GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 13

ECONOMIC POTENTIAL OF THE LOWER FORTESCUE GROUP AND ADJACENT UNITS IN THE SOUTHERN HAMERSLEY BASIN

A STUDY OF DEPOSITIONAL ENVIRONMENTS

DEPARTMENT OF MINES
WESTERN AUSTRALIA

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A STUDY OF DEPOSITIONAL ENVIRONMENTS

by

D. F. Blight

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ABSTRACT

Lithofacies, thickness variations, and palaeocurrent data are used to establish a model for the depositional environment of the lower part of the Fortesque Group in the southern Hamersley Basin. This model involves continental deposition within a west-northwesterly trending half-graben that is confined on the south-southwest but becomes progressively deeper to the west-northwest. Early deposition was influenced by the topography of the Pilbara Craton prior to the deposition of the Fortesque Group, a factor that has important implications with respect to the economic potential of the Fortesque Group.

The lower part of the Mount Roe Basalt is a heterogeneous mixture of clastic sediments, felsic and mafic pyroclastics, and volcanic flows, whereas the upper section is a homogeneous amygdaloidal basalt. Its deposition in a sub-aerial to shallow-water environment mitigates against the occurrence of massive sulphide deposits because the latter are associated with oceanic settings.

The Hardey Sandstone was deposited as braided-stream deposits on a plain where the prevailing current direction was from east to west. An eastern provenance for the sandstone and conglomerate of the formation may have restricted the supply of gold to the system because available evidence indicates that the southeastern part of the Pilbara Craton is chiefly composed of granitic rocks. Despite this possibility, further exploration of the Hardey Sandstone is required before the possibility of Witwatersrand type gold-uranium mineralization can be discounted.

INTRODUCTION

It was during the first year of remapping the Wyloo 1:250 000 sheet in 1980 that the diversity of rock types within the Fortescue Group was first appreciated. The study described in this report was undertaken to provide more detailed information on the geology of the Fortescue Group, especially as this would be relevant to its mineral potential and to the nature of the Hamersley Basin.

This report deals chiefly with the lower section of the Fortescue Group in the southern portion of the Hamersley Basin. The rocks concerned are exposed in the cores of domed tectonic structures between Wyloo Station and the Newman area in the east (Fig. 1). Plates 1 and 2 A, B, C, which are detailed geological maps of the Wyloo, Rocklea, Milli Milli, and Bellary Domes respectively, form the basis of this study. Except for the Wyloo area, which was part of a 1:250 000 remapping programme, geological mapping of these domes terminated at the base of the Mount Jope Volcanics.

The term Hamersley Basin was first used by Trendall (1968) to denote the area in which the Hamersley Group now occurs. Trendall and Blockley (1970) expanded this to encompass the basin of deposition of the Mount Bruce Supergroup. At that time (1970), the Mount Bruce Supergroup was defined as being composed of the Fortescue, Hamersley, and Wyloo Groups. Subsequent revisions of the Mount Bruce Supergroup were summarized by Trendall (1979), who raised the lower part of the Wyloo Group, the Turee Creek Formation, to group status and included it within the Mount Bruce Supergroup; the rest of the Wyloo Group was excluded from the Mount Bruce Supergroup. Thus the Mount Bruce Supergroup is now considered to consist of the Fortescue Group at the base, the Hamersley Group, and at the top, the Turee Creek Group (Trendall, 1979). This in turn is unconformably overlain by the Wyloo Group.

For the purpose of this report, the Hamersley Basin is considered to be the depositional basin of the Mount Bruce Supergroup as defined by Trendall (1979). Its extent is shown in Figure 1. This view of the Hamersley Basin is also implicitly expressed by Gee (1979) and Trendall (1980).

Since the 'first pass' (approximately 20 years ago) 1:250 000-scale geological mapping in the Hamersley district by the Geological Survey, little geological work has been published on the Fortescue Group in the southern part of the Hamersley Basin. The Fortescue Group conformably underlies the Hamersley Group, which is the subject of numerous publications. This is, in some way perhaps, a reflection on the paucity of known mineral deposits within the Fortescue Group in contrast with the Hamersley Group, which hosts a vast quantity of iron ore that is currently being exploited to produce a return of over $A1 billion a year.

During the course of previous 1:250 000-scale mapping, various geologists have erected a Fortescue Group stratigraphy pertinent to a particular sheet. Kriewaldt (1964), Trendall (1975), Hickman and Lipple (1978), and Hickman (1983) endeavoured to correlate these various local stratigraph successions, and on a broad scale, they were moderately successful (Table 1). Nevertheless, the stratigraphy of the Fortescue Group in the southern part of the Hamersley Basin, and to some extent in the western part of the Pilbara Block, remains poorly understood.

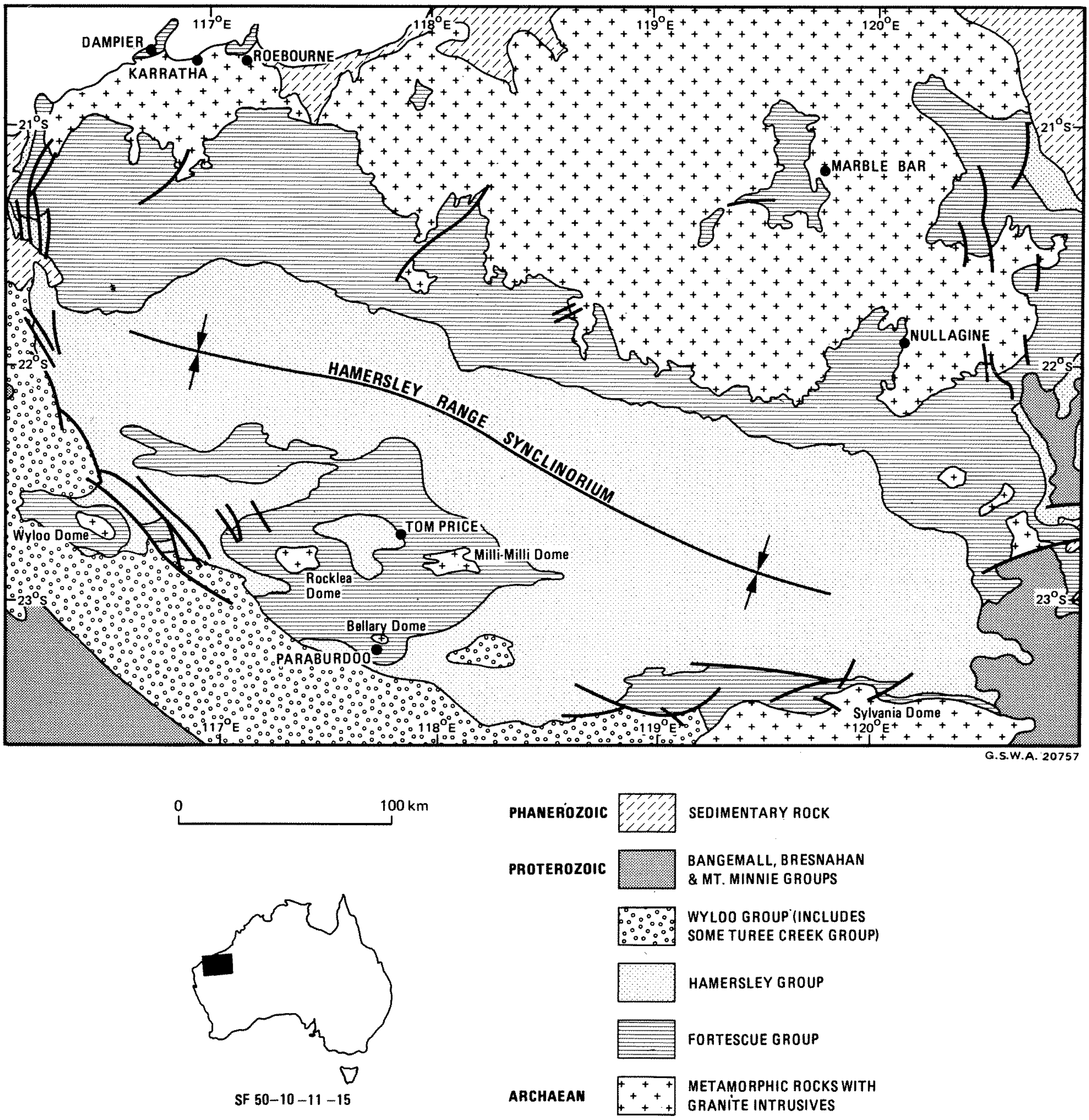

Figure 1 Geological setting of the Hamersley Basin

PREVIOUS INVESTIGATIONS

MacLeod and others (1963), MacLeod (1966), de la Hunty (1965), and Daniels (1968 and 1970), each gave a comprehensive account of the earlier investigations of this region. Since the area was mapped in the early sixties, there have been very few publications dealing with the Fortescue Group in the southern Hamersley Basin. Trendall and Blockley (1970), Trendall (1975, 1976, and 1980), and Horwitz and Smith (1976) discuss the Fortescue Group in wider ranging documentations of the Hamersley Basin. Horwitz (1978) published a more detailed account and map of the Fortescue Group in the Wyloo Dome.

CLIMATE, ACCESS AND PHYSIOGRAPHY

The area is arid to semi-arid, and the average yearly rainfall ranges from 341 mm at Tom Price to 287 mm at Wyloo Station. Summers are hot; and winters, mild; most rain falls in infrequent heavy showers, chiefly in the summer months, as a result of cyclonic influence. The sparse natural vegetation comprises spinifex on the rocky hills, acacia scrub on the plains, and river gums along the main drainages.

