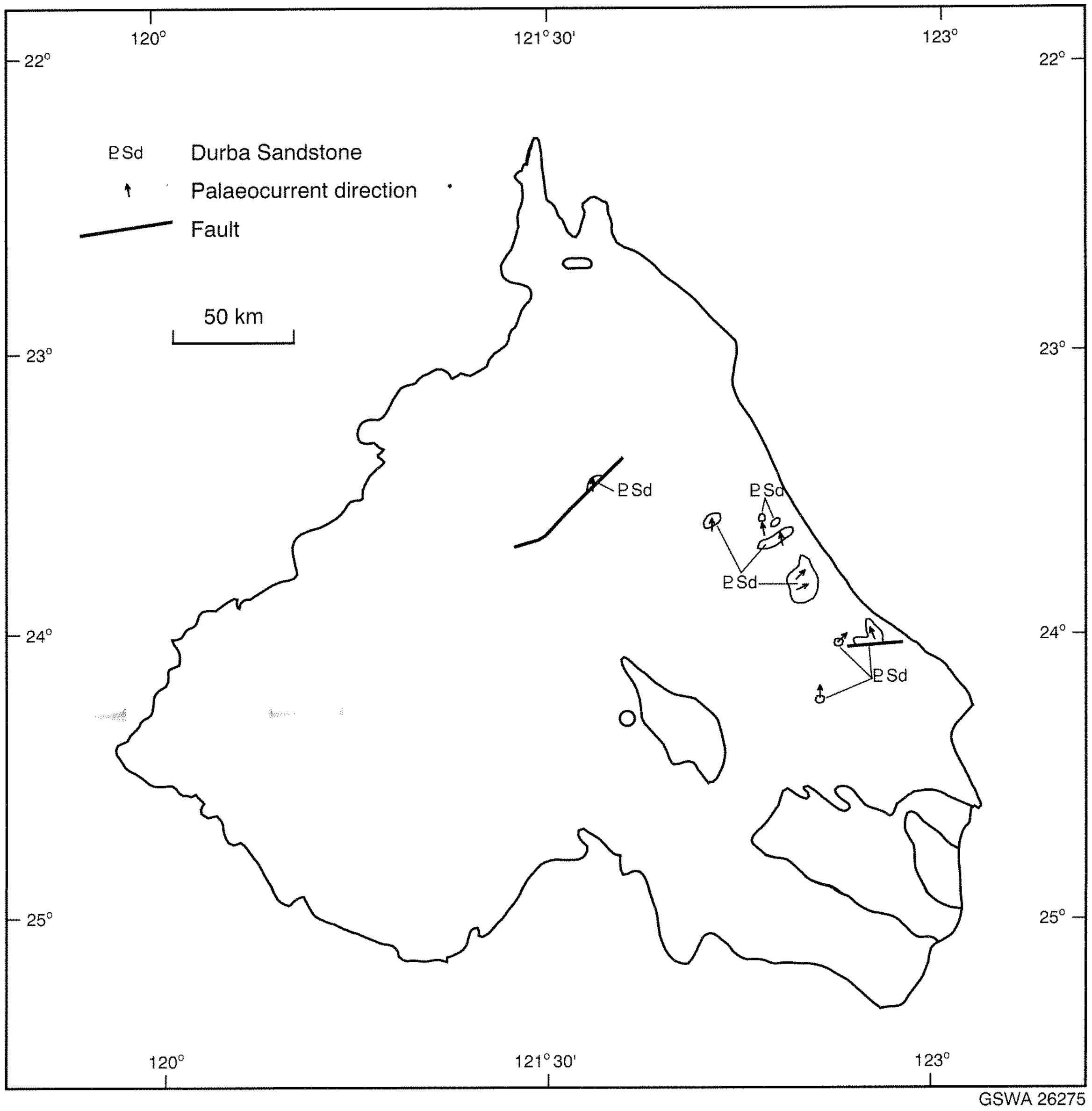


Figure 95. Palaeocurrent directions measured from cross-bedding — Depositional Sequence E — southern provenance

The Durba Sandstone is interpreted as a fluvial deposit (Muhling and Brakel, 1985). The base and lower parts of the formation are poorly sorted polymictic conglomerate that was deposited in channels cut in the basement (McFadden Formation), or within sandstones of the Durba Sandstone that are commonly cross-bedded. The clasts indicate a mature sedimentary provenance. The deposits are characteristic of braided-stream deposits.

A plot of palaeocurrent directions shows a strong north-northeasterly flow (Fig. 94). This is almost a complete reversal of the palaeocurrent direction in the underlying McFadden Formation. The strong unidirectional palaeocurrent, typical of fluvial deposits, suggests a provenance in the south. This backed up by the compositions of the larger clasts, which point to a sedimentary source. The basement highs of the Ward and Oldham Inliers represent possible source areas.

Overall, the Durba Sandstone is an upward-fining sequence. The highest units, which are exposed in the Calvert Range, are interbedded, fine-grained sandstone, minor siltstone, and shale. These show many ripple forms, small cross-bedding, mud cracks, and dewatering structures, akin to those of shallow lakes or tidal flats.

A schematic diagram of palaeocurrent directions is given in Figure 95.

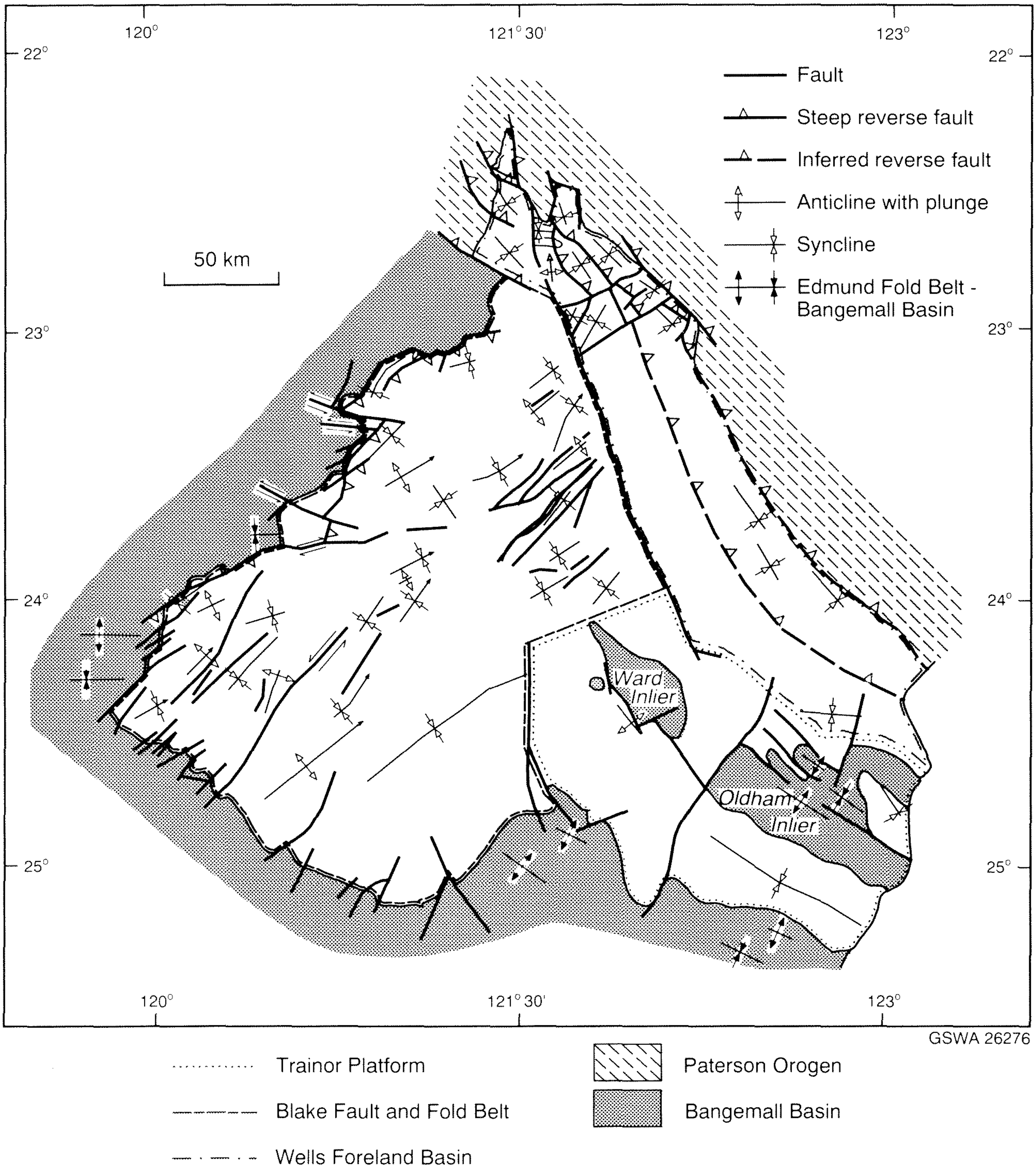


Figure 96. Tectonic units of Savory Basin

Chapter 6

Structure

Introduction

The Savory Basin occupies much of the area previously called the Bullen Platform, the easternmost tectonic unit of the Bangemall Basin as defined by Muhling and Brakel (1985). In that publication, the rocks of the region were described as being gently deformed. However, variations in tectonic style were recognized; and the area was divided into structural domains, representing areas within which there was a consistent style of folding and orientation of fold axes (Muhling and Brakel, 1985, Plate 2). The unifying attributes of the Bullen Platform were broad, open-style folding with gentle dips, and either northeasterly to north-northeasterly or northwesterly trending fold axes. Dome-and-basin folding was recognized in restricted areas, particularly in the eastern parts of the Bullen Platform. However, in the light of work carried out for this bulletin, the continuation of this tectonic unit is no longer justified. It is now known that the Savory Basin has a depositional and tectonic history separate from the surrounding, older sedimentary basins. These basins, including the Bangemall Basin, are major source areas for the epiclastic material deposited within the Savory Basin.

Muhling and Brakel (1985) also identified the important Robertson Fault System, which was then shown to lie between the Pingardy Shelf and Bullen Platform, tectonic units of the Bangemall Basin. This fault system was also thought to be part of the prominent northeasterly trending Tangadee Lineament, a regional lineament produced by parallel photolineaments, joints, faults, dolerite dykes, and axes of small folds. The lineament also appears to be a boundary marking a change in sedimentary facies and tectonic style. (Muhling and Brakel, 1985, p. 176). Muhling and Brakel (1985, p. 174) concluded that the Robertson Fault System was the product of normal block faulting. This conclusion was not borne out in later work. Williams and Tyler (1991) showed that the Robertson Fault System was much more complex, and that it consisted of a mixture of steep reverse and strike-slip faults. The Robertson Fault System is now known to mark the northwestern margin of the Savory Basin.

Regional structure

As discussed in Chapter 2, the Savory Basin is a superimposed basin. Although the boundaries are commonly faulted, the basin can be seen, along its northwest and southern margins, to unconformably overlie rocks of the Bangemall Basin. When this regional distribution is linked to the Bangemall Group rocks exposed in the Ward and Oldham Inliers, it is evident that almost the entire Savory Basin is underlain by Bangemall Group rocks (Fig. 96). The general, curvilinear, east-west, fold trends of the Bangemall Basin — the Edmund Fold Belt of Muhling and Brakel (1985, Plate 2) — pass eastwards beneath the southern part of the Savory Basin. They reappear as the east-southeasterly trending folds of the Oldham Inlier, where it can be seen that bedding steepens and folds tighten northwards in the direction of the Paterson Orogen.

The Manganese Subgroup, which lies along the northwest side of the Savory Basin, shows a dome-and-basin style of folding that has been attributed to block faulting in the underlying Pilbara Craton (Williams and Tyler, 1991). However, these rocks also show a progressive increase in deformation northeastwards. This is expressed in the Talawana and Saltbush Range area by the incipient development of axial-planar cleavage, and by the appearance of tight, asymmetric and overturned folds, whose axial planes dip northeastwards. In neither case are the fold styles of the Bangemall Basin rocks reflected in the overlying or adjacent Savory Basin sedimentary rocks.

The important conclusion to be drawn from this observation is that the Bangemall Group rocks were deformed in conjunction with the rocks of the Paterson Orogen before the sediments of the Savory Basin were laid down. This event may correspond to the Middle Proterozoic Watrara Orogeny, the effects of which, where they have not been obliterated by the Late Proterozoic Paterson Orogeny, can still be recognized in rocks of the Rudall Complex (Paterson Orogen) (Clarke, 1991).

Only the younger components of the Savory Group, mainly Depositional Sequence D, are postulated to unconformably overlie the Yeneena Group and Karara Formation of the Paterson Orogen on the northeast margin of the Savory Basin (Fig. 75). However, this contact has been widely disrupted by strong transpressional faulting, leaving in some doubt the extent to which rocks of the Paterson Orogen form a basement to the Savory Basin in this region. The Late Proterozoic Paterson Orogeny, which affected the northeastern margin of the Savory Basin, is a separate, and much younger, episode than the one that deformed the northeastern and eastern parts of the Bangemall Basin.

The general structural pattern — bedding, fold axes, and fault lines — in relation to the formalized stratigraphy is given in Plate 2. Despite the overall sparseness of

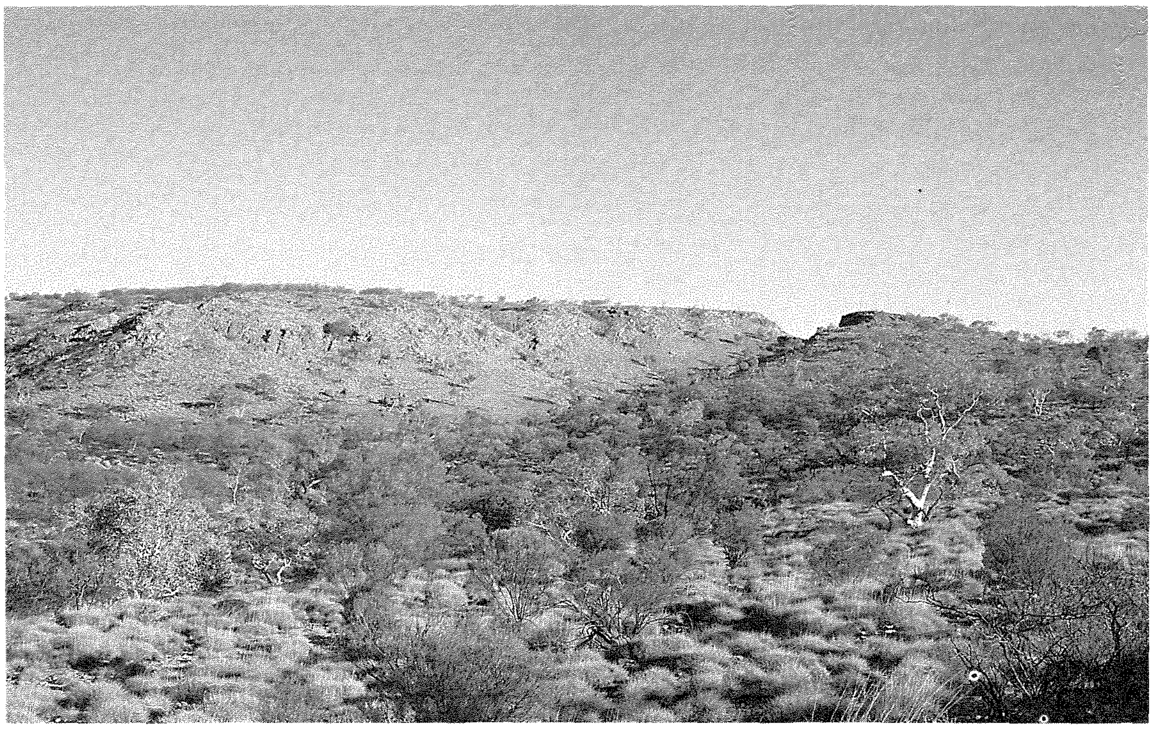


Figure 97. Robertson Fault System, Coondra Formation (left) thrust over Watch Point Formation (right), fault strikes south along valley floor (left foreground to right background)

exposure in the Savory Basin, three tectonic units can be established. Two of these, the Trainor Platform, and the Blake Fault and Fold Belt, involve the oldest components of the Savory Group, Depositional Sequences A, B, and C. The third, the incipient Wells Foreland Basin, involves only the younger Depositional Sequences D and E (Fig. 96).

Trainor Platform

The Trainor Platform is the least-deformed part of the Savory Basin. The rocks of this area, which are seen to overlie unconformably a basement of folded Bangemall Basin rocks (Edmund Fold Belt), have remained stable throughout the depositional history of the Savory Basin (Fig. 96). The area is also partly enclosed by basement highs, the Ward and Oldham Inliers. This suggests that the depth to basement (Bangemall Group rocks) throughout the area of the Trainor Platform is probably small.

The rocks of the platform are mostly flat lying or gently tilted to the northeast. A broad, synclinal fold, trending northwest, lies between the Oldham Inlier and the southern margin of the Savory Basin. Local, northwesterly plunging, open folds are associated with faulting on the southwestern side of the Ward Inlier and the northeastern side of the Oldham Inlier (Fig. 96).