Access to the domes is generally good. The main roads that link the iron-ore mining towns of Tom Price and Paraburdoo to Nanutarra, which is on the sealed North West Coastal Highway, pass over the Wyloo, Bellary, and Rocklea Domes. A network of

TABLE 1. CORRELATION OF THE FORTESCUE GROUP BETWEEN VARIOUS AREAS

<table>
<tr><th>YARRALOOLA</th><th>PYRAMID</th><th colspan="2">MOUNT BRUCE</th><th colspan="2">ROY HILL</th><th>BALFOUR DOWNS</th><th>PILBARA BLOCK</th></tr>
<tr><td>JEERINAH FORMATION</td><td>JEERINAH FORMATION</td><td colspan="2">JEERINAH FORMATION</td><td colspan="2">JEERINAH FORMATION</td><td>LEWIN SHALE (LOWER PART)</td><td>JEERINAH FORMATION</td></tr>
<tr><td>MADDINA VOLCANICS</td><td>MADDINA BASALT</td><td rowspan="5">MOUNT JOPE VOLCANICS</td><td>BUNJINAH PILLOW LAVA MEMBER</td><td rowspan="5">MOUNT JOPE VOLCANICS</td><td>MADDINA BASALT MEMBER</td><td rowspan="3">LITTLE DE GREY LAVA (IN PART)</td><td>MADDINA BASALT</td></tr>
<tr><td rowspan="3">PILLINGINI TUFF</td><td rowspan="3">PILLINGINI TUFF</td><td rowspan="3">PYRADIE PYROCLASTIC MEMBER</td><td>KURUNA SILTSTONE MEMBER</td><td>KURUNA SILTSTONE</td></tr>
<tr><td>NYMERINA BASALT MEMBER</td><td>NYMERINA BASALT</td></tr>
<tr><td>TUMBIANA PISOLITE</td><td>TUMBIANA PISOLITE</td><td>TUMBIANA FORMATION</td></tr>
<tr><td>KYLENA VOLCANICS</td><td>KYLENA BASALT</td><td>BOONGAL PILLOW LAVA MEMBER</td><td>KYLENA BASALT MEMBER</td><td>LITTLE DE GREY LAVA (IN PART)</td><td>KYLENA BASALT</td></tr>
<tr><td>CLIFF SPRINGS FORMATION</td><td>CLIFF SPRINGS FORMATION</td><td colspan="2">HARDEY SANDSTONE</td><td colspan="2">BEATONS CREEK CONGLOMERATE</td><td></td><td>HARDEY SANDSTONE</td></tr>
<tr><td>MOUNT ROE BASALT</td><td>MOUNT ROE BASALT</td><td colspan="2"></td><td colspan="2"></td><td></td><td>MOUNT ROE BASALT</td></tr>
</table>

FROM HICKMAN (1983)

station tracks linking windmills provides reasonable access within these domes. The Milli Milli Dome is in the Hamersley Range National Park and access is more limited. A track linking Juna Downs homestead with the main Tom Price-Paraburdoo road passes along its long axis, but there are few tracks giving access northward and southward.

The physiography is closely related to geology. The Mount Jope Volcanics and overlying Hamersley Group rocks form rugged, resistant, strike ridges, which are cut by numerous, narrow, steep-sided valleys. These rugged strike ridges have a relative relief of the order of 500 m. The lower Fortescue Group rocks normally form moderately rugged hills with somewhat less relief than those already mentioned. The granitic cores of the domes more typically form low, rounded hills separated by sandy plains. The area encompassing the domes forms the watershed between the Fortescue and Ashburton Rivers.

GEOLOGICAL SETTING

Figure 1 shows the regional geology of the northwestern part of Western Australia, and in particular, of the Fortescue and Hamersley Groups, which outline the Hamersley Basin.

The oldest rocks of the region are in the granite-greenstone terrain of the Pilbarra Block. These rocks are well described by Hickman (1983). The granite-greenstone terrain is unconformably overlain by the Fortescue Group, the lowermost unit of the Hamersley Basin. In a recent review of the Hamersley Basin, Trendall (1983) advanced a concept, based chiefly on geochronological data, that the cratonization of the Pilbarra Block and the initiation of the Hamersley Basin were not separated by a significant time gap but, in fact, had a time overlap of the order of two to three hundred million years.

The Fortescue Group is chiefly composed of basic volcanic rocks but contains some clastic zones, particularly near its base. Towards the top of the group, the volcanic rocks become subordinate and give way to fine-grained clastic and chemogenic sedimentary rocks.

These pass conformably upward into the Hamersley Group, a well-documented sequence of iron-rich chemogenic and fine-grained clastic rocks and subordinate felsic volcanics, carbonates, and dolerite sills (Trendall and Blockley, 1970; Trendall, 1980; Ewers and Morris, 1981). The Hamersley Group is conformably overlain by the Turee Creek

Group (Trendall 1979), which is chiefly composed of coarse clastic sedimentary rocks. The Turee Creek Group is restricted to a small area and is not shown separately on Figure 1. It probably represents terrigenous material 'topping up' remant, shallow, isolated basins.

The Wyloo Group was deposited chiefly in the Ashburton Trough (Gee, 1979), a deep sedimentary basin which formed off the southwestern side of the Hamersley Basin after deposition in the latter ceased. The northeastern exposures of the Wyloo Group are coarse clastic rocks, carbonates, and basalts, which together comprise a shelf facies; but a thick sequence of turbidites fills the Ashburton Trough, which deepened to the southwest.

REGIONAL STRUCTURE AND METAMORPHISM

Within the Hamersley Basin, MacLeod (1966) initially defined, from north to south, three progressive structural zones based on the intensity of folding. The boundaries between the zones are not sharp, and there is an overall increase in the tightness of folding southwards. In the northern part of the basin, dips are generally shallow and southwards. However, there is a gentle warping about a south-southwest trending axis, which Gee (1979) postulates was due to basement control by the adjacent and underlying Pilbara Craton. The term Pilbara Craton refers to the total exposed and buried part of the granite-greenstone terrain which, where it outcrops north of the Chichester Range, is termed the Pilbara Block.

The central axis of the basin coincides with the general axial line of a complex synclinorium, the Hamersley Range Synclinorium (MacLeod, 1966). On the southern limb of this synclinorium, the folding intensifies, and the dominant structural feature is a series of roughly east-west trending folds, the axes of which are concave to the north. This is the Ophthalmia Fold Belt (Gee, 1979). Within this fold belt, the major folds commonly have reversals of plunge, and fold axes are offset obliquely in a symmetrical manner. This results in a series of domes and basins (Figs 1 & 2). Both MacLeod (1966) and Gee (1979) considered that the exposure of Pilbara Craton granite-greenstone terrain in the cores of two of these domes (Rocklea and Milli-Milli) is related to basement horsts that are partly masked by the Mount Bruce Supergroup cover rocks.

Along the south and southwestern margin of the basin, the folding is intense and results in steep dips, some near vertical, and local overturning.

A weak fabric is present over most of the study area except the southwestern and western part of the Wyloo Dome, where the metabasalts have a penetrative fabric manifest as a chlorite schist. This fabric direction is consistently west-northwest.

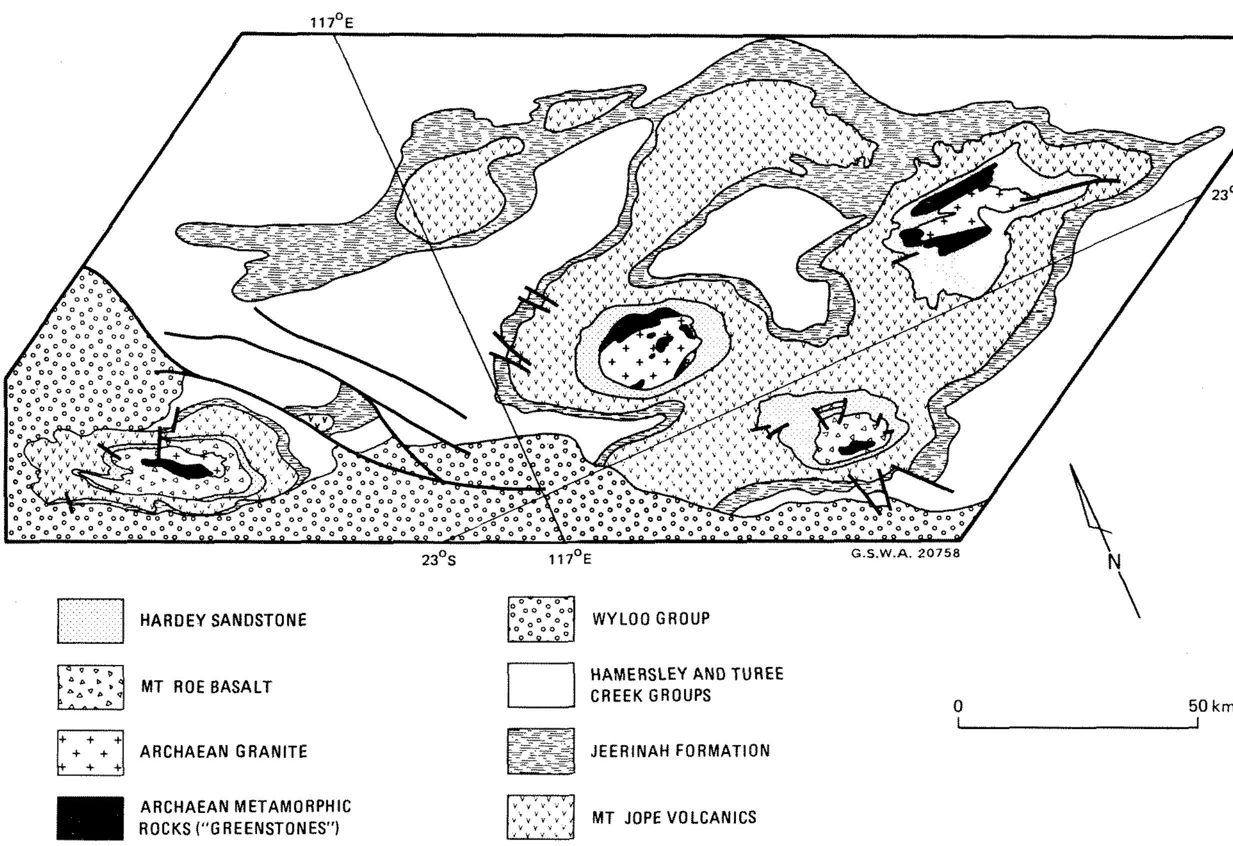

Figure 2 Geology of the southwestern part of the Hamersley Basin

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Figure 3 Banded ferruginous chert (northern Rocklea Dome)

The dominant fault trend is northwest. Most of these faults result in only a small displacement, although movements of the order of several hundreds of metres have been recorded. These faults post-date the deposition of the Mount Bruce Supergroup and are considered to be related to the tectonism responsible for the initiation of the Ashburton Trough. Smith (1975b) and Smith and others (1982) published a regional account of the metamorphism of the Fortescue Group. The area under study lies within Smith's greenschist-facies zone. An examination of the metamorphic mineralogy of rocks collected during this study revealed assemblages compatible with greenschist facies metamorphism.

AGE OF FORTESCUE GROUP

Hickman and de Laeter (1977) presented evidence that the Hardey Sandstone of the Fortesque Group was laid down about 2 650 Ma ago. More recently Compston and others (1981) dated volcanic zircon from the Dales Gorge Member of the Hamersley Group at around 2 500 Ma, and Richards and others (1981) found an age of about 2 700 Ma on galena from veins cutting the Fortescue Group.

These are considerably older than earlier estimates of the age of the Fortescue and Hamersley Groups, for example see Trendall (1976); and tend to support the idea that the Hamersley Basin was perhaps initiated some 2 700 Ma ago. In relation to the commonly accepted chronometric boundary, these rocks are Archaean rather than Proterozoic in age. The age of the Hamersley Basin has recently been reviewed by Trendall (1983).

DETAILED GEOLOGY

ARCHAEAN

Inliers of adamellite-greenstone terrain, exposed in the cores of the Wyloo, Rocklea, Bellary, and Milli Milli Domes, are exposed parts of the basement to the Fortescue Group. The greenstones (symbolized 'AP' on accompanying plates) are assumed to be correlative with the Pilbara Supergroup, which is well exposed in the Pilbara Block to the north; but because of insufficient exposure, it is not possible to assign these greenstones to any previously identified formal group. They have been locally subdivided into two associations: dominantly basaltic (APb), and dominantly metatuff and metasediment (APs).

Both associations are best observed in the Rocklea Dome (Plate 2A). On the northern side of this inlier is a roughly east-trending belt of metasedimentary rocks that includes shale, banded ferruginous chert (Fig. 3), felsic crystal-lithic tuff and quartz-chlorite schist. In the southern section, around Mithgoondy and Chillemarringa Wells, mafic volcanics occur as xenoliths in adamellite. They are mainly tholeiitic basalt, although some quench-textured basalt of presumed komatiitic affinity was noted. Metapyroxenite sills intrude these volcanic rocks near Chillemarringa Well.

The peak metamorphic grade of these rocks is greenschist facies, and this is consistent with the metamorphic zonation described by Smith (1975b) and Smith and others (1982). However, this does not preclude the possibility that the current mineral assemblage results from retrograde metamorphism and totally masks an earlier and higher metamorphic grade. These rocks show evidence of at least three deformations; Figure 4 shows a folded schistosity that has been refolded; this indicates an early metamorphic event that has undergone two subsequent deformations.

Homogeneous adamellite (Ag) with a heterogeneous gneissic marginal facies (Agm), best demonstrated in the Rocklea Dome, intrudes the greenstones (Fig. 5). The transition from homogeneous to heterogeneous is gradual and

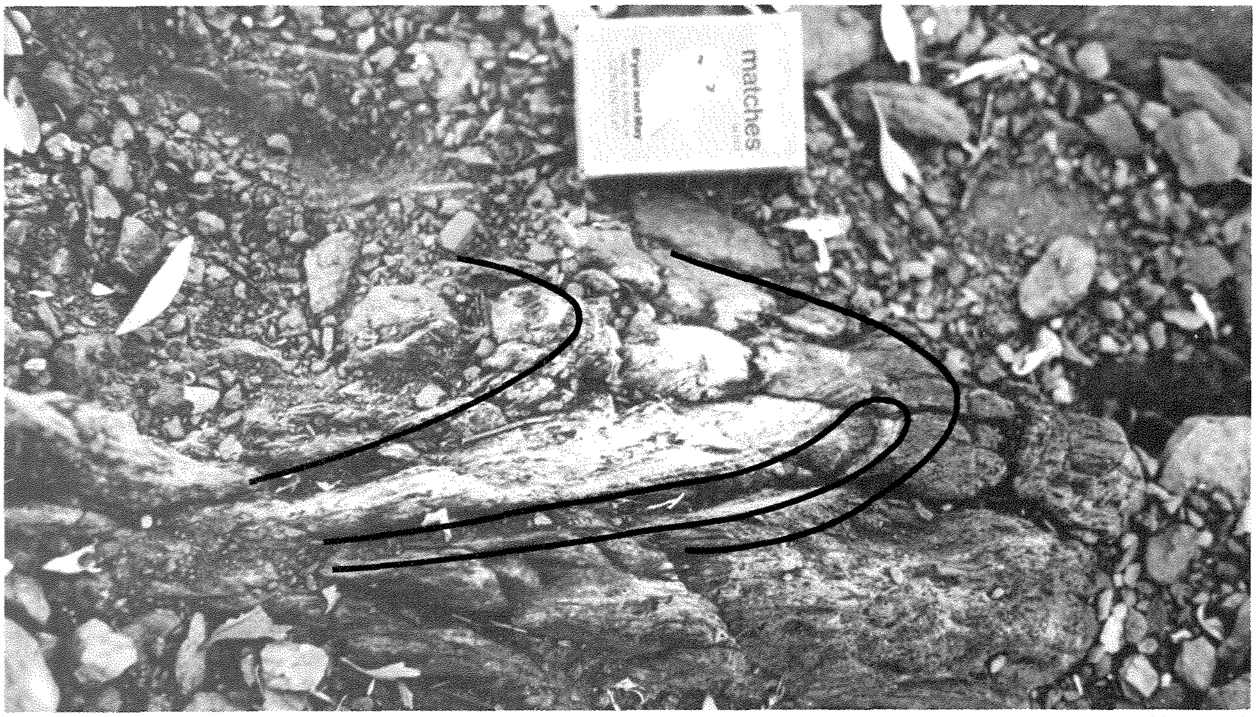

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Figure 4 Refolded fold in Archaean metasedimentary sequence (northern Rocklea Dome)

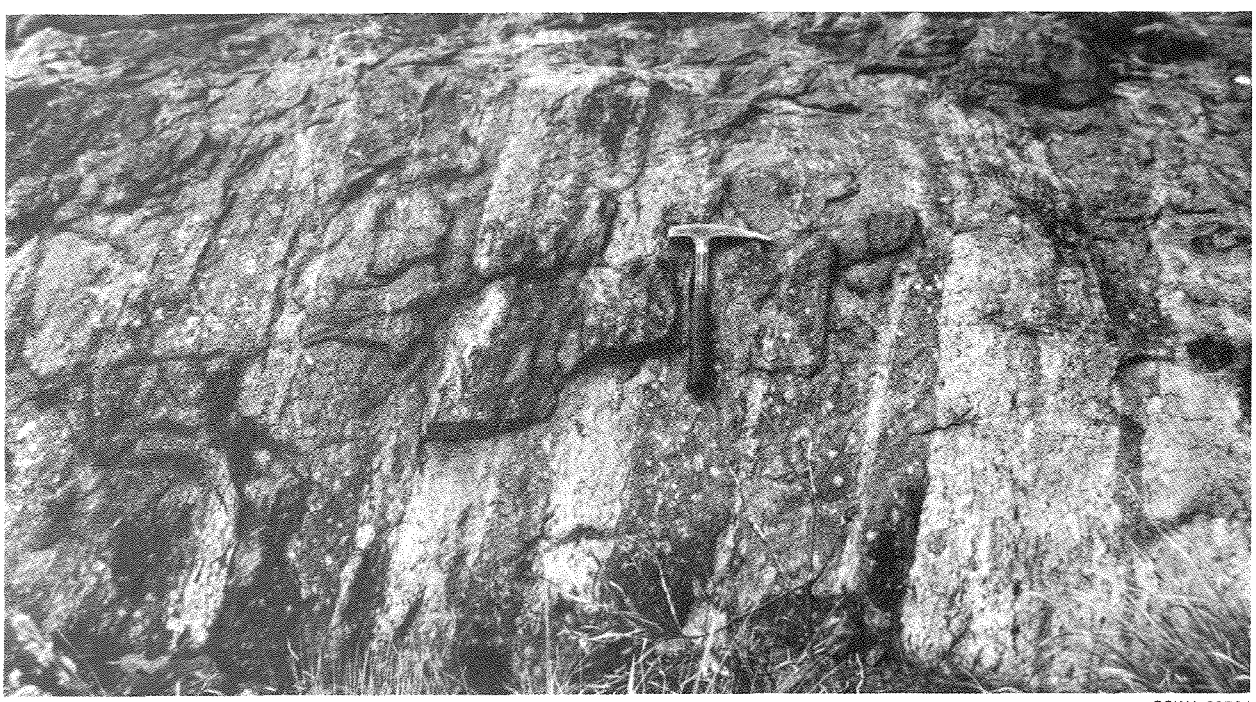

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Figure 5 Heterogeneous gneissic marginal facies of adamellite (Rocklea Dome)

probably reflects a degree of deformation at adamellite-greenstone contacts. This type of relationship is characteristic of the older plutons of the Pilbara Block (Hickman, 1983).

The homogeneous cores of these adamellite plutons were partly recrystallized, presumably during the deformation of the domes after deposition of the Mount Bruce Supergroup. Typical mineralogy is quartz, plagioclase (now albitic), microcline, some biotite, and secondary sericite, epidote and, chlorite. Horwitz (1978) has named the adamellite forming the core of the Wyloo Dome the Metawandy Granite. He assigns an Archaean age to the body and 'compares it to the younger granites of the Archaean of the Pilbara'. However, further geochemical and geochronological data are needed to confirm this comparison.

The heterogeneous marginal facies of the plutons are generally layered adamellite gneiss and probably developed during the emplacement of the batholith. Hickman (1983) considers that similar adamellites in the Pilbara Block were emplaced by solid-state diapirism and that this would account for their highly tectonized margins. The texture of this heterogeneous marginal facies is typically blastomylonitic; porphyroblasts of plagioclase and microcline lie in a matrix of quartz, feldspar, biotite, and secondary white mica.

Transecting these Archaean inliers are large mafic dykes, such as that which runs longitudinally within the Rocklea Dome. They are unconformably overlain by the Fortescue Group and are therefore Archaean in age. The wide, approximately east-trending dolerite dykes cutting the Metawandy Granite in the Wyloo Dome may also be of this generation; but in the absence of convincing field relationships, they are equated, on the basis of petrological similarity, to dolerite sills within the Fortescue Group.

FORTESCUE GROUP

The Fortescue Group unconformably overlies the rocks of the Archaean inliers. In nearly all places where the unconformity was examined, an immature sediment, usually thin, was found to lie directly over the basement. This sediment usually reflects the composition of the underlying basement. For example, 0.5 km south of Chillemarringa Well in the Rocklea Dome, the Fortescue Group rests directly on greenstone. Here the basal sediment is a coarse, immature conglomerate, composed chiefly of angular basaltic fragments in a matrix of quartz and chloritic material. On the other hand, 1 km south-southwest of Horse Well in the Wyloo Dome, R.C. Horwitz (pers. comm. 1980) first recognized an immature arkose directly overlying the Metawandy Granite. It is difficult in the field to distinguish this arkose from the underlying recrystallized adamellite. However, the rare occurrence of bedding, coupled with microscopic examinations of the rock, confirms the relationship (Figs 6, 7). This basal sediment has no formal stratigraphic status; it may be considered a member of the Mount Roe Basalt.