Two large, northerly to north-northeasterly trending faults, the Pumpkin Fault and the Kelly Fault, truncate the fold trends almost at right angles. The Pumpkin Fault is downthrown to the west. It possibly pre-dates the deposition of Depositional Sequence D in the Wells Foreland Basin to the north.

The Kelly Fault has a sinistral strike-slip component as well as a downthrow to the west. It separates the Blake Fault and Fold Belt, which has a northeasterly tectonic grain, from the Trainor Platform, which has a northwesterly tectonic grain.

However, the Trainor Platform and Blake Fault and Fold Belt have already been shown to contain coevally deposited sedimentary rocks (*see* Chapter 5). This close relationship is expressed by the similarities of depositional environment for the two areas. Rocks in the Trainor Platform are deltaic and fluvial, and show a strong palaeocurrent direction towards the northwest. Likewise, the oldest components in the Blake Fault and Fold Belt, which are distal deltaic, shoreline, and shallow-marine shelf deposits, show similar palaeocurrent directions (*see* Chapter 5). Hence, the Kelly Fault, across which there is a continuum of sedimentation, marks the boundary between the stable Trainor Platform and the, relatively unstable, Blake Fault and Fold Belt. The fault may reflect the hinge line that marks the eastern margin of a half-graben structure that has been postulated to underlie and to have initiated the Blake Fault and Fold Belt.

Blake Fault and Fold Belt

The Blake Fault and Fold Belt is typified by roughly parallel, northeasterly trending fold axes, and numerous north-northeasterly to east-northeasterly trending faults

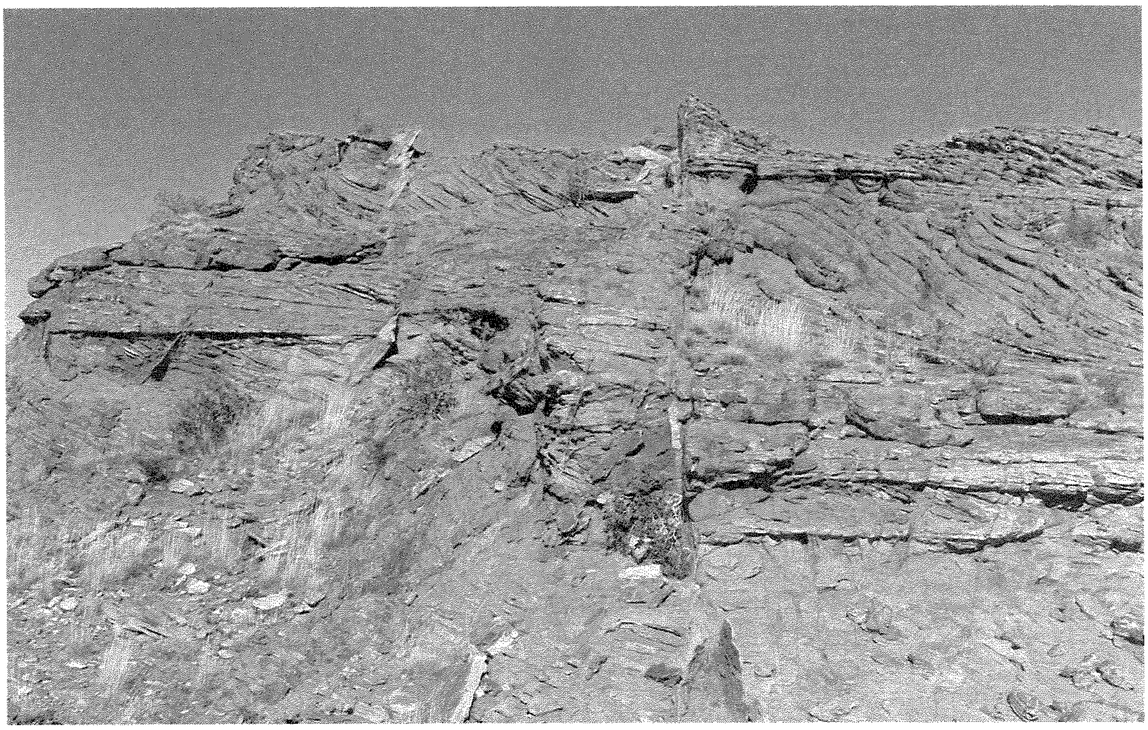


Figure 98. Vertical faults, small movements, brittle fracture, cross-beds — Spearhole Formation

that show a variety of normal, steep reverse and strike-slip movements (Fig. 96).

In the northern parts of the belt, north of Savory Creek, some fold axes swing northwesterly. In the Boondawari Creek area, such axes are truncated by the northeasterly trending faults. Folds within the Blake Fault and Fold Belt are broad and open, with mostly gentle, but in some cases moderate, dips. Overall, the undulate fold axes show a gentle plunge to the northeast. Locally, steepening of bedding adjacent to faults has been observed.

Penetrative foliations and regional metamorphism are absent from the Blake Fault and Fold Belt. With the exception of some tight, similar, mesoscopic folds, associated with the compressive, reverse faulting along the Robertson Fault System in the Watch Point Formation, axial-planar cleavage is also absent from the belt. Orthogonal jointing is prominent throughout the region.

Numerous faults of all scales are characteristic of the Blake Fault and Fold Belt. These range from the large, complex, Robertson and Millarie Fault Systems (Fig. 97), which occur at the northwestern edge of the Savory Basin, and large strike-slip faults, such as the Marloo and Kelly Faults, which mark the eastern boundary of the Blake Fault and Fold Belt, to small, local fractures and micro-faults, with less than a centimetre of movement.

Overall, the Blake Fault and Fold Belt is a brittle-fracture domain. Large, shear and breccia zones are mainly confined to the marginal fault systems. Most faults in the belt are characterized by clean, sharp contacts or breaks, often with well-formed slickensides on glassy or pseudotachylyte surfaces (Fig. 98). These glassy surfaces, which may be less than 40 mm thick (Fig. 99), act as mirrors, and can be seen from a considerable distance. Some of these silicified surfaces also occur on minor or splay faults adjacent to the main fault zone.

Many sandstones next to fault zones contain random, criss-cross, or echeloned arrays of millimetre-thick silicification veins. These are zones of recrystallized quartz grains, some of which show shattering and comminution, but all of which were later cemented by silica. Millimetre-scale movement can be detected along many of these veins. Some may have formed during dewatering of the sandstones, an event possibly triggered by early faulting. However, where such veins were observed, faulting was always found nearby. Kinking, up to centimetre scale, also occurs in sandstones adjacent to faulting. In contrast, true quartz veins or quartz reefs, consisting of sutured quartz crystals, are not commonly associated with faults in the Blake Fold and Fault Belt or elsewhere in the Savory Basin.

Most fault planes in the Blake Fault and Fold Belt dip steeply. Slickensides indicate both normal and reverse movements. Some of the larger faults, such as the Terminal Lake and Mamutjara Faults, have slickensides indicating sinistral and dextral strike-slip movements respectively. The southwestern boundary of the Savory Basin is intersected by many steeply dipping faults which offset the unconformity. Most of these faults trend northeastwards, roughly parallel to the northwestern margin of the Savory Basin and the Robertson Fault System. Although some of

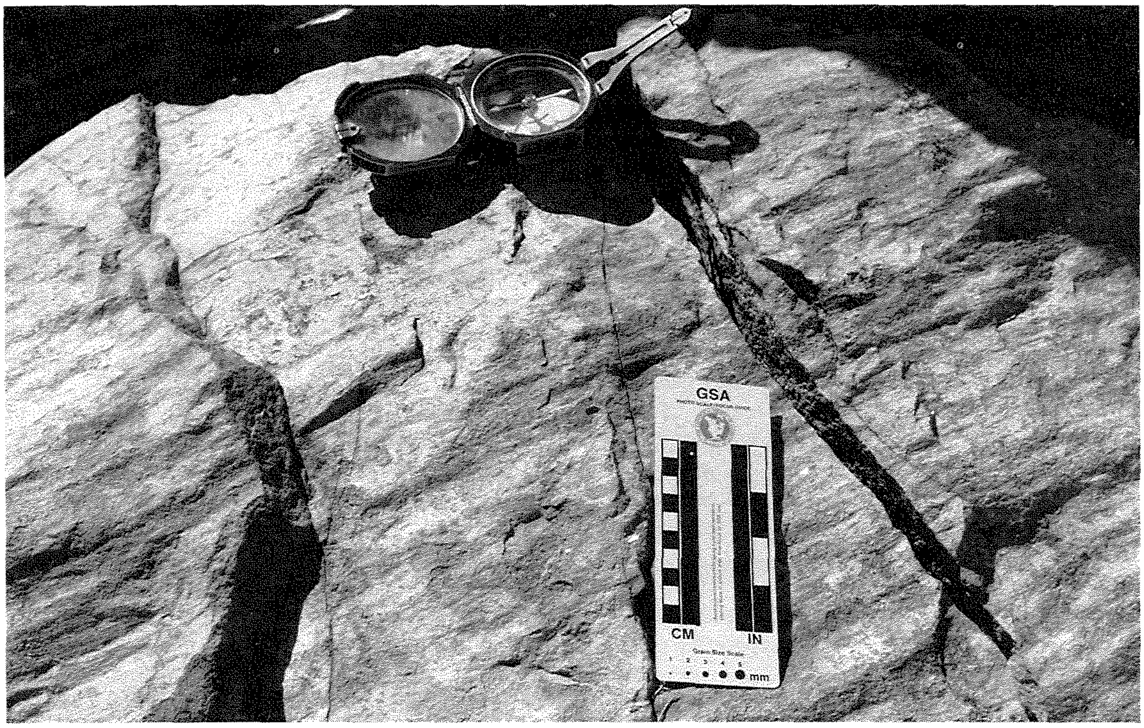


Figure 99. Slickensides, movement left to right, strike-slip fault — Mundadjini Formation

the faults have a strike-slip component, the offset in the unconformity can often be attributed to the erosion of normal and reverse faults.

The large and complex Robertson Fault System on the northwest margin of the Savory Basin was first described by Muhling and Brakel (1985), who concluded that it was the product of normal block faulting (Fig. 97). This conclusion was not supported in later surveys (Williams and Tyler, 1991). The Robertson Fault System, along with the coeval Millarie Fault System to the north (Williams, 1989), and the Kimberley Well Fault to the southwest, are a mixture of anastomosing reverse, vertical, and contemporaneous, largely dextral, strike-slip faults.

This series of, mainly steep, reverse faults resembles the imbricate fans associated with blind thrusts at shallow depths (Morley, 1986). However, lack of evidence for any substantial transport of material northwestwards along thrust planes suggests that the compression is more akin to that produced by basin-inversion tectonics (Cooper and Williams, 1989). The steep reverse faults, in this case, resemble reactivated normal, probably listric, growth faults, which had initiated the development of the Savory Basin in this region. North of Watch Point, Coondra Formation appears to have overridden the basal Watch Point Formation to rest with faulted contact on the Manganese Subgroup of the Bangemall Basin.

Synclinal axes and faulted anticlinal axes occur parallel to the steep reverse fault lines. Tight, similar folds in fine-grained siltstone of the Watch Point Formation have been found beneath major easterly dipping fault zones (in the footwall) east of Robertson Range Homestead. These mesoscopic folds have southeasterly dipping axial surfaces. The Robertson Fault System was later offset by a series of sinistral strike-slip faults, the Watch Point, the Jigalong, and the Murramunda Faults, which trend west-northwestwards (Williams and Tyler, 1991).

The parallelism shown by most of the faults in the Blake Fault and Fold Belt to the large fault systems along the northwestern margin of the Savory Basin suggests that they may all be related. It is envisaged that the early extensional phase of the Savory Basin saw the development of a half graben along the southeast margin of the Pilbara Craton. These growth faults were probably influenced or controlled by weaknesses already evident in the Bangemall Basin rocks in this area, i.e. parallel to the Tangadee Lineament (Muhling and Brakel, 1985). This weakness in the Bangemall Basin probably reflects, in turn, the buried margin of the Pilbara Craton in this region.

The extensional phase of basin development coincided with the intrusion of near-surface basalt and fine-grained dolerite sills in the Watch Point, Coondra, and Glass Spring Formations along the northwestern margin of the Basin (*see* Chapter 4). Similar basalt and fine-grained dolerite intrusions occur in the Brassey Range Formation at the southern margin of the Basin.

After the deposition of Depositional Sequences A and B, the extensional regime relaxed and was replaced by one of gentle compression. This reversal of slip along the original listric or normal growth faults culminated in mild basin inversion along the northwestern margin of the basin. The overall movement of the Savory Basin sediments was up and out onto its northwestern provenance, the

Manganese Subgroup of the Bangemall Basin. The parallel faulting and folding throughout the Blake Fault and Fold Belt appears to be related to this event. This compressional event is also responsible for some back thrusting and strike-slip movements within the Blake Fault and Fold Belt.

Depositional Sequence C, a glacigenic marine event, represents a new marine transgression from east to west across the basin. It occurred during a pause in the tectonism associated with the Blake Fault and Fold Belt. This tectonic regime continued for a short time after the deposition of Depositional Sequence C had been completed and before the onset and development of the Wells Foreland Basin in the northeastern part of the Savory Basin.

The initial development of the half-graben structure that hosted most of the sediment for Depositional Sequences A and B, and the subsequent faulting and folding of the Blake Fault and Fold Belt, is attributed to minor, intermittent adjustments between the Pilbara and Yilgarn Cratons.

Wells Foreland Basin

The Wells Foreland Basin occupies the northeast margin of the Savory Basin (Fig. 96). It is an incipient basin, 50 km wide and 300 km long, that formed in response to southwesterly directed thrust generated in the adjoining, and marginally underlying, Paterson Orogen. The western boundary of the unit corresponds to a series of faults which truncate the earlier northeasterly trending faults and fold axes of the Blake Fault and Fold Belt. These include the inferred Saltbush Fault and the prominent dextral strike-slip Marloo Fault. This tectonic contact is not so obvious in the southern part of the Savory Basin, where the southern extent of the McFadden Formation has been designated the boundary. This boundary lies just north of the Oldham Inlier and disconformably above the Skates Hills Formation.

The Wells Foreland Basin is where the youngest Depositional Sequences, D and E, represented by the McFadden, Tchukardine, and Woora Woora Formations, and Durba Sandstone, were deposited. Disconformable and unconformable contacts with the older components of the Savory Basin are exposed northeast of the Horse Track Range. However, the relationship between the young Depositional Sequence D, and the Yeneena Basin rocks of the Paterson Orogen is not seen.

As pointed out in Chapter 3, the unconformity, where exposed along the northern boundary between the Savory Basin and the Yeneena Group, actually lies between rocks correlated with upper part of Depositional Sequence B (the Mundadjini Formation). Nowhere is the Tchukardine Formation, representative of the younger Depositional Sequence D in this area, seen to rest directly on the older Paterson Orogen: this contact is always faulted. However, there is little doubt that, as the older unconformable Savory Group rocks tend to thin northwards and eastwards, the younger Depositional Sequence D would have rested unconformably on a Paterson Orogen basement further to the northeast.

The main structural characteristics of the incipient Wells Foreland Basin are compressional and strike-slip fault systems, and associated northwesterly to northerly trending axes of open folds. These are best exposed in the northern part of the Savory Basin, between the Emu Range and Marloo Marloo Rock Hole. Large compressive faults are interpreted to occur along the unexposed boundary south of the Emu Range.

The existence of these faults is inferred from regional magnetic data (total magnetic intensity maps published by the Bureau of Mineral Resources) and the straightness of the contact between the Savory Group, and the Yeneena Group and Karara Formation. On the southwest side, and parallel to the boundary fault between the Savory Basin and the Paterson Orogen, is a very strong south-southeasterly striking linear magnetic low. This magnetic lineament corresponds, along strike, to a series of steep reverse faults in the area north and east of the Wells Range. These faults could be a direct continuation of the Vines Fault (Williams and Myers, 1990). Further south, however, there appears to be no surface expression, and it is possible that this magnetic lineament reflects a buried basement fault. This magnetic lineament may also correspond to the buried western margin of the Paterson Orogen, which lies somewhere beneath the Savory Basin in this area. It passes just west of the McFadden Range, curves southeasterly around the Diebil and Durba Hills to pass to the southwest of the Calvert Range.

The main outcrop of the Durba Sandstone, the youngest formation in the Savory Group, lies east of this lineament. The northern part of the Wells Foreland Basin is characterized by a set of moderately northeast-dipping thrusts and steep reverse faults with limited transport towards the southwest. These faults, which postdate the northeasterly trending folds and faults of the Blake Fault and Fold Belt to the south, resemble an imbricate zone associated with a blind thrust. The thrust and reverse faults are intersected in the Wells Range area by several west-southwesterly striking sinistral strike-slip faults.

The whole fault complex is transected by the large dextral strike-slip Marloo Fault. This fault also cuts the unconformity between the Savory Basin and Paterson Orogen in the Hanging Rock area. Northwards, east of Marloo Marloo Rock Hole, the Marloo Fault disappears into a series of stacked reverse faults. It would appear that all the faults in the northern part of the Wells Foreland Basin are interrelated.