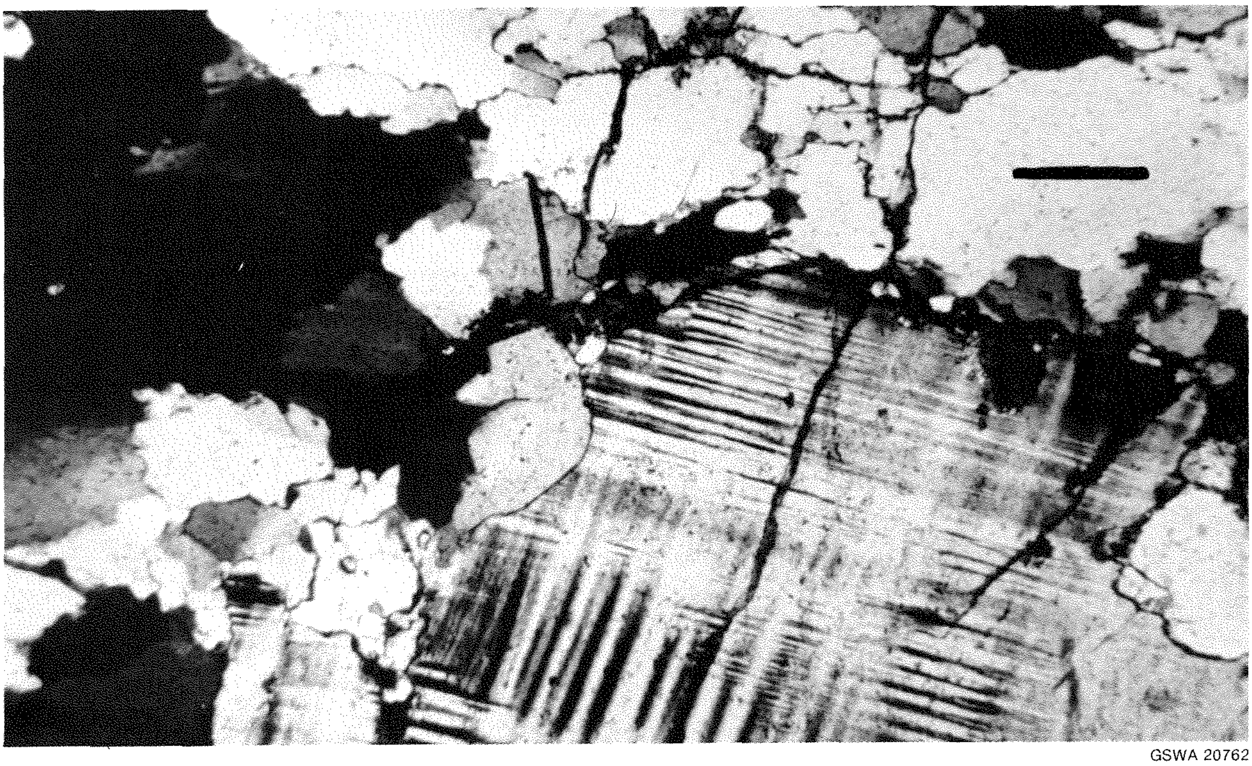

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Figure 6 Photomicrograph of Metawandy Granite; bar is 0.2 mm long

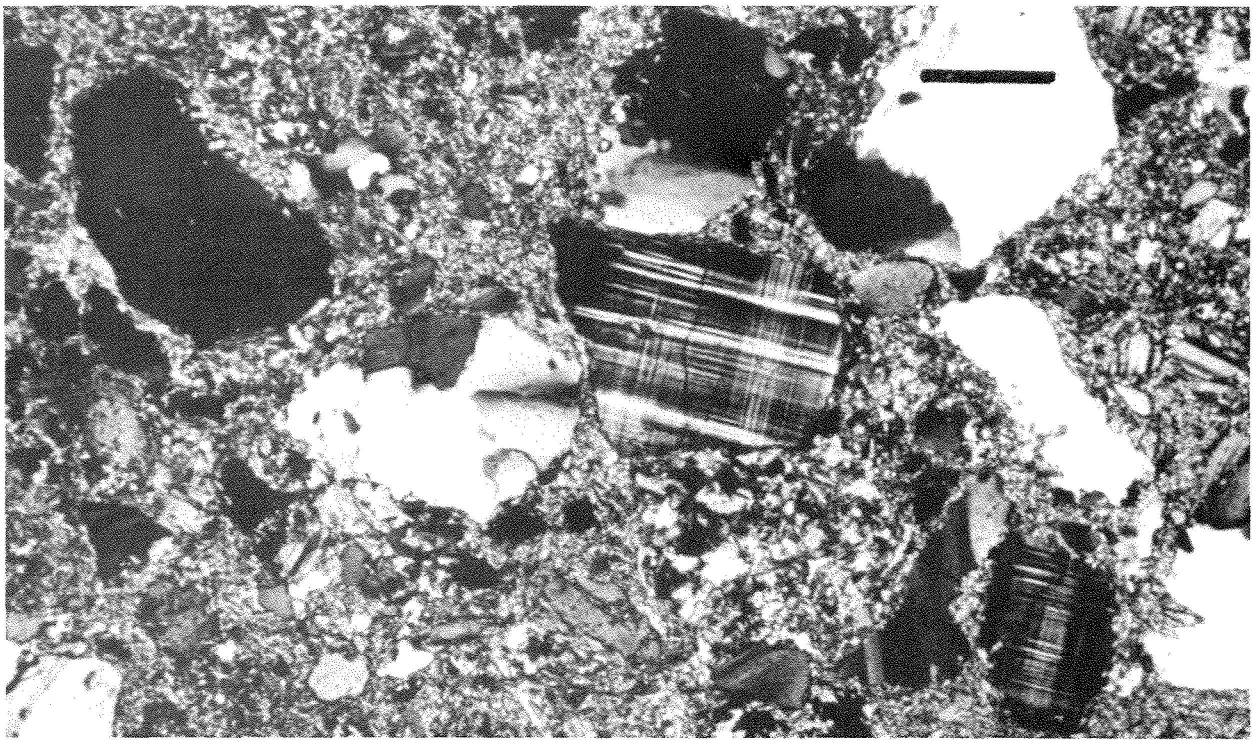

Figure 7 Photomicrograph of arkose directly overlying Metawandy Granite; bar is 0.2 mm long

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Mount Roe Basalt

The lowest formation of the Fortescue Group is the Mount Roe Basalt. It outcrops extensively in the Wyloo and Bellary Domes and to a lesser extent in the Rocklea Dome, but is entirely absent from the Milli Milli Dome. Within the Hamersley Basin, it reaches its maximum thickness of approximately 1.5 km in the Wyloo Dome.

Horwitz (1978) formally gave the name 'Paulsen Volcanics' to a group of rocks in the Wyloo Dome and assigned a late Archaean age to them; however, he did not designate a type section or area. More recent mapping (Plate 1) clearly demonstrates that the 'Paulsen Volcanics' of Horwitz (1978) contains elements of the previously defined Mount Roe Basalt and of the older Pilbara Supergroup. The name 'Paulsen Volcanics' should be discarded.

Hickman (1975, 1983) interpreted the topography on the Pilbara Block prior to the deposition of the Fortescue Group as consisting of gently undulating hills and valleys, where granitic rocks formed the hills and greenstones floored the valleys and basins. He envisaged the Fortescue Group being deposited initially in the valleys and encroaching progressively on the granitic uplands. Horwitz and Smith (1978) and Horwitz (1980) disputed this interpretation, and their palaeogeographic model involved a broad basement ridge plunging to the northwest, the axis of which is approximately the same as the axis of the present Hamersley Range Synclinorium.

On the eastern side of the Rocklea Dome, near Chillemarringa Well, and on the southeastern side, about 5 km west-northwest of Rocklea homestead, two palaeovalleys are developed over mafic rocks, and granitic material forms the intervening uplands (Plate 2B). Detailed mapping has demonstrated that the Mount Roe Basalt does not, as Horwitz and Smith (1978) contend, exist around most of the Rocklea Dome but is confined to the floors of these palaeovalleys and this supports the palaeogeographic model of Hickman (1983).

The Mount Roe Basalt is best exposed in the Wyloo and Bellary Domes. In these areas, the lowermost part of the Mount Roe Basalt is a sequence of intermediate-to-mafic tuff and agglomerate, basaltic flows, and, commonly, coarse-grained clastic sedimentary rocks. In the Wyloo Dome, felsic pyroclastic rocks are a significant component of the formation. Rapid facies changes take place along strike in all of these rock types.

Within the tuff, accretionary lapilli are common (Fig. 8); and the tuff commonly shows evidence of subaqueous deposition, in that it exhibits cross-stratification (Fig. 9) and graded bedding (Fig. 10). In the southwestern part of the Wyloo Dome, a strong penetrative fabric has all but obliterated traces of the original texture. However, in some of the chloritic schist, disc-shaped chlorite clots are interpreted as flattened lapilli. The tuff, which is commonly carbonated, is normally crystal-lithic-vitric tuff, but

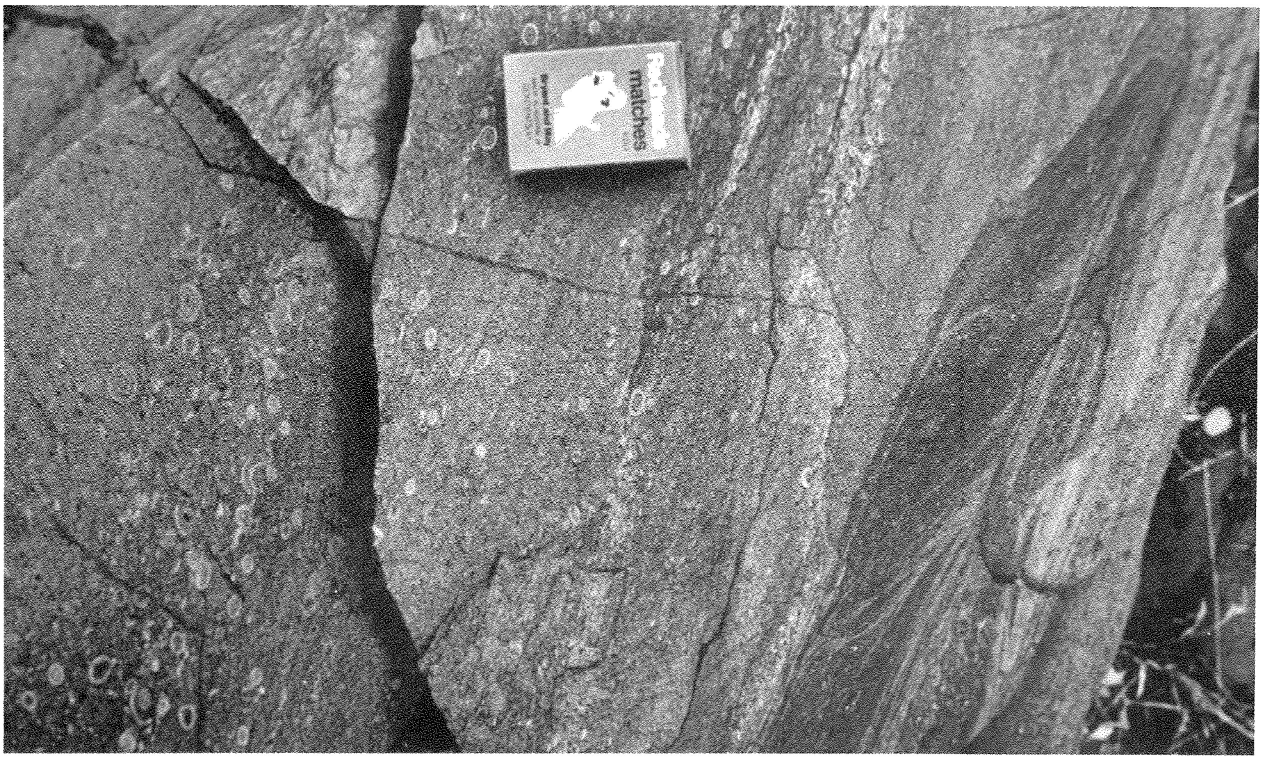

Figure 8 Mafic to intermediate tuff containing accretionary lapilli, Mount Roe Basalt (southern Bellary Dome)

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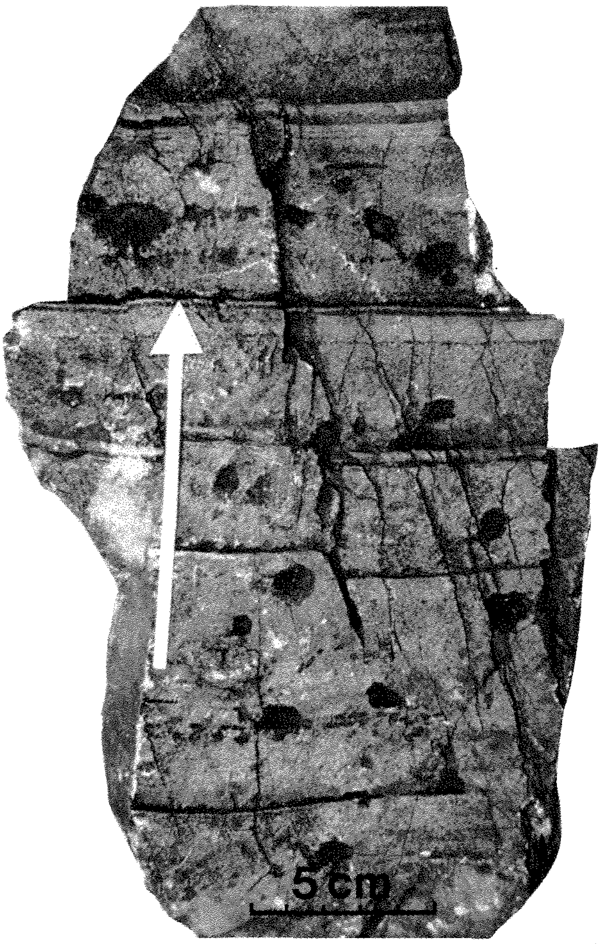
Figure 9 Lapilli tuff showing cross-bedding (southern Bellary Dome)



GSWA 20766
Figure 10 Mafic tuff showing graded bedding (western Wyloo Dome)

the finer grained rocks, which commonly contain lapilli, have a large component of glass that is now expressed as a cryptocrystalline matrix of chlorite and quartzo-feldspathic material.

The agglomerate horizons in the lower part of the Mount Roe Basalt contain some large fragments, including auto-lithic fragments, spindle-shaped bombs, and exotic lithic fragments, such as granitic material (Fig. 11).

The clastic horizons are very discontinuous laterally and also vary lithologically along strike. These rock types include conglomerate, grit, arkose, greywacke, quartzite, and, rarely, shale. The conglomerate tends to be matrix-supported (Fig. 12). The arenite is poorly sorted and generally does not show sedimentary structures. Within the Wyloo Dome, 5 km south of Four Mile Bore, is a lens of matrix-supported conglomerate, approximately 8 km long and up to several hundred metres thick. It consists chiefly of well-rounded granitic cobbles, up to 0.15 m in size, in a sandy matrix now composed of quartz, feldspar, and chlorite. The rock has a strong penetrative fabric, and no imbrication or stratification was observed; however, small sand wedges show a discontinuous wispy layering. These observations are consistent with the interpretation that the lens-shaped body represents a debris flow.

In the Bellary Dome, a large block of mafic tuff, roughly one cubic metre in size, is embedded nearly halfway into a fine-grained laminated shale in the

GSWA 20767
Figure 11 Granitic fragment in mafic agglomerate within Mount Roe Basalt (northeastern Wyloo Dome)

Figure 12 Matrix-supported conglomerate within Mount Roe Basalt (southern Wyloo Dome)

manner of a glacial drop-stone (Fig. 13). There is no other evidence of glacial origin for this rock and it is interpreted as a block which has rolled downslope into a bed of fine-grained sediment.

The acid volcanics present in the Wyloo Dome occur as crystal-lithic-vitric tuffs; some contain accretionary lapilli (Fig. 14). Some specimens of the least deformed material were isotopically analyzed in

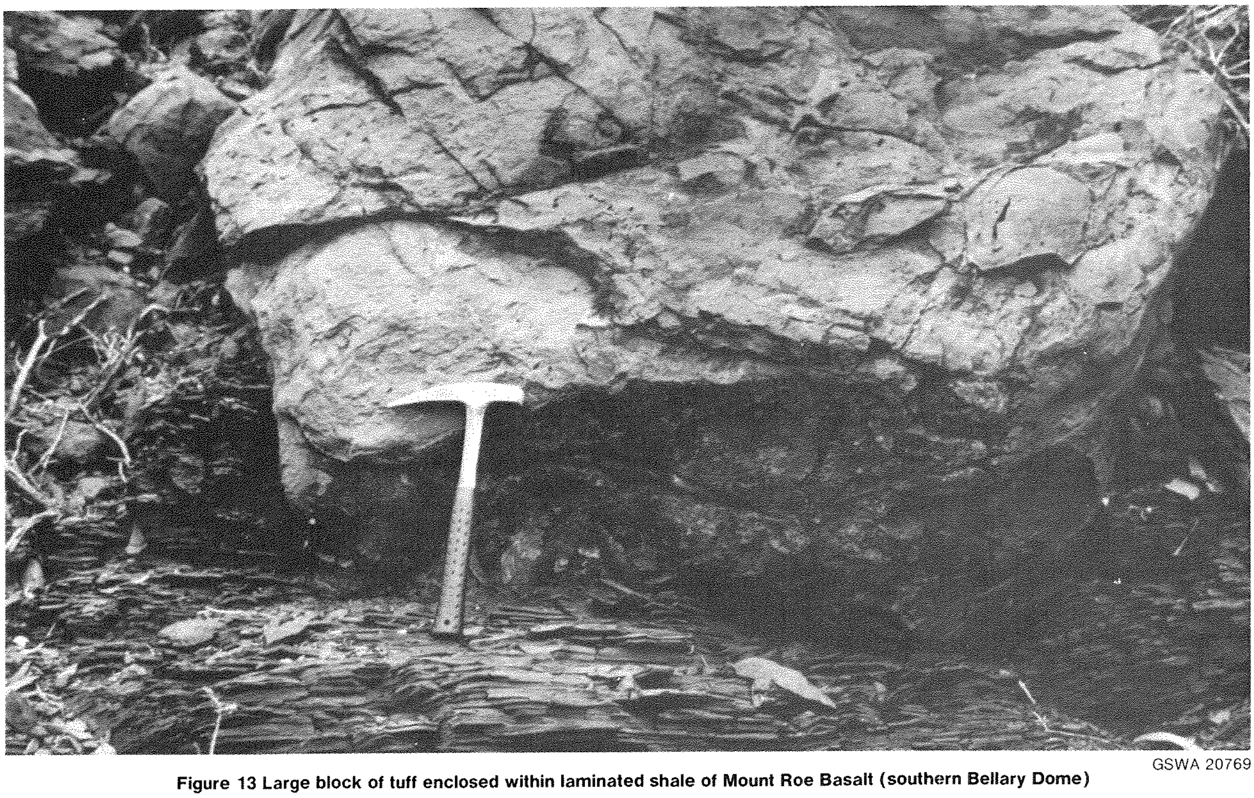


Figure 13 Large block of tuff enclosed within laminated shale of Mount Roe Basalt (southern Bellary Dome)

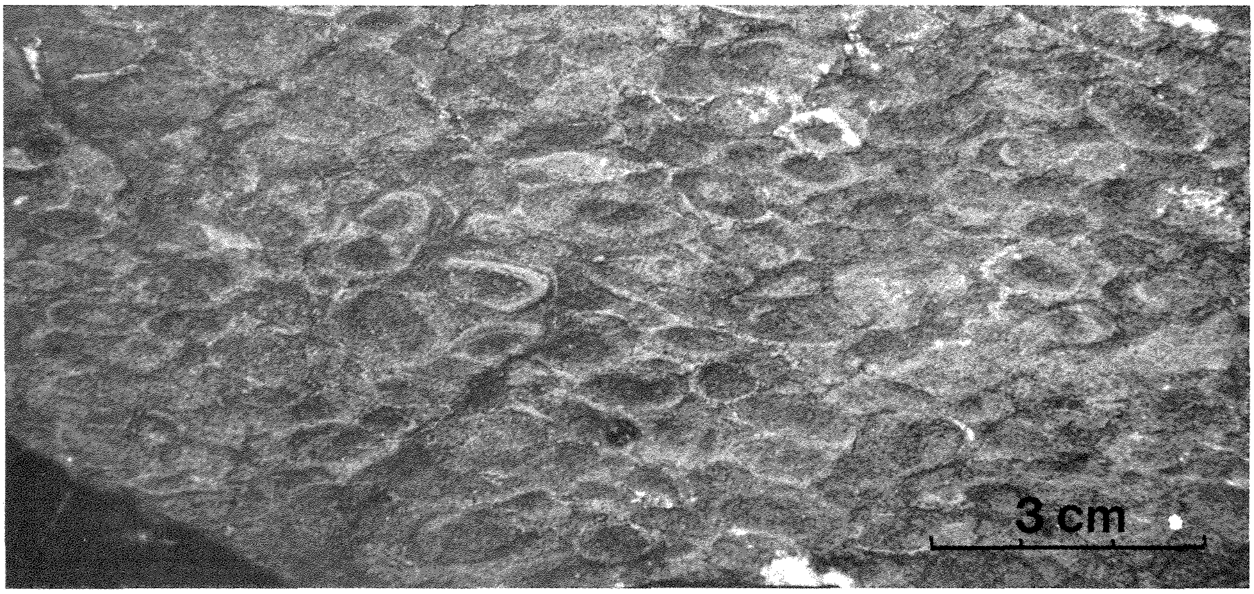


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Figure 14 Felsic tuff containing accretionary lapilli (northeastern Wyloo Dome)

an endeavour to determine the age of formation and hence the age of the initiation of the Hamersley Basin. The Sr-Rb isotopic data are inconclusive, and results are discussed by de Laeter, Seymour, and Libby (in prep.).