The Marloo Fault (Williams, 1990), which seems to be parallel to the large Vines Fault System, separates the weakly deformed western Yeneena Basin from the more strongly deformed eastern Yeneena Basin (Williams and Myers, 1990). In the area 5 km north of the Boorabee Hill (Fig. 100) and 20 km south of Hanging Rock, thrusting has brought Yeneena Group basement rocks up against rocks of the Tchukardine and Mundadjini Formations. Elsewhere, as north of the Wells Range, steep reverse

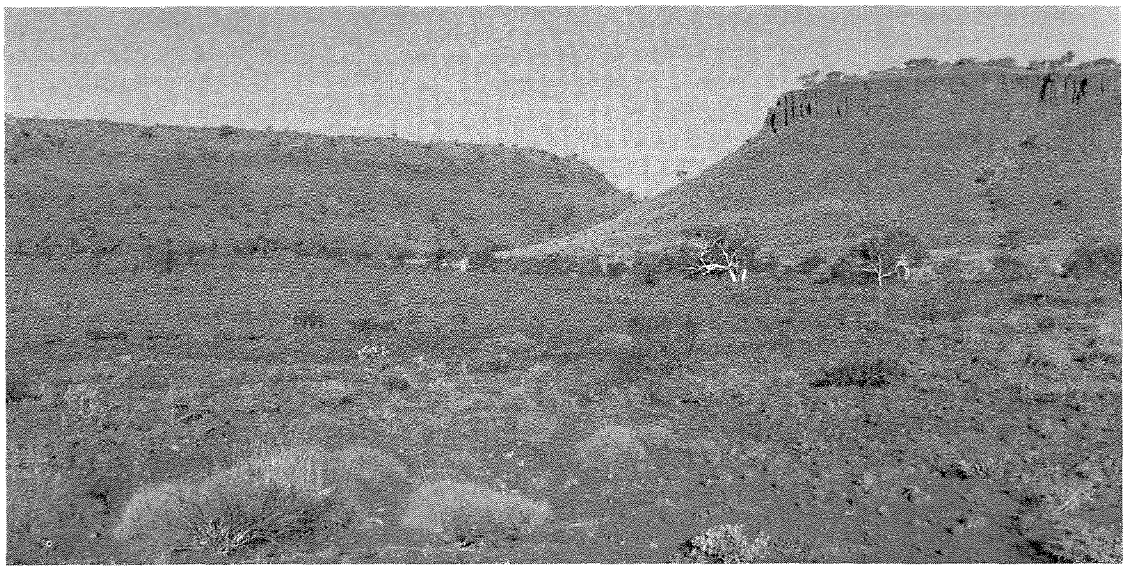


Figure 100. Thrust fault, moderately north-dipping Yeneena Group (left) thrust up over flat-lying Tchukardine Formation (right)

faults have exposed older components of the Savory Basin in faulted anticlinal structures. In this area, the older Mundadjini Formation has been faulted over the younger Tchukardine Formation.

Compressional faulting at all scales is evident in the northern part of the Wells Foreland Basin. Rocks adjacent to the Perentie Fault display microfaults with a north-block south movement. The movement along these microfaults is measured in centimetres (Fig. 101). Flaggy sandstones are commonly intersected by anastomosing kink bands, sometimes with displacement of up to 1 cm along the axial plane. The kinking may be oblique to the faulting, and may form congruent sets; but, close to major faults, it tends to become roughly parallel . Both steep reverse and normal movements have been recorded (Fig. 102). Silicification veins, described previously from the Blake Fault and Fold Belt, are also common in the Wells Foreland Basin. These structural features are probably the product of a compressive, brittle-fracture regime.

Figure 101. Minor thrust faults, displacement 6 cm southwest, Tchukardine Formation, northern margin of basin

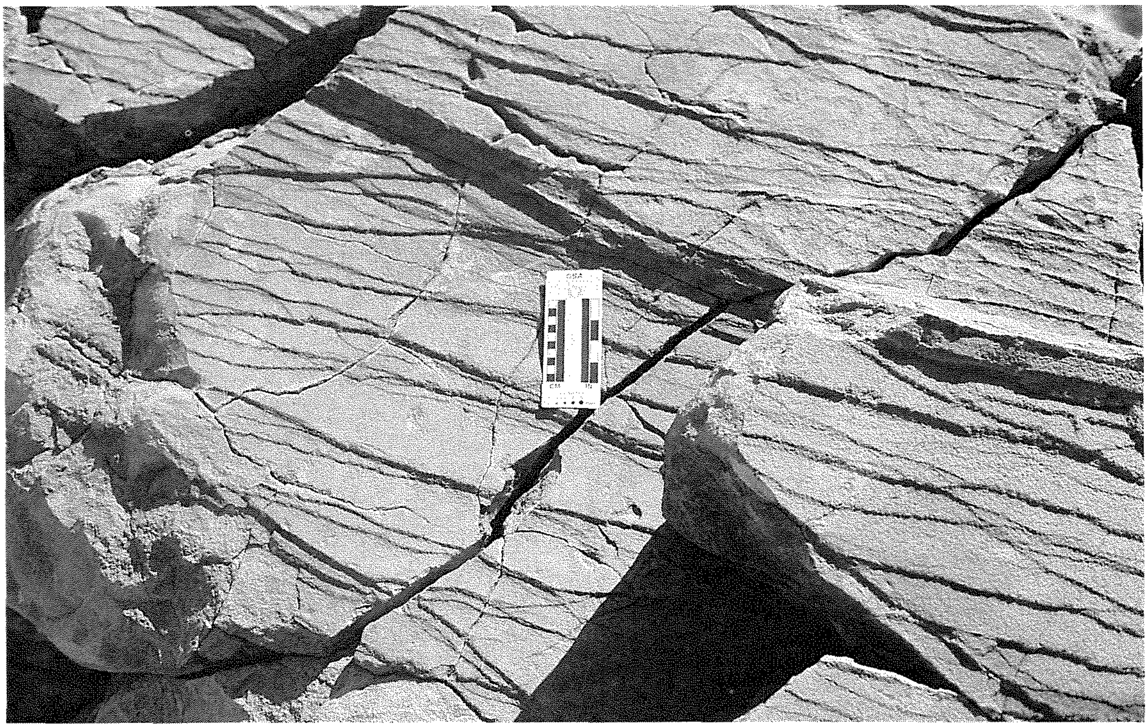


Figure 102. Kinking and microfault, compressional movement to southwest — Tchukardine Formation

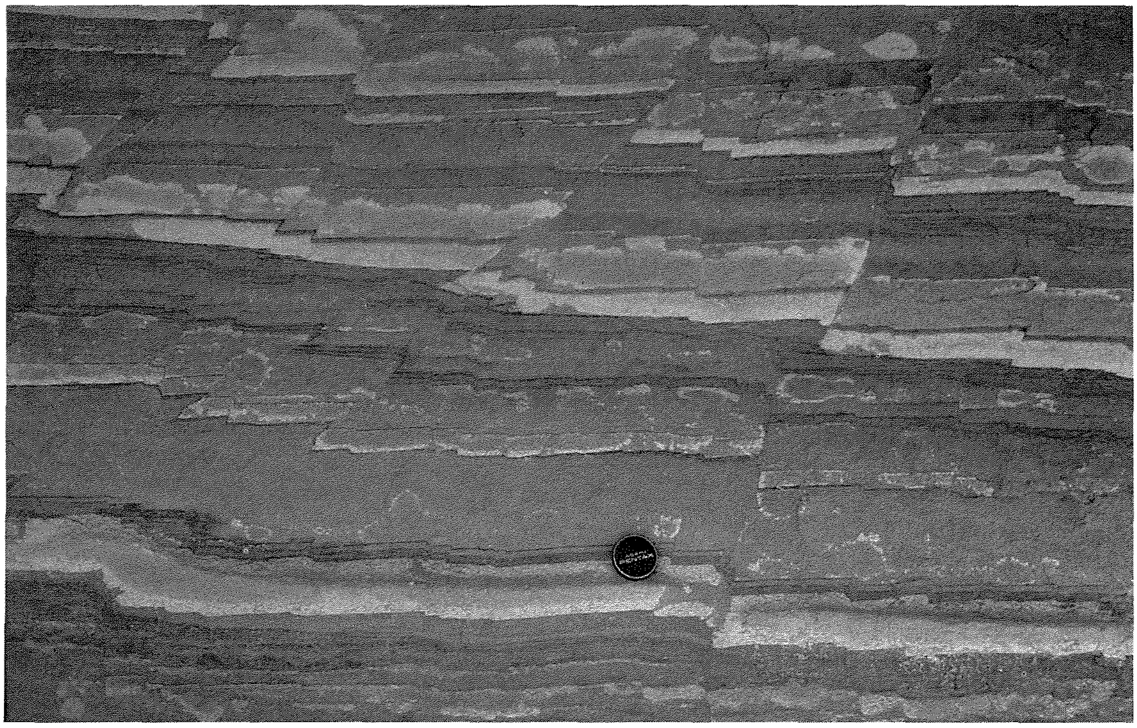


Figure 103. Microfaults, steep reverse faults, movement to south — McFadden Formation

The northerly to northwesterly trending folds that accompanied the compressional faulting are fairly open, but the anticlines are tighter than the synclines. In most cases, the anticlines are faulted and are the focus for the steep reverse faults. There is evidence of fold interference in the Horsetrack Range area; the older, northeasterly trend of the Blake Fault and Fold Belt has been intersected by the younger northwesterly trending folds generated by the Paterson Orogeny.

The deformation pattern south of the Emu Range is difficult to map because of poor exposure. The McFadden Formation is broadly warped, and small microfaults have been recorded in the Diebil Hills (Fig. 103). In general, the intensity of deformation decreases southwesterly across the Wells Foreland Basin.

As described in Chapter 6, the sediment that constitutes Depositional Sequence D was derived from the nearby Paterson Orogen. This resulted from an episode of faulting and folding, followed by uplift, that was generated by the Paterson Orogeny concurrently with the development of this part of the Savory Basin. The southwesterly directed fold and thrust movements produced an incipient foreland basin into which sediments, eroded from the uplifted Paterson Orogen, were deposited. This coincided with the later, post glacial stages of development of the Savory Basin. However, the southwesterly directed faulting continued, and eventually incorporated the northeastern margin of the Savory Basin, together with earlier sediments that had been eroded from the Paterson Orogen rocks. The faulting and minor folding of the Wells Foreland Basin could be regarded as the final episode of tectonism associated with the Paterson Orogeny.

The timing of the deformation in the Paterson Orogen during the Paterson Orogeny is constrained by two events. Firstly, the deformation post-dates the glacial event in the Savory Basin. The glacigenic Boondawari Formation was deposited before Depositional Sequence D was laid down in the Wells Foreland Basin. Some uncertainty still exists as to the exact age of this Late Proterozoic glaciation in the Savory Basin. However, field evidence is weighted towards the younger 670 Ma event (*see* Chapter 5).

Secondly, the upper limit for deformation is constrained by the age of the post-tectonic Mount Crofton Granite, which has intruded Yeneena Basin rocks to the north of the Savory Basin (Clarke, 1991). Trendall (1974) reported a Rb–Sr isotope date of 598 ± 24 Ma — since recalculated at 601 ± 42 Ma (R_i = 0.709) by D. Nelson (pers. comm.), for the Mount Crofton Granite — while McNaughton and Goellnicht (1990) produced a Pb/Pb age of 690 ± 48 Ma (Fig. 51).

Chapter 7

Basin synthesis

Pre-Savory Basin tectonic evolution

The Savory Basin rests on the Bangemall Basin, which, in turn, developed along the Capricorn Orogen. The Capricorn Orogen (Gee, 1979a) resulted from the collision, between 2.0 and 1.6 Ga, of two separately formed Archaean cratons, the Pilbara and the Yilgarn Cratons (Myers, 1990). In the west, the Bangemall Basin rests unconformably on the high-grade metamorphic Gascoyne Complex of the Capricorn Orogen. The Gascoyne Complex is believed to coincide with the major suture zone between the two cratons (Thorne and Seymour, 1991)

Muhling and Brakel (1985) postulated that the Gascoyne Complex (then called province) formed an unstable basement for the developing marine basin of the unconformably overlying Bangemall Basin. This basin was initiated during a period of crustal extension and subsidence that centred on the Gascoyne Complex. Subsequent compressional deformation was strongest in the region overlying the Gascoyne Complex.

This deformation formed the Edmund Fold Belt by crustal shortening of the basement, which squeezed the Bangemall cover rocks against the stable Pingardy Shelf. The shortening was explained by a northward movement of the Gascoyne Complex towards the Pilbara Craton (Muhling and Brakel, 1985, p. 219). More recent work (Myers, 1990) suggested that the same event could be interpreted as intermittent readjustment following the earlier collision between the Yilgarn and Pilbara Cratons.

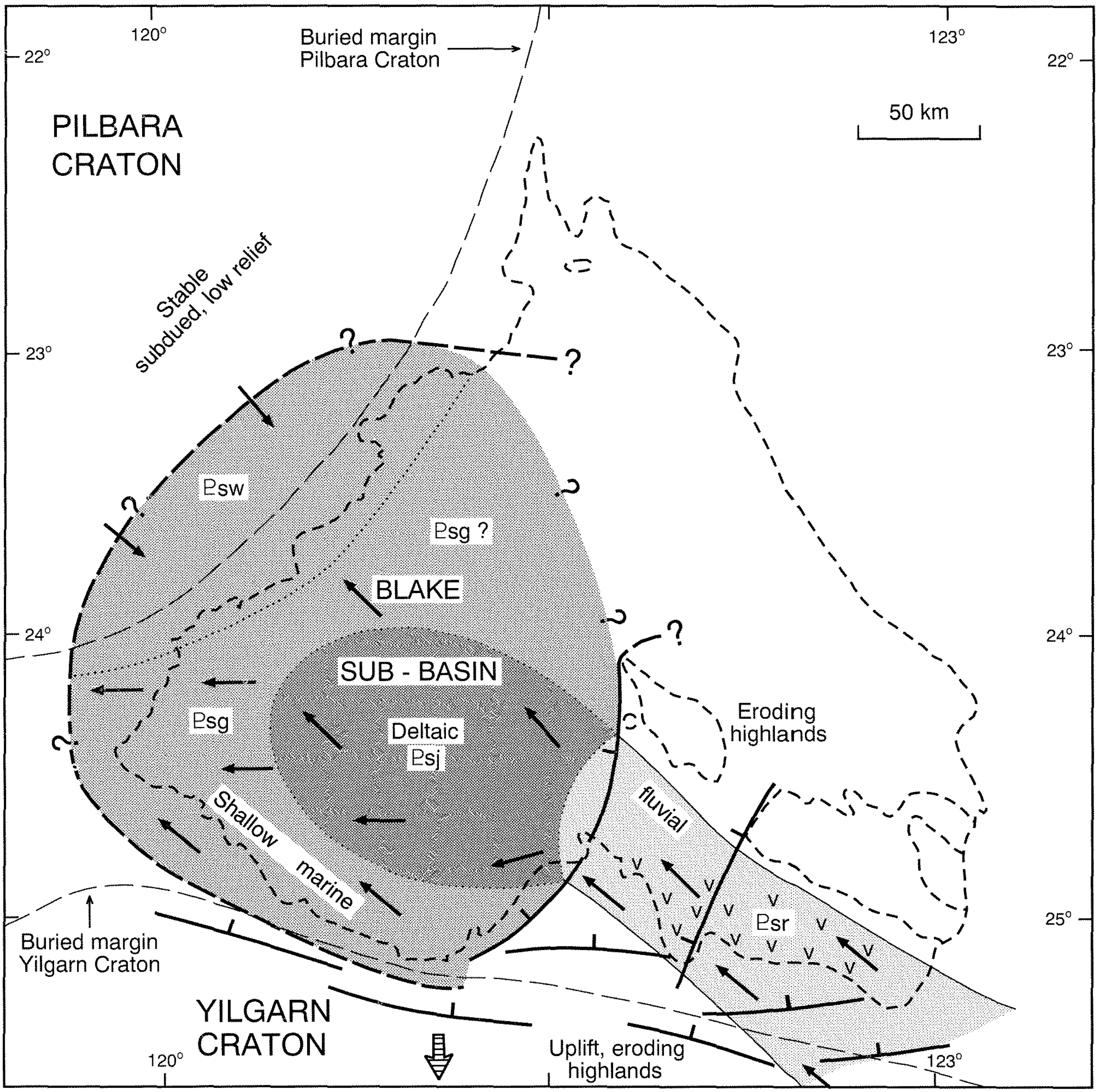
Muhling and Brakel (1985, Plate 2) showed the Edmund Fold Belt terminating at the boundary of what they called the Bullen Platform. It is now known that the rocks of the Bullen Platform are younger than those of the Edmund Fold Belt, and that the Bullen Platform coincides with the Savory Basin.

It also appears that the Edmund Fold Belt extended further to the northeast and east. It is now, however, covered by rocks of the Savory Group east of Kumarina. The Savory Basin must have been initiated by renewed instability following uplift and erosion of the Bangemall Basin. Hence, the tectonic processes which brought about the development of the Bangemall Basin may also have contributed to the initiation of the Savory Basin. These processes are attributed to further adjustments in the positioning of the Pilbara and Yilgarn Cratons.

The 1.6–1.0 Ga Bangemall Basin (Muhling and Brakel, 1985) is centrally positioned about the axis of the Capricorn Orogen (Myers, 1990). A reassessment of the Bangemall Group (Williams, 1990) showed that the distinct west to east change in lithostratigraphy could be more satisfactorily explained by a younging of the basin to the east rather than by a broad facies change. Preliminary geochronological data support this contention, and show that the oldest component in the Bangemall Group is the Edmund Subgroup, which is situated in the western part of the basin (1.6–1.2 Ga). The central and eastern parts of the basin are occupied by the (1.2–1.0 Ga) Mucalana, Collier, Manganese, and Kahrban Subgroups (Williams, 1990a). More recently, glauconite ages obtained from the Stag Arrow Formation of the Manganese Subgroup suggest that these subgroups may be slightly older, between 1.33 and 1.26 Ga (J. R. de Laeter, pers. comm.).

It would appear that, in the region between the southeastern Pilbara and the northern Yilgarn Cratons, there has been a migration of sedimentary basins from west to east, culminating in the Late Proterozoic Savory Basin. The driving force for this migration is thought to have been the continuing readjustments between the two cratons. However, the fold style in the Manganese Subgroup north of Millarie Bore and, to a lesser degree, in the Cornelia Formation along the northern sides of the Ward and Oldham Inliers indicates that the Bangemall Basin rocks have also been influenced by tectonic events that occurred northeast of the Bangemall Basin and prior to the development of the Savory Basin. The Bangemall rocks in both of these areas are tightly folded, and show northwesterly trending axes, overturning, and northeasterly dipping axial planes. The folds and axial trends are similar to those formed in the Paterson Orogen. All fold trends in the Bangemall Basin pre-date the Savory Basin.

It has been suggested that the Bangemall Basin is terminated in the northeast by the Paterson Orogen, and that it was influenced by the earlier 1.3–1.25 Ga Watrara Orogeny (Clarke, 1991). This orogeny folded and metamorphosed the Tjingkulatjatjarra Formation, and reworked an older basement of metasedimentary Yandagooge Formation and orthogneiss. These three units make up the Rudall Complex of the Paterson Orogen. It is possible that the metasedimentary rocks of the Tjingkulatjatjarra Formation are equivalent to units in the Bangemall Basin. The Watrara Orogeny was followed by the deposition of the 1.2–1.0 Ga Yeneena Basin on eroded Rudall Complex east of the Pilbara Craton before the advent of the Savory Basin at about 0.9 Ga. Both the Yeneena Basin and, to a lesser extent, the Savory Basin, were folded by the Paterson Orogeny (c. 600 Ma).



KEY TO FIGURES 104 - 110

– – – – – –	Outline Savory Basin	ᏢSg	Glass Spring Formation
················	Formation boundary (approximate)	ᏢSj	Jilyili Formation
———	Fault	ᏢSr	Brassey Range Formation
—┴—	Normal fault	ᏢSw	Watch Point Formation
—▽—	High angle reverse fault	ᏢSc	Coondra Formation
⇄	Strike-slip fault	ᏢSp	Spearhole Formation
⇕	Anticlinal axis	ᏢSm	Mundadjini Formation
⇕	Synclinal axis	ᏢSs	Skates Hill Formation
⇨	Inferred relative movement (tension)	ᏢSb	Boondawari Formation
➡	Inferred relative movement (compression)	ᏢSf	McFadden Formation
←	Prevailing palaeocurrent direction	ᏢSt	Tchukardine Formation
v v v v	Shallow mafic intrusion	ᏢSo	Woora Woora Formation
◇	Large dolerite intrusion	ᏢSd	Durba Sandstone

Note: ᏢSw transitional to depositional sequence B

Figure 104. Basin development, Phase I (Depositional Sequence A), 890–860 Ma

Except for the northeast margin, which rests unconformably on the Yeneena Basin of the Paterson Orogen (1.9–0.9 Ga), the Bangemall Basin forms the visible basement for the Savory Basin. The Bangemall Basin, followed by the Paterson Orogen, was the main provenance for detrital material deposited in the Savory Basin.

The developmental history of the Savory Basin can be broken into seven phases.

Basin development

Phase I

Phase I involves three formations, the Glass Spring, the Jilyili, and the Brassey Range, which make up Depositional Sequence A, plus a possible fourth, the Watch Point Formation, which is the basal unit of the overlying Depositional Sequence B. The full extent of the Phase I activity is not known, because exposure, except at the southwestern and southern margins of the basin, is obscured by a cover of younger Savory Group rocks.

The first evidence (Glass Spring Formation) of deposition in the newly evolving Savory Basin was a shallow-marine transgression from east to west and northwest. Coeval with the westerly marine transgression was an active transverse fluvial system (Brassey Range Formation), which flowed northwest to feed a lobate deltaic system (Jilyili Formation). This also prograded to the west and northwest over the shallow-marine Glass Spring Formation. The fluvial Brassey Range Formation was confined to a broad valley restricted in the north by what are now the Ward and Oldham Inliers. The source areas eroded by the fluvial system were the Bangemall and Nabberu Basins and possibly some granitic terrains of the underlying Yilgarn Craton.

The northwesterly directed fluvial system emptied into a depocentre in the southwestern part of the Savory Basin. Whether this area forms a local sub-basin, the Blake Sub-basin, or is part of a larger, now buried, area of sedimentation that stretched to the northeast and swung around the northern side of the Ward and Oldham Inliers, is not known. Gravity data (BMR Bouguer Anomaly Maps, BULLEN) suggest that a thick sedimentary sequence occupies the southwestern part of the Savory Basin. The relationship between this early marine transgression and similar Late Proterozoic rocks in the Officer and Amadeus Basins is also unknown.

The full extent of the marine transgression westward is also difficult to determine. If the prodelta, shallow-marine Watch Point Formation is included in Phase I, it would suggest that Depositional Sequence A may have extended a little further to the west than its outcrop indicates. Large clasts in the Glass Spring Formation, however, are locally derived from the underlying Bangemall Basin. The general configuration of Depositional Sequence A is given in Figure 104.

The Savory Basin probably started as a faulted interior fracture basin (Kingston et al., 1983). A similar process was envisaged for the genesis of the Bangemall Basin (Muhling and Brakel, 1985). The process entails block faulting and subsidence because of increased tension between the Pilbara and Yilgarn Cratons. In normal circumstances, non-marine clastics are initially deposited in such basins (Kingston et al., 1983). The basal units of the Glass Spring Formation, at least along the southern margin of the basin, are coarse-grained, probably fluvial sediments. However, these sediments were quickly overwhelmed by clastic sediments that indicate deposition on a shallow-marine shelf. These, in turn, were transgressed by the active west-northwesterly directed fluvial and deltaic system already mentioned (Brassey Range and Jilyili Formations). The southerly and southeasterly provenance of the fluvial material suggests that the southern margin of the Savory Basin was tectonically active in the initial stages. Marginal faults, parallel to the edge of the basin, have been preserved in the adjacent basement rocks. These may be eroded remnants of listric growth faults. Near-surface basalt intrusions occur in the Brassey Range Formation north of Sunday Well. The basalt may be associated with deep-seated faulting related to the tensional regime present at the initiation of the Savory Basin. The Kelly Fault, which marked the eastern edge of the Blake Sub-basin, may also have been active at that time.

Phase II

Five formations, the Watch Point, the Coondra, the Spearhole, the Mundadjini, and the Skates Hills, make up Phase II of the Savory Basin. These formations, which constitute Depositional Sequence B, indicate a radical change in palaeogeography and provenance. Phase II was initiated by extensive development of listric growth faults, the Robertson Fault System, along the northwestern margin of the basin. This fault system, whose uplift was concentrated along the northwestern side of the basin is the boundary of a half graben; and the Kelly Fault, which marks the boundary between the Trainor Platform and Blake Sub-basin, is part of the hinge line.

The early, shallow-marine shelf deposits (Watch Point and Glass Spring Formations) were dramatically overwhelmed by very coarse fan-delta deposits (Coondra Formation) and extensive, braided-stream deposits (Spearhole Formation), whose provenance lay in the Bangemall Basin to the west and southwest. Both these formations pass upwards and eastwards into the deltaic, sabkha, lagoonal, tidal flat, and probable near-shore, shallow-marine deposits of the Mundadjini Formation. The latter formation is correlated with, and coeval with, the Skates Hills Formation to the southeast. Both formations contain evidence that semi-arid conditions prevailed at the time. Most importantly, the Skates Hills Formation can be biostratigraphically correlated by means of stromatolites to the Loves Creek Member of the Bitter Springs Formation in the central Australian Amadeus Basin (Grey, 1989). Similar rocks, including evaporites (the Madley and Woolnough Diapirs), have also been found in the northern part of the Officer Basin.

It was during Phase II that a strong link may have existed between the Savory, Officer, and Amadeus Basins.

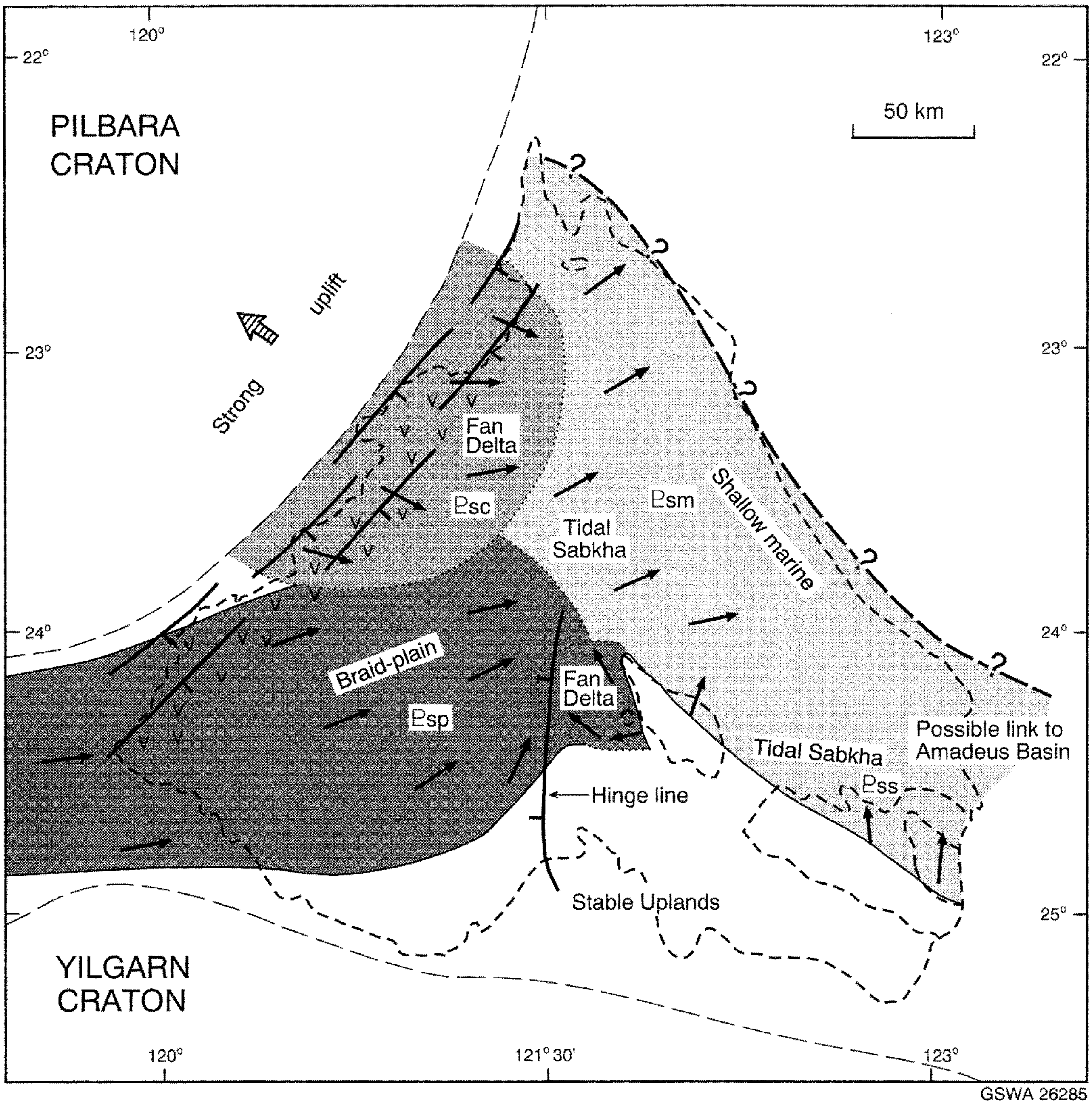


Figure 105. Basin development, Phase II (Depositional Sequence B), 860–812 Ma

If this proposal is correct, a large basin (more than 1700 km from west to east) stretched across central Australia during the period 815–840 Ma.

During Phase II, the Savory Basin most closely resembled a marginal sag basin, between two relatively stable cratons. The sedimentary rocks are asymmetrically disposed across the basin from the southwest to northeast. The build-up of these sediments progressed from non-marine clastics to shallow-marine clastics and minor carbonate rocks. The general configuration of Phase II of the Savory Basin development is given in Figure 105.

The strong, deep faulting along the northwestern margin of the Savory Basin may have enabled emplacement of near-surface basalt, amygdaloidal basalt, and fine-grained dolerite sills and intrusions, along the northwest margin of the basin to take place. Later reactivation of these faults has dislocated some intrusions.

Overall, Phase II can be viewed as a regressive marine stage with active fluvial non-marine sedimentation progressing east and northeast across the basin.

Phases III and IV

The exact relationship between Phase III, a tectonic episode leading to basin inversion, and Phase IV, a transgressive glacigenic marine period, is difficult to

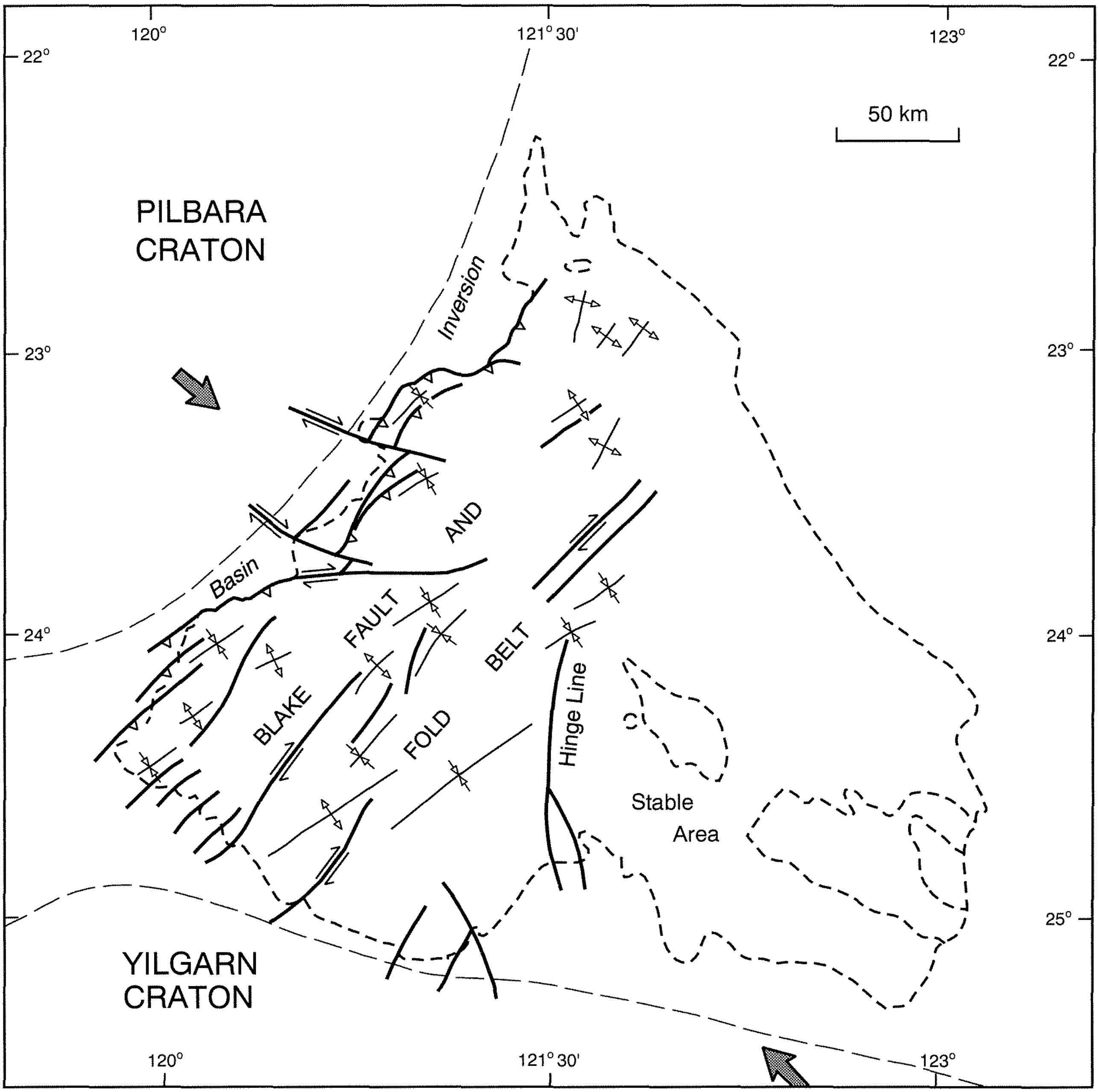


Figure 106. Basin development, Phase III (Blake Movement), 800–?700 Ma

clarify. It is partly dependent on the stratigraphic position and timing of Depositional Sequence C, the glacigenic Boondawari Formation, which is here allocated to Phase IV.