The upper section of the Mount Roe Basalt is generally more widespread and far more homogeneous than the lower section. It is characteristically an amygdaloidal, porphyritic metabasalt and consists of altered plagioclase phenocrysts set in a chloritized and epidotized matrix. The amygdales, which commonly consist of carbonate, quartz, and feldspar, are a distinctive feature of the rock, enabling its recognition in highly deformed areas such as the southwestern part of the Wyloo Dome. This rock is characteristic of the Mount Roe Basalt and has been recognized in distant areas such as Roebourne and Nullagine (Fig. 1), as well as on the southern margin of the Hamersley Basin.

GSWA 20771

Figure 15 Contact between vesicular Mount Roe Basalt and overlying basal conglomerate of the Hardey Sandstone. Hammerhead is on the contact (eastern Rocklea Dome)

Hardey Sandstone

Conformably overlying the Mount Roe Basalt is the Hardey Sandstone (Fig. 15). In the type area in the Rocklea Dome, this unit is about 1 200 metres thick (de la Hunty, 1965). In the study area, the dominant components of this unit are coarse-grained arkose, fine-grained arenite, and shale (some, pyritic); some subarkose, grit, and conglomerate, occur near the base. The sandstone is white to reddish-brown and green in colour. Because of the propensity of the finer grained sediments to weather, they are poorly exposed, and the coarse arkose appears to be dominant.

Trough cross-bedding is common; some troughs are up to 2 m deep. In one area, about 8 km northeast of Mithgoondy Well in the Rocklea Dome, ripple marks and tabular cross-stratification were observed. Lag gravels can be seen in many cliff sections, as can large channels (Fig. 16). These features are well exposed in an outcrop on the banks of the Beasley River, about 300 m west of the abandoned stock-yards on the west side of the Rocklea Dome.

Conglomerate beds are present on the eastern side of the Rocklea Dome and on the southern side of the Milli Milli Dome. They occupy positions within the palaeovalleys previously mentioned. These conglomerates are clast-supported and have sandy lenses that define bedding (Fig. 17). No imbrication was observed in these conglomerate beds.

A basal conglomerate of the Hardey Sandstone that is exposed in one palaeovalley on the eastern side of the Rocklea Dome, contains large angular blocks of the underlying Mount Roe Basalt and indicates a local hiatus in deposition between the two units.

The coarser units within the Hardey Sandstone are confined to the Rocklea, Milli Milli, and Bellary Domes; in the Wyloo Dome, the sandstone is finer grained and better sorted, and does not contain pebble layers or conglomerates. No sedimentary structures, such as cross-beds, were observed in the Wyloo Dome.

The Hardey Sandstone in the southern Hamersley Basin is thought to have been deposited by the action of braided streams, flowing on an alluvial plain, the 'braidplain' of Allen (1975); the change in lithology westward into the Wyloo Dome is regarded as a transition from proximal facies to distal facies. This interpretation is expanded in the section 'Depositional environment of the lower Fortescue Group'.

Within the Hardey Sandstone, approximately midway through the sequence, is a tuff unit, which is here formally named the Madang Tuff Member. It is regionally lensoid in distribution but occurs around most of the Milli Milli Dome, except on the northern and northeastern sides. It also occurs around the northwestern side of the Bellary Dome and around both the eastern and western ends of the Rocklea Dome. It has not been observed around the Wyloo dome; however, a lithologically similar rock was seen in the Hardey Sandstone near Nullagine. On the Marble Bar 1:250 000-scale geological sheet (1979 edition) this unit is labelled 'Pfhw' and described as

GSWA 20772

Figure 16 Lag gravel in a large channel within the Hardey Sandstone (western Rocklea Dome)

GSWA 20773

Figure 17 Sand bar in a conglomerate near the base of the Hardey Sandstone (eastern Rocklea Dome)

'wacke (lithic and clayey) sandstone (poorly sorted) with some tuff and shale'. Thus, this member may prove to be a particularly useful marker horizon in any attempt to correlate the Fortescue Group over the whole of the Hamersley Basin.

The type area of the Madang Tuff Member is 1 km east of Madang Well. It ranges in thickness to 130 m on the western side of the Milli Milli dome. The tuff, which is intermediate to mafic in composition, is characterized by xenocrystic quartz and subordinate

GSWA 20774

Figure 18 Madang Tuff Member containing large fragments of Hardey Sandstone (southwestern Milli Milli Dome)

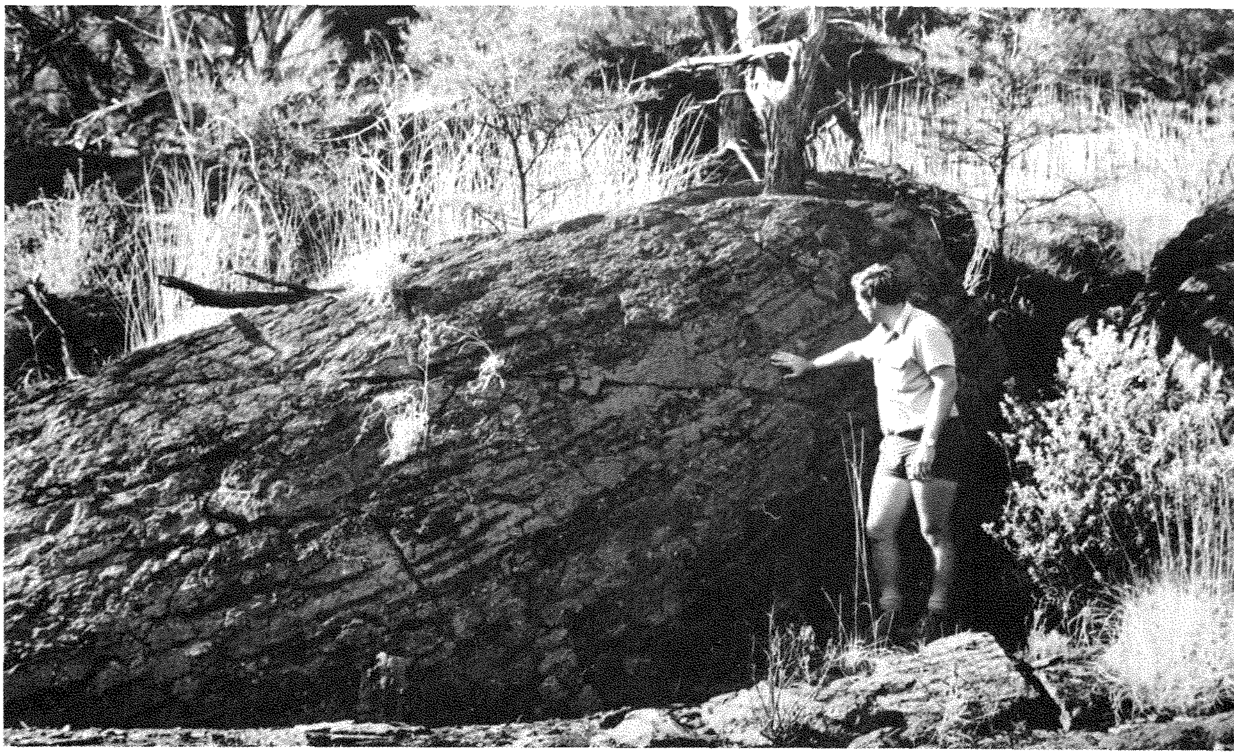


Figure 19 Layering within the Madang Tuff Member (southwestern Milli Milli Dome) GSWA 20775

K-feldspar. The quartz and feldspar are rounded to subrounded and are regarded as being components of the Hardey Sandstone that were deposited during the accumulation of the tuff. This interpretation is supported by the observation that, at one location, 14 km north of Mount Bennett in the Milli Milli Dome, the tuff horizon contains a lens with large, lithic fragments of Hardey Sandstone up to 50 mm across (Fig. 18). Presumably this rock indicates that the eruptive vent was nearby.

In most places where the tuff was examined, it was massive; but in one location, 10 km north of Mount Bennett in the Milli Milli Dome, it exhibited conspicuous, coarse layering (Fig. 19). As the tuff was deposited on the braidplain where the Hardey Sandstone formed, it is most probably sub-aerial.

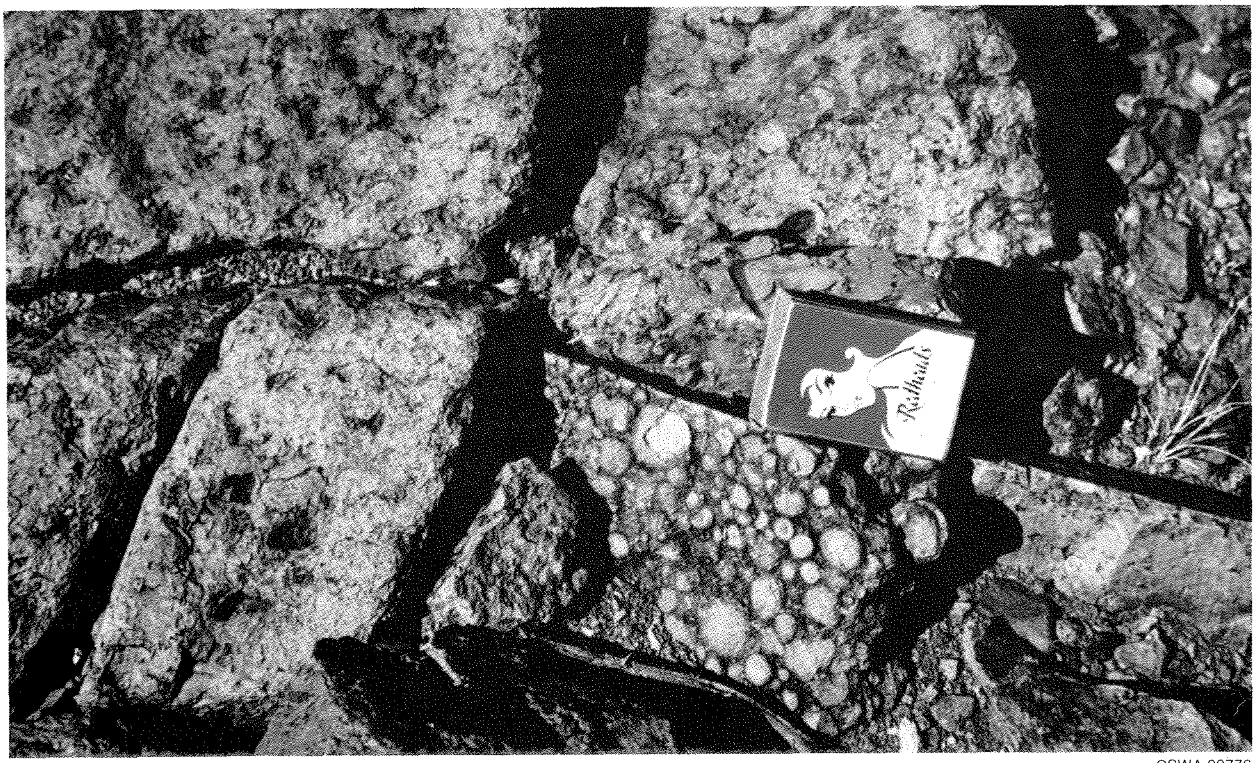
The lithic and vitric fragments, and the matrix of the Madang Tuff Member, are andesitic to basaltic in composition, and are now composed of fine-grained chlorite, actinolite, plagioclase, subordinate quartz, traces of stilpnomelane, and secondary calcite. In a few localities, such as the type area and the northwestern section of the Rocklea Dome 12 km northwest of Mithgoondy Well, the base of the Madang Tuff Member is represented by a tuff that contains accretionary lapilli similar to those observed within the Mount Roe Basalt in the Wyloo Dome. About 4.5 km north of Gobo Well in the Bellary Dome, the Madang Tuff Member contains an amygdaloidal basalt flow of limited extent.