If the proposed correlation between the Boondawari Formation and the 'Pertatataka Sequence', specifically the glacigenic Olympic Formation (670 Ma) and the Pioneer Sandstone of the Amadeus Basin succession, is valid (M. Walters, pers. comm., 1991), then a long hiatus must have occurred between the Mundadjini Formation and the overlying Boondawari Formation. This proposal would leave a relatively short hiatus between the glacigenic event and the onset of the Wells Foreland Basin succession, which was a product of the Paterson Orogeny.

On the other hand, if the glacigenic Boondawari Formation is Sturtian age (c. 750 Ma), then the hiatus between the Mundadjini and Boondawari Formations must have been much shorter, and would have been of the same length as the period recorded in the Amadeus Basin as the Areyonga Movement. This proposal leaves a longer hiatus between the Boondawari Formation and the Wells Foreland Basin succession.

The Boondawari Formation is recognized as a separate depositional sequence showing both disconformable and unconformable relationships with overlying and underlying formations. Apart from the proposed correlation with the Amadeus Basin, the main constraints on the age of the Boondawari Formation in

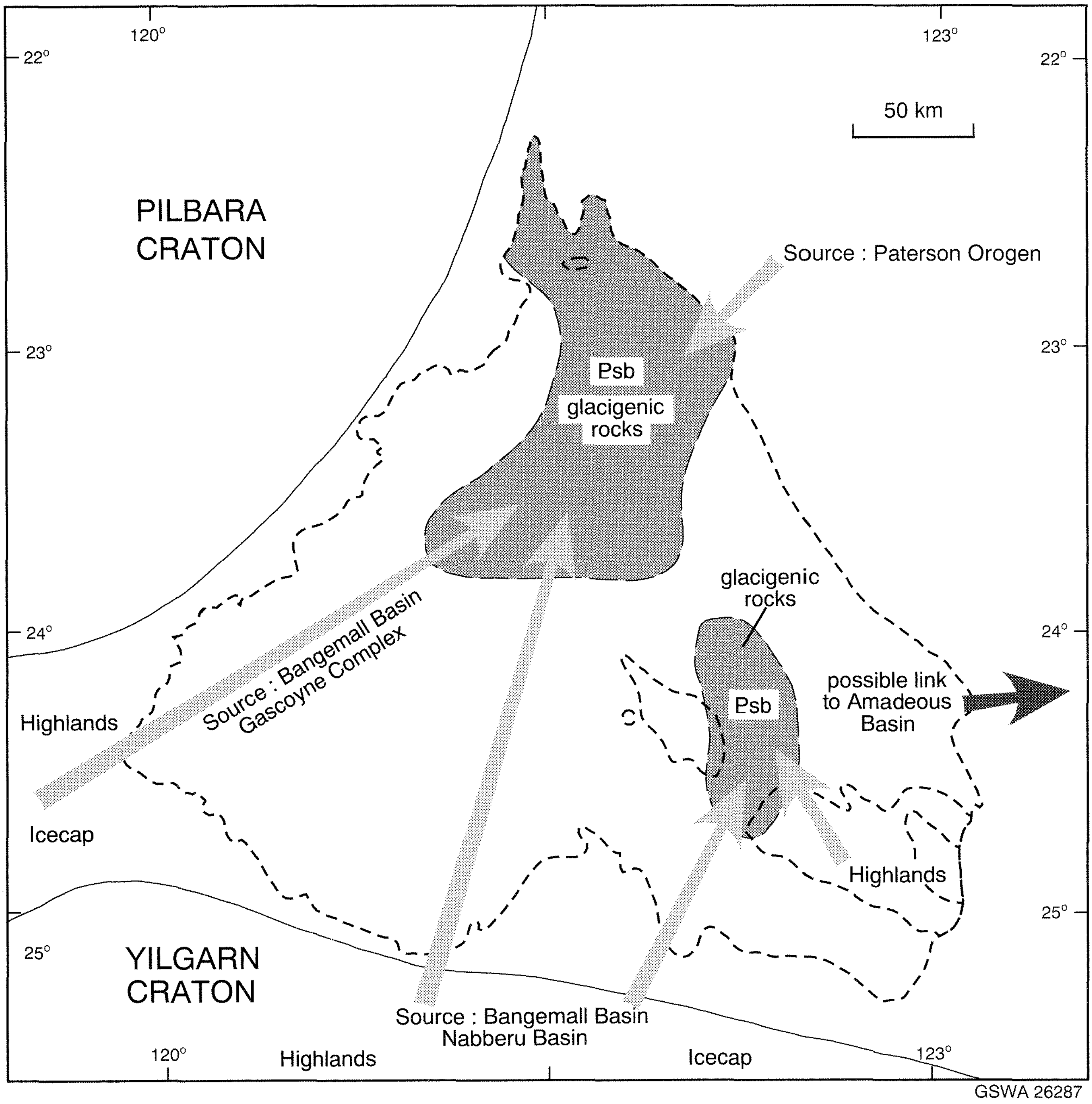


Figure 107. Basin development, Phase IV (Depositional Sequence C), 680–650 Ma

the Savory Basin are the intrusion of the Boondawari Dolerite at 640 Ma, and field evidence showing that the Boondawari Formation was folded and faulted before the McFadden and Tchukardine Formations were deposited in the Wells Foreland Basin. This later event is, in turn, constrained to the 630–600 Ma period by the intrusion of the post-tectonic (post-Paterson Orogeny) Mount Crofton Granite at 601 ± 42 Ma.

A mild compressional episode that replaced the tensional regime operative during deposition of Depositional Sequences A and B is herein called the Blake Movement. The change produced uplift, gentle folds, and a mixture of steep reverse, normal, and strike-slip faults. The culmination of the movement was expressed in local basin inversion along the half-graben structure, the Robertson Fault System, on the northwestern margin of the Savory Basin (*see* Chapter 5). The deformation caused by this event is concentrated in the southwestern part of the Savory Basin, which coincides with the Blake Sub-basin, and resulted in the Blake Fault and Fold Belt. The adjoining Trainor Platform remained stable and shows little evidence of these movements.

A pause during the Blake Movement saw a widespread, but brief, marine transgression from east to west. This was recorded by the deposition of the upward-shallowing glacigenic marine sequence of the Boondawari Formation. The lithologies of the large ice-rafted boulders found in the diamictite indicate that the provenance was

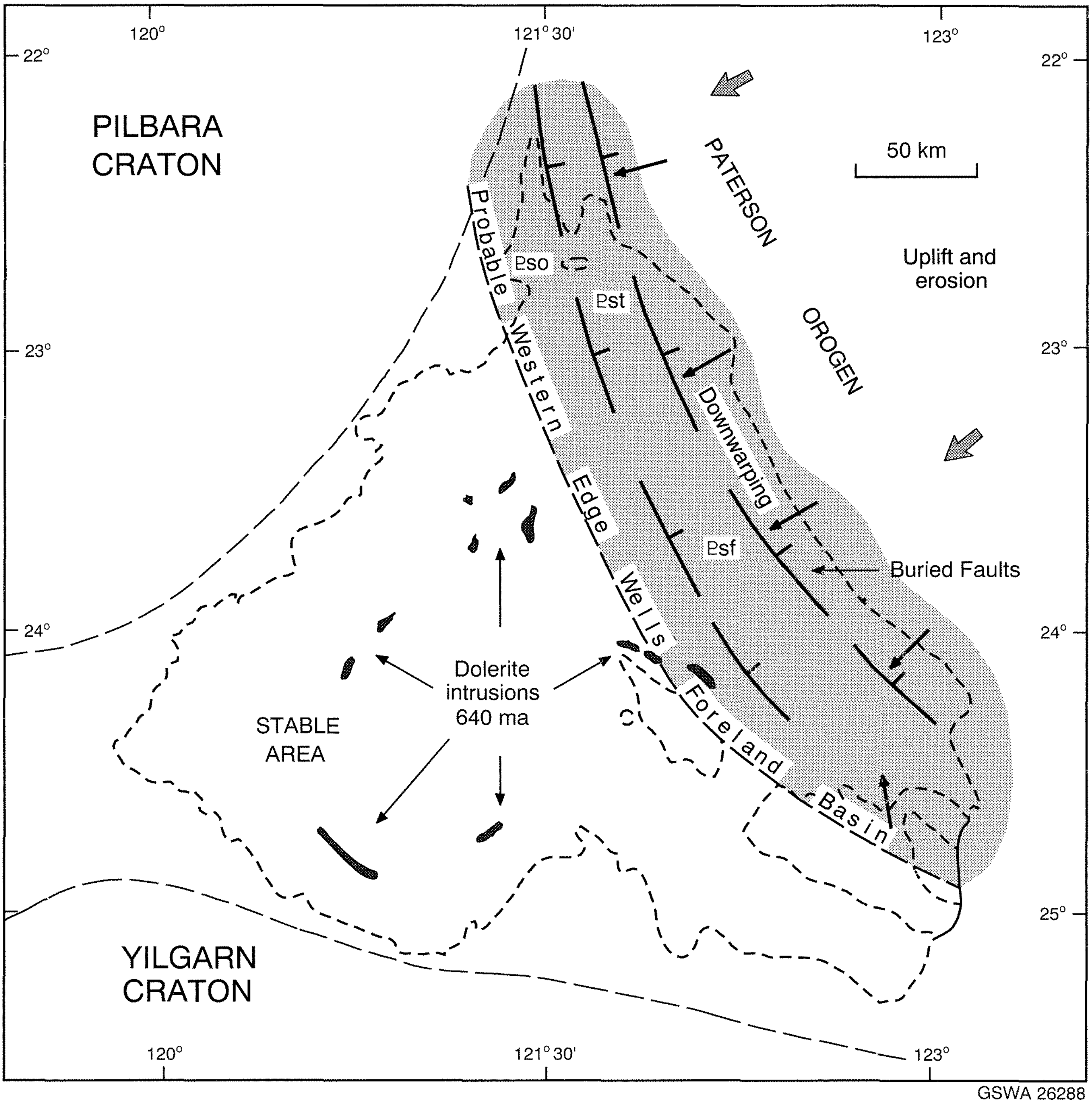


Figure 108. Basin development, Phase V (Depositional Sequence D), 640–620 Ma

extrabasinal and that it lay mainly to the southwest and south of the Savory Basin in the Bangemall and Nabberu Basins, and possibly the Gascoyne Complex (*see* Chapter 3).

Renewed folding and faulting followed deposition of the Boondawari Formation (Depositional Sequence C). The duration and timing of the event that caused basin inversion is not clear; but, in the main, it probably preceded deposition of the Boondawari Formation. Certainly, the folding and faulting of the Boondawari Formation belong, in style and trend, to the Blake Movement.

The general configuration of the Savory Basin during Phases III and IV is given in Figures 106–107.

Phase V

Phase V events were restricted to the northeastern part of the Savory Basin. This area recorded the last major influx of clastic material. Palaeocurrent data from these clastics showed that there had been a significant change in provenance, a change which saw the Paterson Orogen in the northeast supersede the Bangemall Basin in the west as the major supplier of clastic material to the basin.

This new influx of clastic material constitutes Depositional Sequence D, which comprises three formations ranging from the widespread McFadden Formation to the more restricted, but coeval, Tchukardine and Woora Woora Formations. All three units are faulted

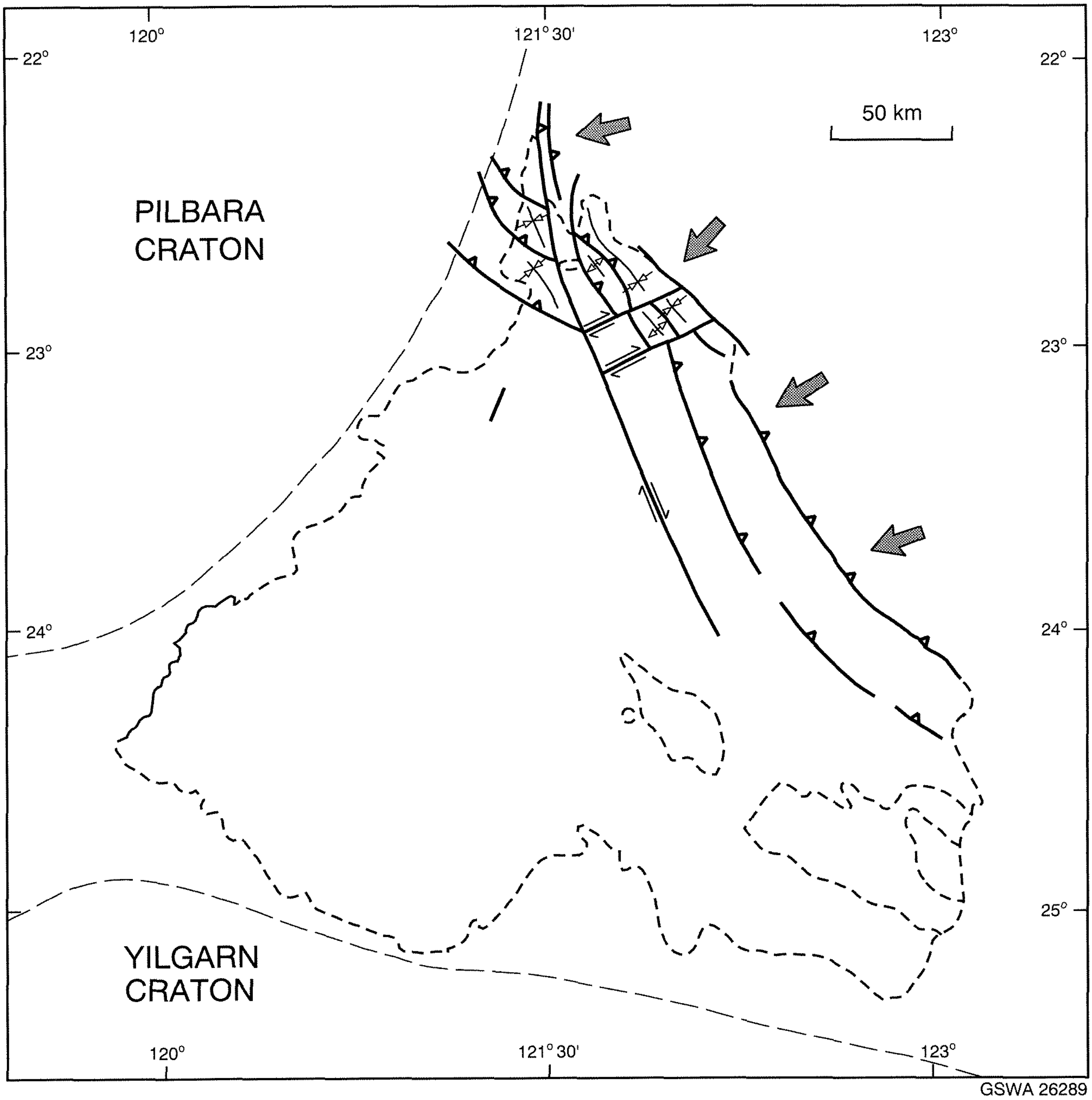


Figure 109. Basin development, Phase VI (Paterson Orogeny), 620–600 Ma

against, or rest disconformably and/or unconformably on, older units of the Savory Basin.

The tectonic unit which hosts the Depositional Sequence D is the incipient Wells Foreland Basin. This gentle depression formed between uplifted Paterson Orogen (Yeneena Group, Rudall Complex, and Karara Formation) and the stabilized older components of the Savory Basin, namely the Trainor Platform in the south, the Blake Sub-basin in the southwest, and the Bangemall-covered margin of the Pilbara Craton to the west. Increasingly active thrust forces, the beginnings of the Paterson Orogeny (c. 620–600 Ma), formed southwesterly directed compressive folds in the Paterson Orogen at this time (Clarke, 1991, p. 4).

Large faults, such as the Marloo Fault, and the southern extensions of the Vines Fault (Williams and Myers, 1990), may have been zones of tensional weakness during the early stages of the Wells Foreland Basin. These same faults were probably growth faults during the deposition of the earlier Yeneena Basin, the sedimentary cover sequence on the Rudall Complex. Hence, renewed movement on these old faults that were associated with the activity in the Paterson Orogen enabled deposition to take place along the northeastern margin of the Savory Basin. The strong fault control of sedimentation in the Wells Foreland Basin suggests that it did not extend much further west than the present day Marloo Fault. This event can be also described as a further marine transgression westward into the Savory Basin.

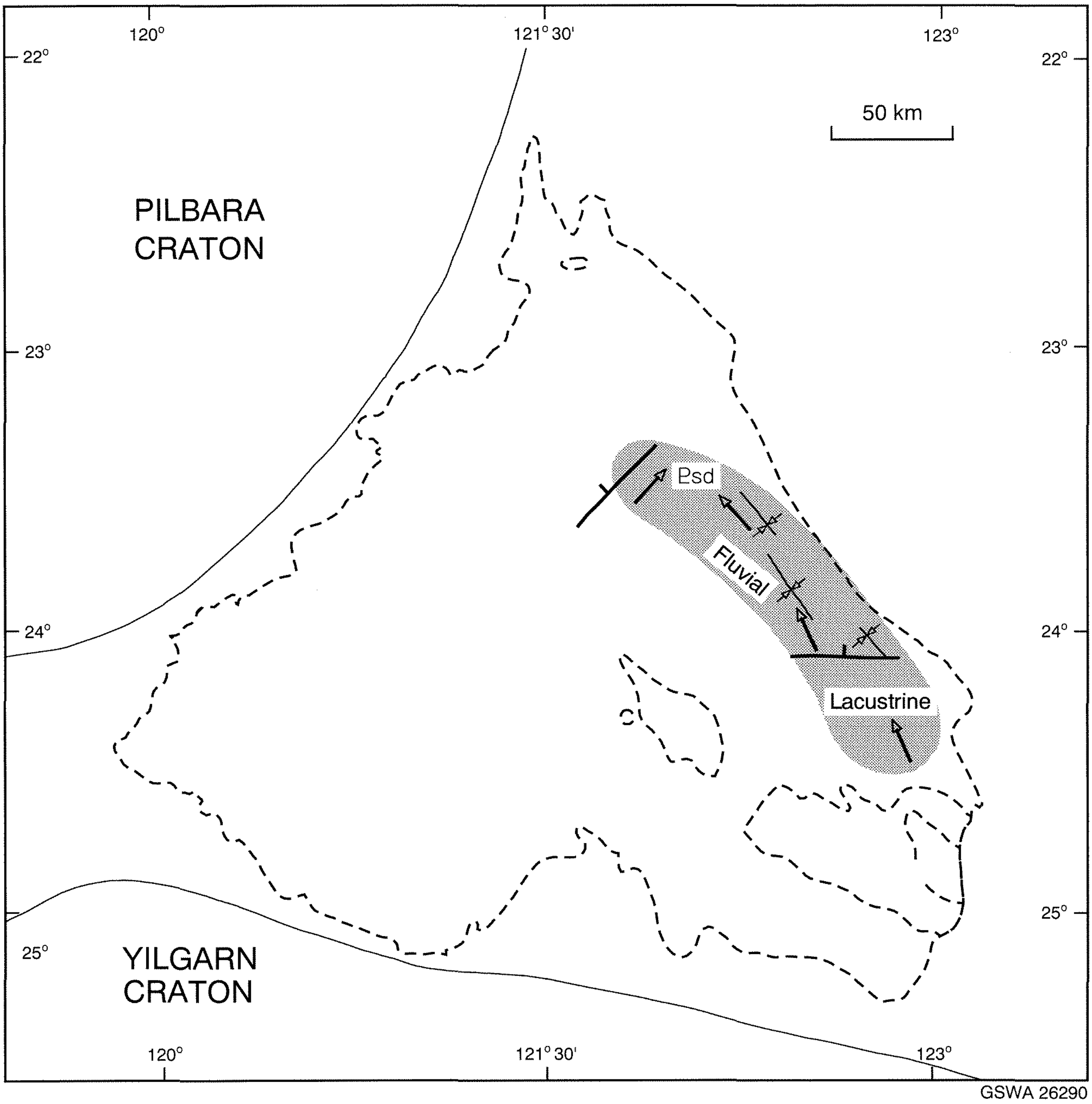


Figure 110. Basin development, Phase VII (Depositional Sequence E), ?605 Ma

Further south, the Ward and Oldham Inliers appear to have formed a southern boundary to the Wells Foreland Basin. Palaeocurrent data and a change of composition in the sandstone of the McFadden Formation in this area suggest that these inliers were exposed and contributed clastic material to the basin.

The general configuration of the Savory Basin during Phase V is given in Figure 108.

Phase VI

The deposition, in the Wells Foreland Basin, of clastic material derived from the Paterson Orogen was brought to a close by uplift associated with the encroachment of southwesterly directed folds and thrusts of the Paterson Orogeny into the Savory Basin. This event forms Phase VI of the Savory Basin Development.

The Paterson Orogeny (c. 620–600) is the last tectonic episode, for which there is evidence of Savory Basin involvement. The main effects of the Paterson Orogeny on the Savory Basin were the production of minor thrusts and steep reverse faults, with limited transport and strong dextral and sinistral movement on strike-slip faults. Folding is moderate and open. Faulted anticlinal structures can be found in some areas. All faults are brittle fractures with well-formed slickensided fault surfaces; penetrative foliations are absent from the Savory Basin rocks. The

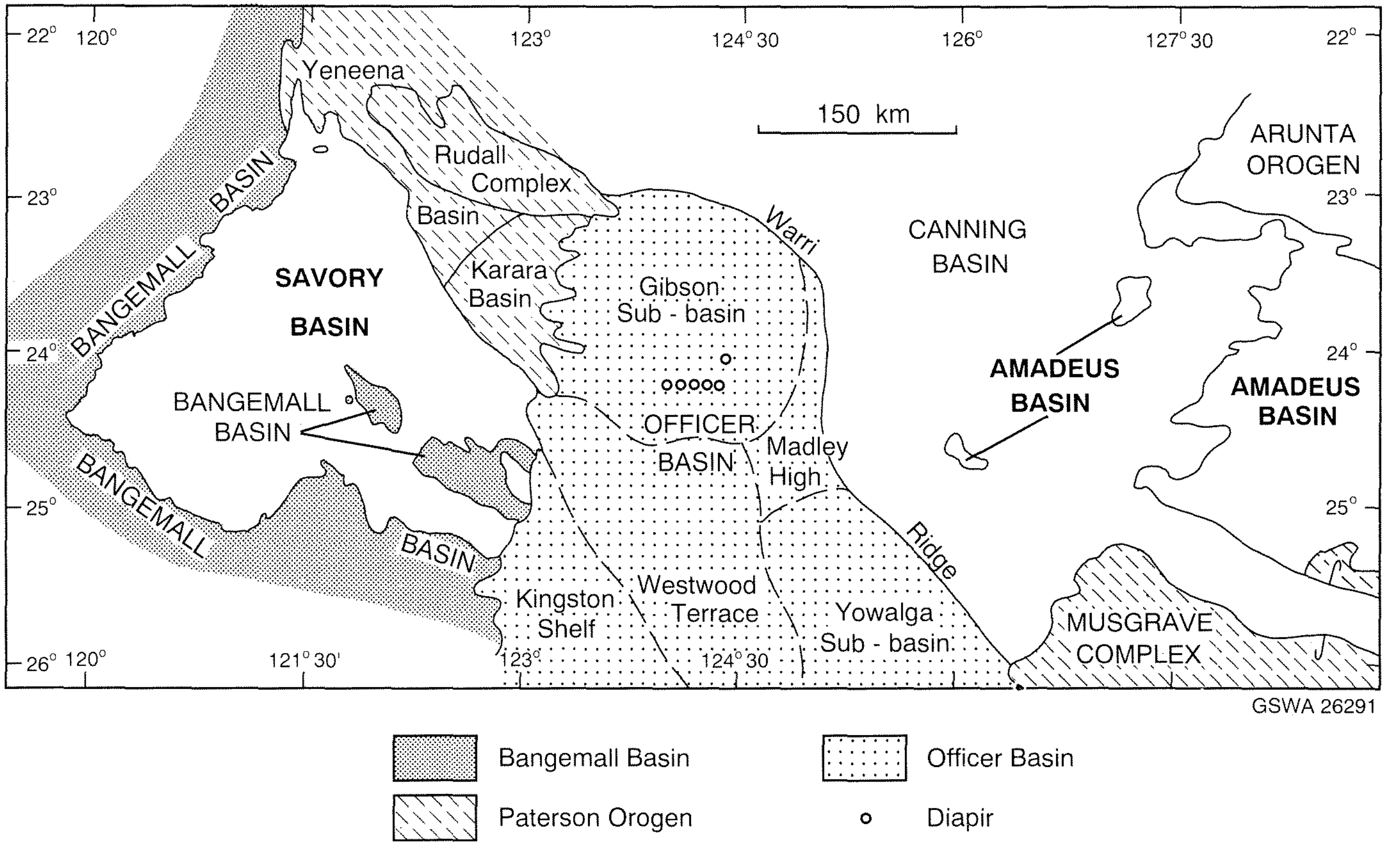
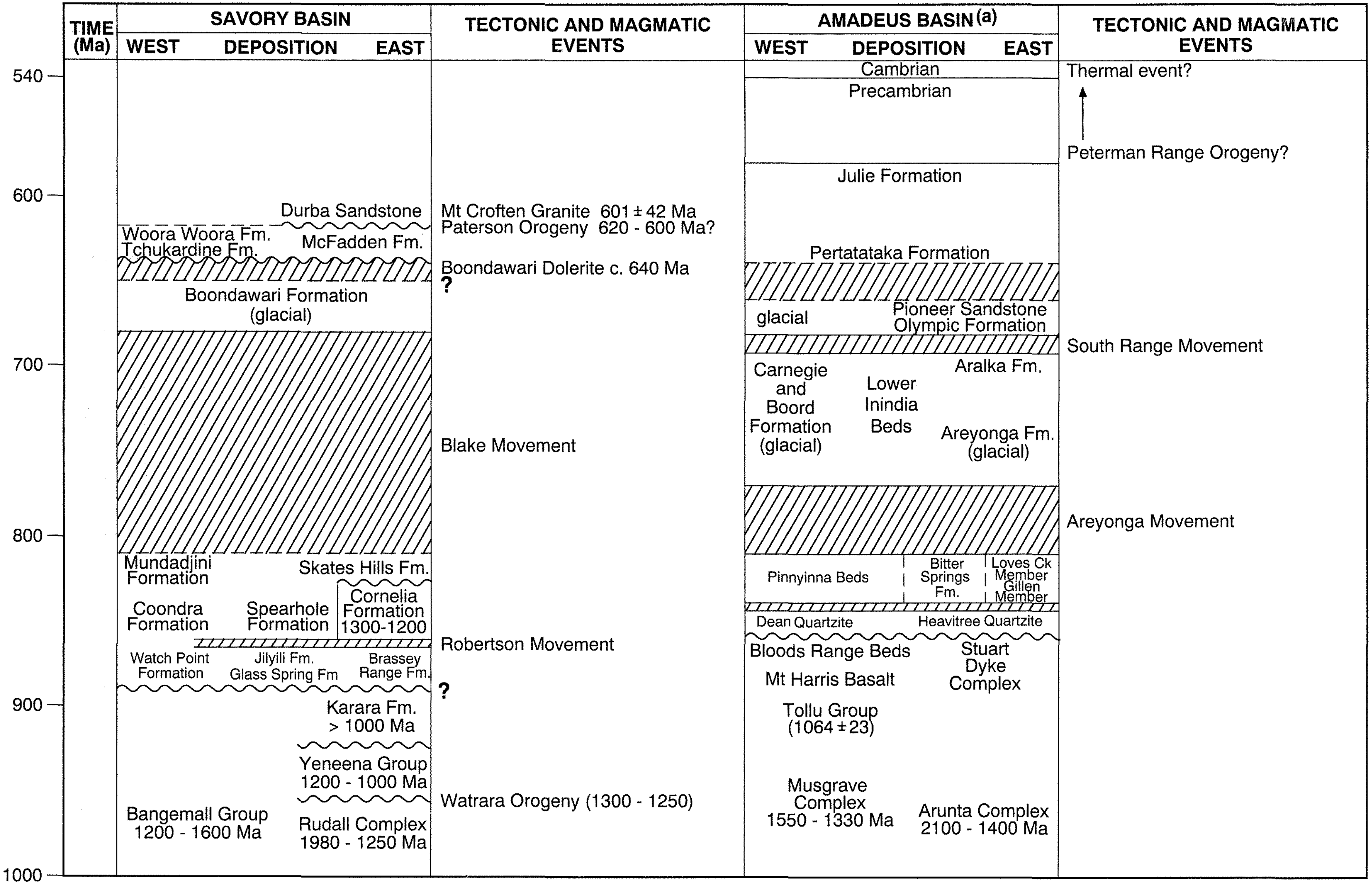


Figure 111. Regional setting of Savory and Amadeus Basins



(a) Lindsay and Korch, 1991

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Figure 112. Correlation chart, Savory and Amadeus Basins

Paterson Orogeny affected only the northeastern margin of the Savory Basin (Fig. 110).

Phase VII

The final sedimentation recorded is Depositional Sequence E, which consists of one formation, the Durba Sandstone. This unit, which is seen to unconformably overlie the McFadden and Boondawari Formations, remains only as isolated exposures. The Durba Sandstone appears to have been confined to the northeastern part of the Savory Basin, to a shallow basin that was elongated parallel to the northwesterly trending Paterson Orogen (Fig. 110).

The sediments are largely fluviatile, but some, possibly shallow-marine or lacustrine, are found at the top of the formation. This material appears, from the composition of larger clasts and palaeocurrent data, to have been derived from basement highs now represented by the Ward and Oldham Inliers in the southern part of the Savory Basin. The age of the Durba Sandstone is not known, but it may be 600 Ma or less.

Concluding remarks

As pointed out in Chapter 2, the Savory Basin probably did not extend much past the present-day erosional boundaries, which are exposed on the southern, western, and northern sides of the basin. Because the eastern boundary of the basin is now defined by the unconformably overlying Phanerozoic portion of the Officer Basin, the depositional boundary cannot be seen. A summary by Iasky (1990) indicates that, while the Officer Basin is dominantly Late Proterozoic, the present boundaries are loosely defined by the limits of the unconformably overlying Phanerozoic component of the basin. The basal units of the Officer Basin rest unconformably on the Tollu Volcanics (1064 ± 23 Ma; Page et al., 1984) in the east, and on the Bangemall Basin (1.2–1.0 Ga; Williams, 1990) in the west. Seismic surveys and a few petroleum exploration wells suggest that as much as 7 km of Proterozoic and about 1 km of Phanerozoic sedimentary rocks are present in the western part of the Officer Basin.

At present, the defined boundaries of the Savory Basin and the Amadeus Basin are about 450 km apart. The two basins lie roughly between the same latitudes, 23° and 25°S. In the area between the two basins, Proterozoic inliers, including the Madley and Woolnough Hills diapirs, contain glacigenic and evaporitic units and stromatolites similar to those described from the Savory and Amadeus Basins (Fig. 111).

The Officer Basin is separated from the Canning Basin by the Warri Ridge (Iasky, 1990) — also called the Anketell gravity ridge by Fraser (1976) — which links the exposed part of the Paterson Orogen to the Musgrave Complex. The Warri Ridge is assumed to be the subsurface expression of the Paterson Orogen. Two deep troughs, the Gibson and the Yowalga Sub-basins, lie adjacent to the southwestern margin of the Warri Ridge. If one takes into account the observations made on the exposed Rudall Complex and Yeneena Basin of the Paterson Orogen (Clarke, 1991), the two asymmetric sub-basins can be interpreted as foreland basins, similar to the newly described Wells Foreland Basin of the Savory Basin. All of these basins are postulated to have formed in front of the southwesterly directed fold and thrust belt generated during the Paterson Orogeny (620–600 Ma). The Karara Formation, which unconformably overlies the Yeneena Group, is probably the surface expression of the western part of the Gibson Sub-basin.

The geological histories of the Savory and Amadeus Basins are summarized in Figure 112. Even with the limited amount of data available, it has been possible to show that the Savory Basin has lithostratigraphic and biostratigraphic similarities to the Amadeus Basin and that the two basins also formed at the same time. However, these relationships can be interpreted in two ways:

1. The two basins are remnants of a single basin which occupied a large part of central Australia in Late Proterozoic times. As a result of the Paterson Orogeny (620–600 Ma), the (western) Officer and Savory Basins became separated from the (eastern) Amadeus Basin, a separation now marked by the Warri Ridge. In consequence, it appears that the Savory Basin, and that part of the Officer Basin which occupies the area north of latitude 25°S, did not participate in the continuous lower Palaeozoic deposition characteristic of the Amadeus Basin and Phanerozoic Canning Basin. Evidence for lower Palaeozoic deposition in the Officer Basin north of latitude 25° is very poor (Jackson and van de Graaff, 1981, p. 79). Permian and Cretaceous sedimentary rocks rest unconformably on both basins.