Mount Jope Volcanics

The Mount Jope Volcanics conformably overlie the Hardey Sandstone. On the basis of air-photo patterns, de la Huntly (1965) subdivided the volcanics into a lower Boongal Pillow Lava Member, a middle Pyradie Pyroclastic Member, and an upper Bunjinah Pillow Lava Member. These units possibly correlate with units further to the north, described by Hickman (1983) as follows: the Boongal Pillow Lava Member is considered to be equivalent to the Kylena Basalt; the Pyradie Pyroclastic Member embraces the Tumbiana Formation, The Nymerina Basalt, and the Kuruna Silstone; and the Bunjinah Pillow Lava Member is correlated with the Maddina Basalt (Table 1).

In the course of this study, these members were not distinguished except in the Wyloo Dome area. However, it was noted that, in many places, the base of the Mount Jope Volcanics is a (rarely pisolitic) basaltic tuff (Fig. 20). This tuff unit is very widespread and distinctive and has been mapped. It could probably be excluded from the Boongal Pillow Lava Member and be raised to separate member status itself, but until further work is done on the poorly understood stratigraphy of the Mount Jope Volcanics, it is not intended to formalize the unit.

Typically, the Mount Jope Volcanics is composed of pillow basalt (Fig. 21) and basaltic pyroclastics, and subordinate felsic volcanics, arenite, chert, and shale. Some spinifex-textured komatiitic metabasalt was noted on the southern side of the Rocklea Dome.



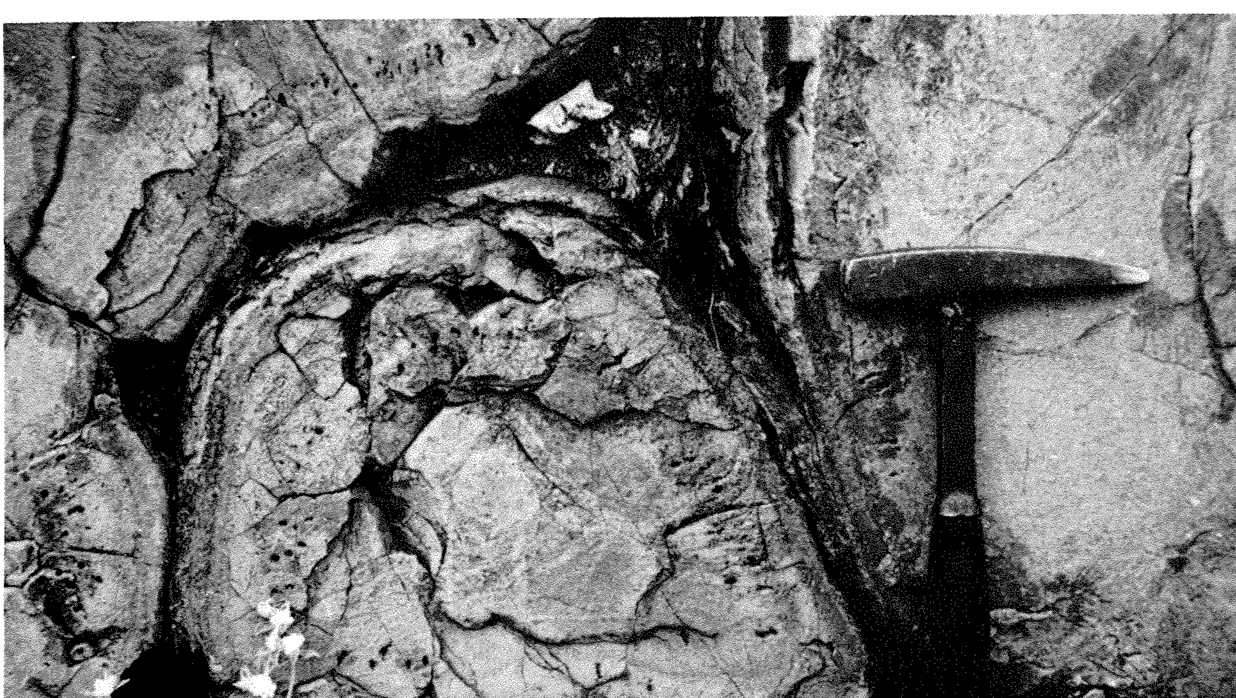
GSWA 20776

Figure 20 Pisolitic tuff at the base of the Mount Jope Volcanics (southeastern Milli Milli Dome)

Its existence within the Mount Jope Volcanics was brought to the author's attention by Dr Ray Smith of the CSRIO at Floreat Park.

Sills

Intruding the Fortescue Group is a series of mafic and ultramafic sills. They are particularly prevalent in the Hardey Sandstone, where their dark colour contrasts with the light colour of adjacent sedimentary rocks. Presumably the laminated nature of the Hardey Sandstone contributed to their apparent concentration within this unit. The mafic sills (BFd) have a typical relic sub-ophitic texture, and a meneralogy of actinolite pseudomorphs after stubby, elongate clinopyroxene prisms, altered plagioclase, and subordinate interstitial quartz, opaques, and apatite. The



GSWA 20777

Figure 21 Pillow basalt within Mount Jope Volcanics (eastern Wyloo Dome) ultramafic sills (BFu) are of altered orthopyroxenite, which has a medium- to coarse-grained cumulate texture and a mineralogy of tremolite-chlorite pseudomorphs after orthopyroxene, in a matrix of chlorite, tremolite, talc and serpentine, and some sphene (presumably after opaques). The sills may be the intrusive equivalents of the extrusive mafic and ultramafic flows of the Mount Jope Volcanics higher in the sequence.

Dykes

Thin (<10 m) dolerite dykes (d) intrude Archaean rocks, the Fortescue Group, and the overlying Hamersley Group. They commonly have a northeasterly strike. They are well displayed in the core of the Rocklea Dome, where the dark colour of the dolerite contrasts with the light-coloured granitic material to produce a pattern that is strikingly visible on air photos. In the western half of the Wyloo Dome, where the Fortescue Group is most deformed, the dykes themselves have been folded, in places quite tightly. This suite of dykes was not observed transecting Wyloo Group rocks and thus is thought to pre-date the Wyloo Group.

In the Wyloo Dome, two wide (up to 50 m) gabbro dykes (Pd) trend approximately northeast. These dykes show evidence of differentiation in that some samples contain olivine (olivine gabbro) whereas others contain graphically intergrown quartz (granogabbro). However, the dykes are generally poorly layered. They cut, and are thus younger than, the previously described thin dolerite dykes; and are equated with large, coarse-grained, northeast-trending dykes that were observed cutting the Ashburton Formation of the Wyloo Group.

Cainozoic

A pisolitic limonite (T) was deposited in incised stream channels. Subsequent erosion has removed the surrounding rocks and left the resistant limonite as long narrow mesas, whose meandering outcrop preserves the course of the original stream. This original course differs considerably from the present drainage. The maximum thickness of the limonite is about 30 m. Pisolitic limonite defining an old stream is best illustrated in the area of the Rocklea Dome (Plate 2C). Limestone and calcareous gravel with opaline silica, which are correlated with the Oakover Formation, are included in this unit.

DEPOSITIONAL ENVIRONMENT OF THE LOWER FORTESCUE GROUP

MOUNT ROE BASALT

The Mount Roe Basalt was deposited on an undulating topography and is generally confined to palaeovalleys. The widespread, monotonous, vesicular basalt which is so characteristic of the upper section of the Mount Roe Basalt gives very few clues to the depositional environment. The lack of pillow basalt suggests deposition was not sub-aqueous. However, in the lower horizons of the Mount Roe Basalt there are intercalated clastic sediments and tuffs which probably indicate shallow water. Tuff containing accretionary lapilli shows cross-stratification indicative of sub-aqueous conditions. Within the clastic beds, features such as the rapid facies changes along strike, the presence of matrix-supported conglomerate, the recognition of a debris flow, and the pronounced lack of sedimentary structures, all indicate a somewhat chaotic regime. The recognition of a chaotic regime, and in particular the evidence of mass flows of debris, means that, during the early stages of development of the Hamersley Basin, slopes must have been moderately steep. Further support for the existence of steep slopes is provided by the observation (noted earlier) of a large boulder of tuff embedded in shale in the Bellary Dome. If a glacial origin is disregarded because of the lack of other evidence for glaciation, then this block must have rolled downslope during deposition of the Mount Roe Basalt.

HARDEY SANDSTONE

The Hardey Sandstone is composed of about two-thirds coarse, and one-third fine-grained clastic sedimentary material deposited on continental crust. The prevalent large-scale trough cross-stratification, abundant channelling, lag gravel, and pebble and conglomerate horizons, so characteristic of this unit, are features expected of an alluvial deposit (Rust, 1979; Collinson, 1978). The fine-grained beds would therefore represent overbank deposits.

In the Rocklea, Milli Milli, and Bellary Domes, the Hardey Sandstone is of similar facies. This facies occupies an area about 125 x 50 km; thus it is reasonable to suppose that the Hardey Sandstone developed in a similar manner over at least 6 000 square km. Clearly this is too vast an area to be the result of a simple alluvial fan, and the favoured interpretation of the depositional environment of the Hardey Sandstone is a braidplain. The beds of coarse conglomerate which occur near the base of the Hardey Sandstone are not sorted, and show abundant channelling indicative of a high-flow regime. Furthermore, they are generally confined to palaeovalleys. They clearly represent proximal parts of the alluvial system. As the basin filled, and the alluvial fans migrated upslope, the coarse-grained lower units were progressively overlain by finer material deposited on a braidplain. Current data and stratigraphic thicknesses (discussed later) indicate that the Wyloo Dome lies downslope of this palaeo-braidplain. As discussed before, within the Wyloo Dome the Hardey Sandstone lacks the coarse-grained units that are present elsewhere and, furthermore, is better sorted. It is likely that here the Hardey Sandstone represents the distal part of the alluvial system or even a beach deposit if the 'Hardey braidplain' flowed westward into an ocean.