2. The Savory and Amadeus Basins developed separately, but at the same time and under similar climatic conditions. In this case, the Warri Ridge (Paterson Orogen) always acted as a barrier or basement high during the last part of the Proterozoic Era. The Savory Basin extended southeast into the Officer Basin whilst, to the north of the Warri Ridge, the Amadeus Basin extended northwest into the Canning Basin region.

On the basis of available evidence, the first proposal is favoured.

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Appendix 1

Summary of previous investigations of region covered by Savory Basin

Name	*Year*	*Remarks* *(1:250 000 map names are printed in full capitals)*	*Reference*
		Phase 1—Early exploration and surveys 1874–1908	
John Forrest	1874	Exploration north of Weld Spring; parts of TRAINOR	Feeken et al., 1970
Ernest Giles	1876	Exploration, west to east traverse; mainly just south of latitude 24°; crossed COLLIER, BULLEN, TRAINOR	Giles, 1889 Feeken et al., 1970
Lawrence Wells	1896	Exploration; leader of the Calvert Scientific Exploring Expedition; traversed parts of GUNANYA, TRAINOR, STANLEY; first reference to sandstone in this region.	Wells, 1902 Feeken et al., 1970
W. F. Rudall	1896–1897	Exploration; search party for lost members of the Wells expedition; ROBERTSON, BALFOUR DOWNS, RUDALL	Feeken et al., 1970
F. H. Hann	1897	Surveying; pastoral investigations; RUDALL, BALFOUR DOWNS	Government Statistician (Australian Bureau of Statistics), 1906, p. 103–104.
F. H. Hann	1902–1906	Surveying; pastoral investigations; NABBERU, BULLEN, TRAINOR	Hann's Notebooks held in J.S. Battye Library, Perth, Western Australia
A. W. Canning	1906–1907	Explored and surveyed Canning Stock Route; crossed NABBERU, STANLEY, TRAINOR, GUNANYA	Canning, 1908
	1908	Completion of No. 1 Rabbit Proof (Vermin) Fence; ROBERTSON, BULLEN	Government Statistician's Office, Perth, (Australian Bureau of Statistics), 1958
		Phase 2—Early Geological Work 1908–1959	
H. W. B. Talbot	1908–1909	Accompanied A. W. Canning's well-sinking party; first geological account of rocks from STANLEY, TRAINOR, GUNANYA; assigned sedimentary rocks to Nullagine Series; proposed a Devonian age	Talbot, 1910
H. W. B. Talbot	1913–1914	Geological reconnaissance covering parts of NABBERU, BULLEN, COLLIER, ROBERTSON; assigned sedimentary rocks to Nullagine Beds; proposed Ordovician age	Talbot, 1914, 1919, and 1920
E. Kidson	1914	Magnetic survey along Canning Stock Route	Kidson, 1921
A. Gibb Maitland	1920	Geological sketch map of Western Australia; showed sedimentary rocks of the Savory Basin region as Nullagine; ?Upper Proterozoic age	Map only: GSWA plan no. 6469 on microfiche aperture card 6469
H. W. B. Talbot	1928	Revised publication of maps to accompany Bulletin 83; showed region as Nullagine Beds; proposed Lower Cambrian or Precambrian age	Talbot, 1928
T. Blatchford	1933	Geological sketch map of Western Australia; showed region as Nullagine of Proterozoic age	Map only: GSWA plan no. 4567
J. H. Lord and N. M. Gray	1949	Geological sketch map of Western Australia; showed region as Nullagine System of Proterozoic age	Map only: GSWA plan no. 711 and plan no. 1587

Name	*Year*	*Remarks* *(1:250 000 map names are printed in full capitals)*	*Reference*
J. T Veevers and A. T. Wells	1956	Traversed and described Precambrian sedimentary rocks, later to be assigned to the Savory Basin, between Boorabee Hill and the Emu Range	Veevers and Wells, 1961
G. H. Low and R. R. Connelly	1957	Geological sketch map of Western Australia; showed region as Nullagine System of Proterozoic age	Map only: GSWA plan no. 14844
		Phase 3—Systematic regional mapping 1959- 1982	
L. de la Hunty	1959–1960	Field work on BALFOUR DOWNS marked beginning of regional 1:250 000-scale geological mapping by Geological Survey of Western Australia in this area; sedimentary rocks, later to be included in the SavoryBasin, were mapped as 'Bocrabee Sandstone' of Proterozoic age	de la Hunty, 1964
Geological Survey of Western Australia	1964	Provisional subdivision of the Precambrian in WA; sedimentary rocks, later assigned to the Savory Group, placed in the Upper Proterozoic	Geological Survey of Western Australia, 1965, p. 71, plate 35; 1980, p. 9. GSWA plan no. 2124
L. de la Hunty	1965	Field work on ROBERTSON; sedimentary rocks, later to be assigned to the Savory Group, mapped as Waltha Woora Beds of Middle Proterozoic age	de la Hunty, 1969
R. C. Horwitz	1965	Geological Map of Western Australia, 1966, placed sedimentary rocks, later to be assigned to the Savory Group, in the Bangemall Group of Middle Proterozoic age	Horwitz, 1966
P. J. Kennewell	1971	Field work on MADLEY, described unnamed Proterozoic rocks along western margin of the sheet; first description of stromatolitic dolomites from the Skates Hills	Kennewell, 1975
J. L. Daniels	1967–1971	Work for Memoir 2; sedimentary rocks, later assigned to the Savory Group, were included in the Bangemall Group; the Waltha Woora Beds (de la Hunty, 1969) tentatively correlated with the Kurabuka Formation	Daniels, 1975
Geological Survey of Western Australia	1973	Geological Map of Western Australia shows area, later to be assigned to the Savory Group, as middle Proterozoic Bangemall Group; assigned an age range of 1.1–1.0 Ga	Geological Survey of Western Australia 1975, Plate 1
A. T. Brakel M. Elias J. C. Barnett	1974–1975	Field work on COLLIER; a small area of sandstone on the eastern edge of the sheet, now assigned to the Savory Group, was mapped as Calyie Sandstone of the Middle Proterozoic Bangemall Group	Brakel et al., 1982
R. J. Chin I. R. Williams S. J. Williams	1975	Field work on RUDALL; helicopter reconnaissance mapping; sandstones in the southwest quarter of the sheet, later to be assigned to the Savory Group, mapped as Calyie and McFadden Sandstones of the Middle Proterozoic Bangemall Group; unconformity established between these rocks and the underlying Yeneena Group	Chin et al., 1980
I. R. Williams S. J. Williams R. J. Chin	1975	Field work on GUNANYA; helicopter reconnaissance mapping; rocks, later to be assigned to the Savory Group, mapped as Calyie, McFadden, and Durba Sandstones of the Middle Proterozoic Bangemall Group; unconformity recognized at base of Durba Sandstone	Williams and Williams, 1980
A. T. Brakel R. E. J. Leech I. R. Williams	1975	Field work on TRAINOR; helicopter reconnaissance mapping; rocks, later to be assigned to the Savory Group, mapped as Calyie, McFadden, and Durba Sandstone, and Skates Hills Formation of the Middle Proterozoic Bangemall Group; unconformity recognized at the base of the Skates Hills Formation; first identification of the stromatolite *Acaciella* in the Skates Hills Formation (Grey, 1976)	Brakel and Leech, 1980

Name	*Year*	*Remarks* *(1:250 000 map names are printed in full capitals)*	*Reference*
R. E. J. Leech A. T. Brakel	1975	Field work on BULLEN; helicopter reconnaissance mapping; rocks, later to be assigned to the Savory Group, mapped as Calyie Sandstone of the Middle Proterozoic Bangemall Group	Leech and Brakel, 1980
R. E. J. Leech I. R. Williams	1975	Field work on STANLEY; helicopter reconnaissance mapping; rocks, later to be assigned to the Savory Group, mapped as Calyie Sandstone of the Middle Proterozoic Bangemall Group	Commander et al., 1982
A. T. Brakel R. E. J. Leech	1975	Field work on NABBERU; helicopter reconnaissance mapping; rocks, later to be assigned to the Savory Group, mapped as Calyie Sandstone of the Middle Proterozoic Bangemall Group	Bunting et al., 1982
I. R. Williams A. T. Brakel R. J. Chin S. J. Williams	1976	Paper summarizing helicopter reconnaissance mapping program on RUDALL, GUNANYA, BULLEN, TRAINOR, STANLEY, NABBERU; the region, later to be assigned to the Savory Basin, was called the East Bangemall Basin	Williams et al., 1976
R. D. Gee	1979	Geological map of Western Australia, 150th Anniversary Edition; shows the area, later to be assigned to the Savory Group, as Middle Proterozoic Bangemall Group, with an age range between 1.1 and 1.0 Ga	Gee, 1979b Map only: GSWA plan no. 18811
P. C. Muhling A. T. Brakel	1973–1982	Definitive work on the Bangemall Basin; the region now occupied by the Savory Basin was regarded as an integral part of the Bangemall Basin	Muhling and Brakel, 1985

Appendix 2

Analyses of mafic intrusions in Savory Basin

	76345	*76386*	*81966*	*81968*	*81983*	*87404*	*91658*	*91660*	*91666*	*96002*	*96009*	*96014*	*96038*	*96041*	*96042*
	Percentage														
SiO_2 (a)	54.5	54.1	53.2	53.7	54.4	52.1	53.3	54.1	53.8	54.1	54.8	54.1	53.7	53.1	53.1
Al_2O_3 (a)	15.3	14.0	13.7	15.6	15.5	15.8	14.7	17.0	14.4	13.3	14.3	13.6	16.1	14.0	13.9
Fe_2O_3 (a)	2.19	3.01	4.98	10.6	2.40	1.53	2.99	2.17	3.06	2.82	3.76	2.73	2.57	1.80	2.03
FeO (b)	7.84	8.27	6.61	1.49	7.48	7.57	8.55	6.44	9.27	8.51	7.65	8.25	7.20	9.90	9.76
MgO (a)	3.86	4.14	5.08	3.11	3.71	6.77	4.15	4.05	3.08	5.97	3.51	5.92	4.14	5.72	5.68
CaO (a)	7.68	7.71	7.22	0.73	8.00	10.6	8.55	8.92	6.80	7.96	7.16	7.97	8.89	9.18	9.22
Na_2O (a)	2.82	2.60	2.87	5.69	2.88	2.45	2.70	2.93	3.12	2.59	3.14	2.68	2.79	2.54	2.52
K_2O (a)	1.89	1.84	2.29	2.64	2.05	0.90	1.45	1.40	2.17	1.56	1.88	1.55	1.54	1.30	1.27
H_2O (b)	0.32	0.32	0.43	2.03	0.20	0.25	0.30	0.28	0.31	0.37	0.41	0.37	0.18	0.22	0.21
H_2O+ (b)	1.73	1.45	1.60	3.21	2.04	0.98	1.57	1.75	1.96	1.51	2.11	1.71	0.67	0.60	0.53
CO_2 (b)	0.29	0.14	0.02	0.14	0.42	0.23	0.33	0.28	0.50	0.28	0.30	0.28	0.18	0.15	0.04
TiO_2 (a)	1.16	1.31	1.80	1.60	1.16	0.90	1.41	0.95	1.66	1.20	1.41	1.18	1.08	1.76	1.77
P_2O_5 (a)	0.14	0.16	0.20	<0.05	0.13	0.08	0.13	0.12	0.15	0.13	0.16	0.13	0.12	0.20	0.21
S (a)	0.09	0.04	0.01	0.01	0.09	0.05	0.12	0.09	0.13	0.10	0.11	0.09	0.09	0.03	0.04
MnO (a)	0.21	0.28	0.17	0.08	0.21	0.18	0.22	0.19	0.25	0.21	0.21	0.21	0.19	0.20	0.20
O=S (c)	0.04	0.02	<0.01	<0.01	0.05	0.02	0.06	0.04	0.06	0.05	0.05	0.05	0.05	0.01	0.02
Other (d)	0.19	0.22	0.29	0.23	0.20	0.17	0.21	0.17	0.24	0.18	0.20	0.19	0.17	0.24	0.24
Total (e)	**100.2**	**99.6**	**100.5**	**100.9**	**100.8**	**100.5**	**100.6**	**100.8**	**100.9**	**100.8**	**101.1**	**100.9**	**99.6**	**100.9**	**100.7**
	Parts per million, except where indicated														
Ba (a)	378	367	801	379	335	150	291	255	385	266	357	293	264	415	430
Ce (a)	47	54	53	28	47	28	45	38	52	44	56	47	40	52	50
Cr (a)	5	6	25	31	11	157	<4	15	<4	26	<4	26	7	41	45
Cu (a)	47	56	145	14	62	73	77	53	44	49	51	51	59	143	140
Ga (a)	20	20	20	23	18	17	20	20	20	19	20	20	21	21	20
Hf (a)	5	7	8	5	7	<4	<4	6	4	7	5	7	6	4	6
La (a)	23	24	23	33	18	11	22	20	25	21	27	23	24	21	24
Li (f)	21	29	23	10	27	9	18	19	20	16	21	20	18	8	8
Nb (a)	8	9	7	11	9	<7	9	8	9	8	7	<7	8	8	9
Ni (a)	19	22	89	46	22	73	32	27	14	44	22	39	29	117	114
Pb (a)	17	41	11	26	25	8	12	31	31	11	11	14	16	11	13
Pd (g)	<5	<5	5	5	<5	5	<5	<5	<5	<5	<5	<5	<5	5	5
Pt (g)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Rb (a)	81	88	91	230	109	39	73	70	109	76	90	77	74	43	40
Sc (f)	28	31	24	36	27	30	32	26	30	33	29	33	28	25	25
Sn (a)	5	<4	4	4	4	<4	<4	<4	6	<4	<4	4	4	<4	<4
Sr (a)	157	157	319	111	160	149	159	176	161	147	159	160	173	264	271
Th (a)	12	11	7	14	11	6	10	10	12	10	12	10	10	7	6
U (a)	2	2	<2	3	2	<2	<2	2	2	2	3	2	2	<2	<2
V (a)	260	283	304	325	258	247	419	214	427	283	290	276	249	310	298
Y (a)	34	35	31	44	32	24	32	28	36	33	38	32	30	31	31
Zn (a)	106	252	94	152	145	76	117	116	215	97	107	105	89	103	104
Zr (a)	157	166	195	213	152	105	146	136	173	156	181	149	141	189	187

KEY: 76345—dolerite (ROBERTSON; 23°59'08"S,120°53'38"E). **76386**—dolerite (BULLEN 24°46'28"S, 120°45'00"E). **81966**—basalt (ROBERTSON; 23°45'49"S, 120°35'39"E). **81968**—basalt (ROBERTSON; 23°47'58"S, 120°47'55"E). **81983**—gabbro (ROBERTSON; 23°27'22"S, 121°23'50"E). **87404**—dolerite (ROBERTSON; 23°05'42"S, 121°16'29"E). **91658**—dolerite (ROBERTSON; 23°36'20"S, 121°27'14"E). **91660**—dolerite (ROBERTSON; 23°37'15"S, 121°27'23"E). **91666**—dolerite (ROBERTSON; 23°33'24"S, 121°27'46"E). **96002**—dolerite (TRAINOR; 24°06'37"S, 122°03'17"E). **96009**—dolerite (TRAINOR; 24°12'05"S, 122°10'45"E). **96014**—dolerite (TRAINOR; 24°18'11"S, 122°12'22"E). **96038**—dolerite (TRAINOR; 24°05'52"S, 122°01'33"E). **96041**—dolerite (STANLEY; 25°06'02"S, 122°22'48"E). **96042**—dolerite (STANLEY; 26°06'18"S, 122°04'25"E).

(a) X-ray fluorescence spectrometry. (b) Classical chemistry. (c) Calculated. (d) Sum of trace elements expressed as oxides. (e) Sum of components—O=S is deducted. (f) ICP emission spectrometry. (g) Classical chemistry—parts per billion.

Index

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

BULLETIN 141 PLATE 1

GEOLOGY OF THE SAVORY BASIN

HON. GORDON HILL, J.P., M.L.A.
MINISTER FOR MINES
D.R. KELLY, DIRECTOR GENERAL OF MINES

P.E. PLAYFORD
DIRECTOR, GEOLOGICAL SURVEY
OF WESTERN AUSTRALIA

SCALE 1:500 000

5000 0 10 20 30 40 50
Metres Kilometres

TRANSVERSE MERCATOR PROJECTION
Grid lines indicate 50 000 metre interval of the Australian Map Grid Zones 50 and 51

Compilation and geology by I. R. Williams 1984-1989

Cartography by the Cartographic Services Branch, Surveys and Mapping Division, Department of Mines, Western Australia.
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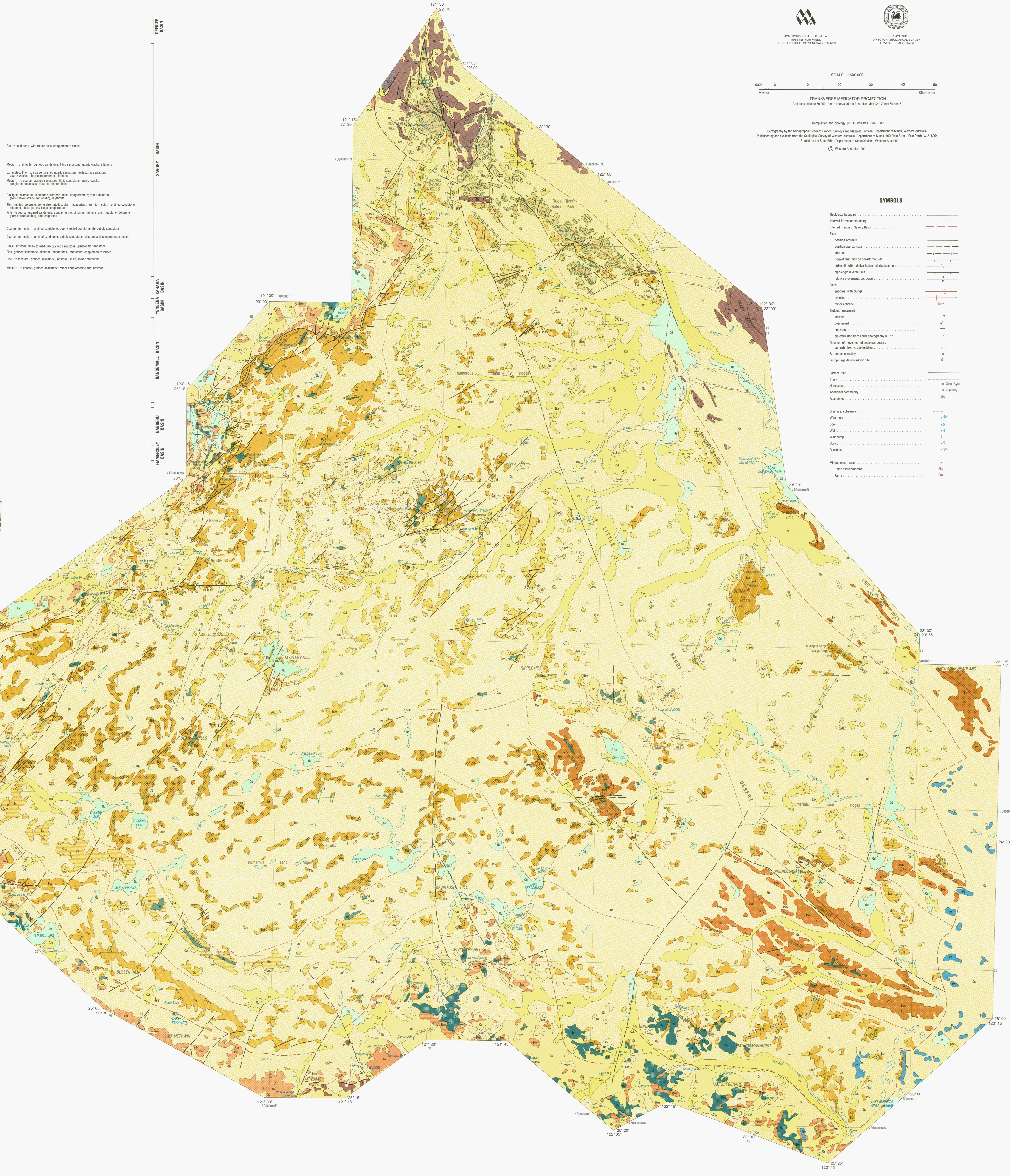


REFERENCE

PHANEROZOIC

CAINOZOIC — QUATERNARY

Qa	Alluvium—clay, silt, sand, gravel; in drainage channels and adjacent flood plains
Qd	Lacustrine deposits—clay, silt, sand; saline and gypsiferous in part; in playa lakes and claypans
Qs	Eolian sand—sand sheets; longitudinal (seif), chain and net dunes abundant; areas of ironstone pebble veneer
Qc	Colluvium—clay, silt, sand, gravel, quartz-pebble veneer; sheet wash, scree, and low slope deposits
Czk	Valley calcrete; sheet carbonate, secondary opaline silica
Czc	Consolidated colluvium; hardpan, laterite, silcrete

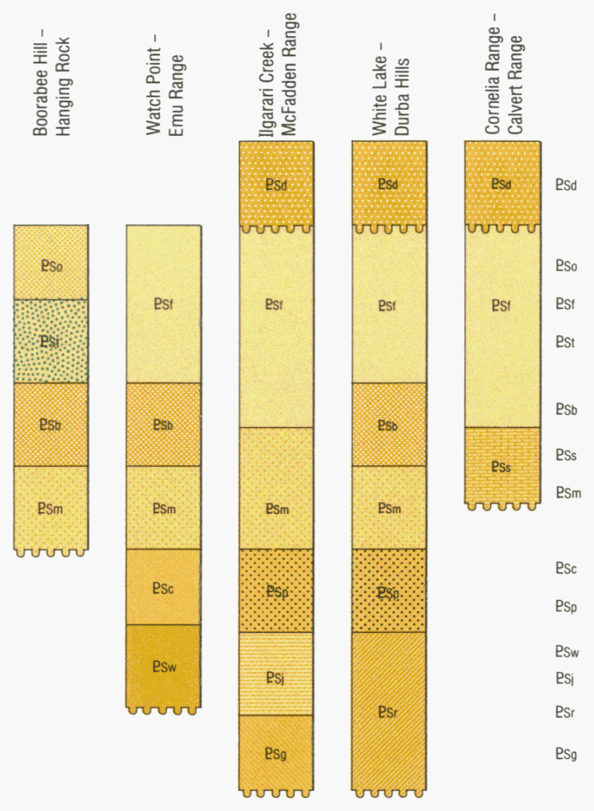
PALAEOZOIC — LOWER PERMIAN — **OFFICER BASIN**

Pp	Mainly **PATERSON FORMATION:** glacigene diamictite, sandstone, conglomerate

PROTEROZOIC

	d	Dolerite dykes, various ages
c. 640 Ma	dg	Medium- to coarse-grained dolerite, gabbro, granophyre; in sills, dykes, and small intrusions
	ds	Basalt, amygdaloidal basalt, fine-grained dolerite; in shallow-level sills, dykes and small intrusions

Savory Group — **SAVORY BASIN** (c. 670 Ma; c. 900 Ma)



ESd	**DURBA SANDSTONE**	Quartz sandstone, with minor basal conglomerate lenses
ESo	**WOORA WOORA FORMATION**	Medium-grained ferruginous sandstone, lithic sandstone, quartz wacke, siltstone
ESf	**McFADDEN FORMATION**	Laminated, fine- to coarse-grained quartz sandstone, feldspathic sandstone, quartz wacke: minor conglomerate, siltstone
ESt	**TCHUKARDINE FORMATION**	Medium- to coarse-grained sandstone, lithic sandstone, quartz wacke, conglomerate lenses, siltstone; minor shale
ESb	**BOONDAWARI FORMATION**	Glacigene diamictite, sandstone, siltstone, shale, conglomerate; minor dolomite (some stromatolitic and oolitic), rhythmite
ESs	**SKATES HILLS FORMATION**	Thin-bedded dolomite, some stromatolitic; chert, evaporites, fine- to medium-grained sandstone, siltstone, shale, patchy basal conglomerate
ESm	**MUNDADJINI FORMATION**	Fine- to coarse-grained sandstone, conglomerate, siltstone; minor shale, mudstone, dolomite (some stromatolitic), and evaporites
ESc	**COONDRA FORMATION**	Coarse- to medium-grained sandstone, poorly sorted conglomerate, pebbly sandstone
ESp	**SPEARHOLE FORMATION**	Coarse- to medium-grained sandstone, pebbly sandstone, siltstone and conglomerate lenses
ESw	**WATCH POINT FORMATION**	Shale, siltstone, fine- to medium-grained sandstone, glauconitic sandstone
ESj	**JILYILI FORMATION**	Fine-grained sandstone, siltstone; minor shale, mudstone, conglomerate lenses
ESr	**BRASSEY RANGE FORMATION**	Fine- to medium-grained sandstone, siltstone, shale; minor mudstone
ESg	**GLASS SPRING FORMATION**	Medium- to coarse-grained sandstone; minor conglomerate and siltstone

	EK	**KARARA FORMATION:** quartz sandstone, feldspathic sandstone, quartz wacke, shale, siltstone, conglomerate	KARARA BASIN
Yeneena Group	EY	Quartz sandstone, siltstone, shale; minor conglomerate, dolomite	YENEENA BASIN

BANGEMALL BASIN

	dd	**DAVIS DOLERITE:** very fine- to medium-grained dolerite in sills; prominent magnetite
	dc	Medium- to coarse-grained dolerite in sills and small intrusions
c. 1300 Ma	EMm	**MANGANESE SUBGROUP:** shale, siltstone, sandstone, conglomerate, dolomite, glauconitic sandstone, chert
	EMc	**COLLIER SUBGROUP:** sandstone, siltstone, shale; minor conglomerate, glauconitic sandstone
	EMk	**KAHRBAN SUBGROUP:** sandstone, siltstone, shale
	EMs	**CORNELIA FORMATION:** sandstone, siltstone, shale, mudstone; minor glauconitic sandstone
c. 1500 Ma	EMo	**SCORPION SUBGROUP:** dolomite (some stromatolitic), sandstone, siltstone; minor shale

Bangemall Group

NABBERU BASIN

c. 1700 Ma	Earaheedy Group	EE	Granular iron-formation, hematitic shale
		Et	**TROY CREEK BEDS:** shale, phyllite, sandstone, chert

ARCHAEAN — **HAMERSLEY BASIN**

c. 2700 Ma	Fortescue Group	AF	Mafic volcanic rocks

INDEX TO 1:250 000 SHEETS

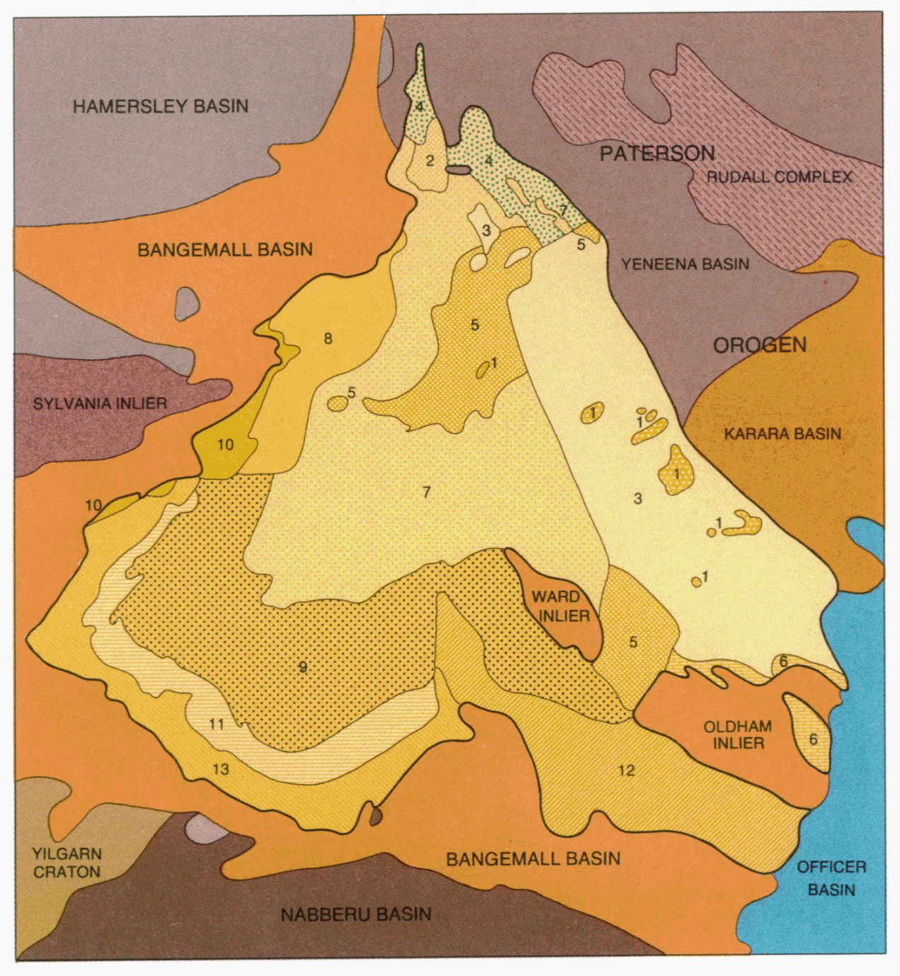
ROY HILL SF 50-12	BALFOUR DOWNS SF 51-9	RUDALL SF 51-10	TABLETOP SF 51-11
NEWMAN SF 50-16	ROBERTSON SF 51-13	GUNANYA SF 51-14	RUNTON SF 51-15
COLLIER SG 50-4	BULLEN SG 51-1	TRAINOR SG 51-2	MADLEY SG 51-3
PEAK HILL SG 50-8	NABBERU SG 51-5	STANLEY SG 51-6	HERBERT SG 51-7

LOCALITY DIAGRAM

SYMBOLS

Geological boundary	
Inferred formation boundary	
Inferred margin of Savory Basin	
Fault	
position accurate	
position approximate	
inferred	—?— —?—
normal fault, tick on downthrow side	
strike-slip with relative horizontal displacement	⇆
high-angle reverse fault	
relative movement, up, down	U D
Folds	
anticline, with plunge	
syncline	
minor anticline	
Bedding, measured	
inclined	10
overturned	75
horizontal	+
dip estimated from aerial photography 0-15°	
Direction of movement of sediment-bearing currents, from cross-bedding	→
Stromatolite locality	
Isotopic age determination site	@
Formed road	
Track	
Homestead	■ Glen-Ayle
Aboriginal community	□ Jigalong
Abandoned	(abd)
Drainage, ephemeral	
Waterhole	•WH
Bore	•B
Well	•W
Windpump	
Spring	•S
Rockhole	•RH
Mineral occurrence	•
Halite pseudomorphs	Na
Barite	Ba

REGIONAL GEOLOGY OF SAVORY BASIN



1	DURBA SANDSTONE	8	COONDRA FORMATION
2	WOORA WOORA FORMATION	9	SPEARHOLE FORMATION
3	McFADDEN FORMATION	10	WATCH POINT FORMATION
4	TCHUKARDINE FORMATION	11	JILYILI FORMATION
5	BOONDAWARI FORMATION	12	BRASSEY RANGE FORMATION
6	SKATES HILLS FORMATION	13	GLASS SPRING FORMATION
7	MUNDADJINI FORMATION		

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
BULLETIN 141 PLATE 2

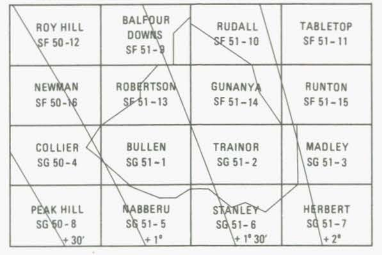
STRUCTURAL INTERPRETATION OF THE
SAVORY BASIN

HON. GORDON HILL, J.P., M.L.A.
MINISTER FOR MINES
D.R. KELLY, DIRECTOR GENERAL OF MINES

P.E. PLAYFORD
DIRECTOR, GEOLOGICAL SURVEY
OF WESTERN AUSTRALIA

Scale 1: 1 000 000

INDEX TO 1 : 250 000 ADJOINING SHEETS



The lines indicate magnetic declination, 1985
+ means declination is east and correction must be added to compass bearing to give true bearing
– means declination is west and correction must be subtracted from compass bearing to give true bearing

Annual change is – 1' westerly

Pp	Mainly **PATERSON FORMATION**	**OFFICER BASIN**
Ꞓsd	**DURBA SANDSTONE**	**SAVORY BASIN**
Ꞓso	**WOORA WOORA FORMATION**	
Ꞓst	**TCHUKARDINE FORMATION**	
Ꞓsf	**McFADDEN FORMATION**	
Ꞓsb	**BOONDAWARI FORMATION**	
Ꞓss	**SKATES HILLS FORMATION**	
Ꞓsm	**MUNDADJINI FORMATION**	
Ꞓsp	**SPEARHOLE FORMATION**	
Ꞓsc	**COONDRA FORMATION**	
Ꞓsw	**WATCH POINT FORMATION**	
Ꞓsr	**BRASSEY RANGE FORMATION**	
Ꞓsj	**JILYILI FORMATION**	
Ꞓsg	**GLASS SPRING FORMATION**	
Ꞓk	**KARARA FORMATION**	**KARARA BASIN**
ꞒY	**Yeneena Group**	**YENEENA BASIN**
ꞒM	**Bangemall Group**	**BANGEMALL BASIN**
Pt	TROY CREEK BEDS	**NABBERU BASIN**
ꞒF	**Fortescue Group**	**HAMERSLEY BASIN**

Savory Group

Formation boundary
Fault
High-angle reverse fault
Inferred high-angle reverse fault
Strike – slip fault
Relative fault movement, up, down
Anticlinal fold, with plunge
Synclinal fold, with plunge
Bedding, inclined

Interpretation by I.R. Williams, 1991

Cartography by the Cartographic Services Branch, Surveys and Mapping Division, Department of Mines, Western Australia.

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