Data gathered during this study were not sufficiently comprehensive to determine whether flow on this alluvial system was ephemeral, flowing only during intermittent flash flooding, or whether there was a continuous discharge of water through the system.

Palaeocurrent data

Nearly all current directions measured within the Hardey Sandstone show a source of sediment approximately from the east (Fig. 22A). These directions were measured from long axes of trough cross-beds. One anomalous area is the eastern side of the Bellary Dome, where current directions are from the west, diametrically opposed to the other areas. In an endeavour to understand this divergence, the thickness of the Hardey Sandstone was measured from

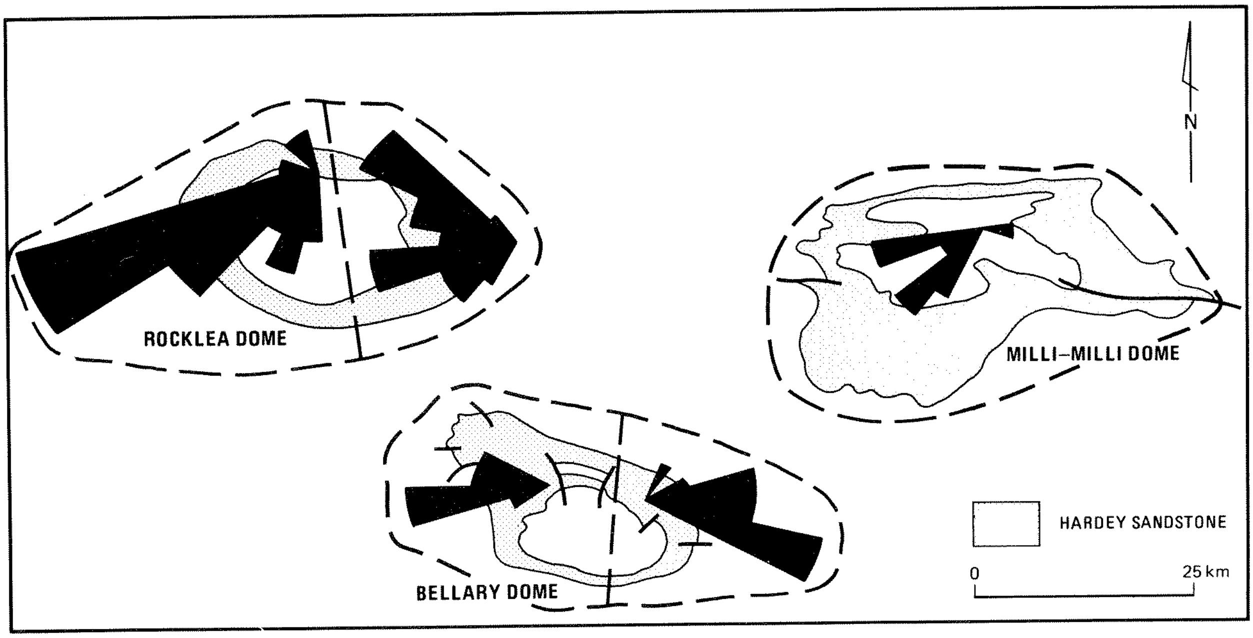


Figure 22A. Outcrop map of the Hardey Sandstone showing current-direction rosettes (84 measurements) around the Rocklea, Milli Milli, and Bellary Domes. Each rosette is generated from data obtained from the areas enclosed by dashed lines

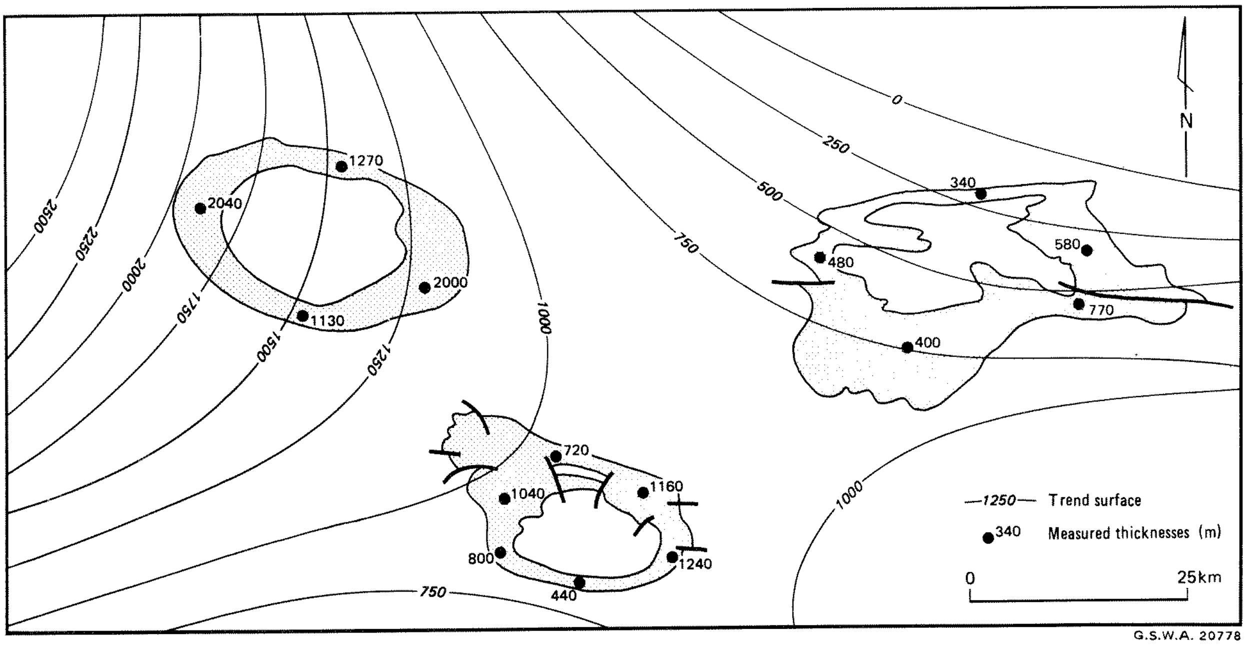


Figure 22B Quadratic trend-surface analysis and measured thicknesses of the Hardey Sandstone

airphotos (at a scale of 1:40 000) at 15 localities around the Rocklea, Milli-Milli, and Bellary Domes. Allowances were made for intrusive sills. No allowance was made for tectonic thickening or thinning, but in most places deformation is relatively mild and it is considered unlikely that tectonism has greatly influenced present thicknesses. If it is assumed that the environment of deposition of the Hardey Sandstone was a braidplain, then, at the close of sedimentation, the top of this unit would have been close to a planar surface. Thus the thickness of the sandstone will give some idea of the depositional basin topography and/or the concurrent deformation. Figure 22B shows these thicknesses plotted in relation to the present outcrop pattern of the Hardey Sandstone. A quadratic trend-surface analysis was applied to these thickness data.

As can be seen from Figure 22B, the trend-surface analysis shows that the contours of the palaeoslope generally fall from east to west in accord with the current direction data. However, a small 'sub-basin' is shown to exist on the eastern flank of the Bellary Dome. This accounts for the apparently anomalous reversal of current directions at this location. This north-northeast-trending ridge is probably due in part to an Archaean basement high, coupled with a build-up of Mount Roe Basalt, in the vicinity of the Bellary Dome.

BASIN-SHAPE AND MODEL

Trendall and Blockley (1970) presented an isopach map of the Dales Gorge Member of the Hamersley group, which shows the Dales Gorge Member is thickest along a west-northwest-trending axis that corresponds to the central portion of the known outcrop. The member thins, both to the north and south. Trendall and Blockley (1970) considered that the most logical explanation of the feature is that the Hamersley Group was deposited in a barred basin. On the other hand, Horwitz and Smith (1978) and Horwitz (1980) suggested 'that the Hamersley Group was deposited on a submerged shelf not in a basin outlined more or less by the present outcrop'. In support of this proposal, Horwitz and Smith (1978) and Horwitz (1980) presented a series of sections of the Fortescue Group designed to show how 'during deposition of the Mount Bruce Supergroup, transgression and progradation resulted in the overlapping on to a broad basement ridge, or geanticline, which was plunging to the northwest and which tilted, or subsided faster, towards the southwest already during sedimentation of the Fortescue Group'.

This study sheds little light on the basin-versus-shelf question, but evidence presented here places constraints on the shape of the southern part of the depositional area during deposition of the lower Fortescue Group.

Figure 23 is a columnar presentation of the thickness of the Mount Roe Basalt and the Hardey Sandstone measured at different localities in the various domes. As stated before, the top of the Hardey Sandstone is regarded as having formed a planar surface. This planar surface would dip gently (1-2°), certainly less than the 5° stated by McGowen and Groat (1971) for the proximal reaches of typical arid alluvial fan. This diagram clearly indicates that, during deposition of the lower Fortescue Group, the depositional area was deepening in a westward direction and, furthermore, was shallowing to the south in the vicinity of the Bellary Dome.

The palaeocurrent directions, which show a predominant flow from east to west, in the direction of the inferred westward deepening, imply a hinterland to the east. Uncertainly as to the nature of the northern margin of the depositional area is due to a lack of northward exposure of the Hardey Sandstone for a considerable distance from the area under study. A short visit was made to the area around Nullagine, about 250 km northeast of Tom Price, where the Hardey Sandstone is well exposed. Here the Hardey Sandstone has a lithofacies similar to that in the study area, but the few current-directions measured indicate a southerly source. Since the current direction data indicate such a distinctive east-to-west flow, the 'Hardey braidplain' must have been confined to the south, presumably by an east-trending topographic high or escarpment. Such an escarpment would probably have been generated by faulting. As discussed earlier, the lower part of the Mount Roe Basalt indicates a chaotic environment and steep slopes. These steep slopes may be a manifestation of an east-trending fault system, located just to the south of the Bellary and Wyloo Domes resulting in a half-graben depositional basin. The large debris flow noted in the southern portion of the Wyloo Dome would then have been derived from the upthrown or southern side of such a fault system. The presence of significant quantities of Mount Roe Basalt in these two domes (the Wyloo and Bellary) may be a result of proximity to this postulated fault system which tapped the magma chamber and acted as lava conduits.

All these data are combined in an interpretation of the Hamersley Basin during the time of deposition of the lower Fortescue Group and presented in Figure 24.

ECONOMIC POTENTIAL

KNOWN MINERALIZATION

Archaean

Within the Archaean inliers of the Rocklea, Milli Milli, and Bellary Domes, small gold shows have been worked and investigated over the past century. The

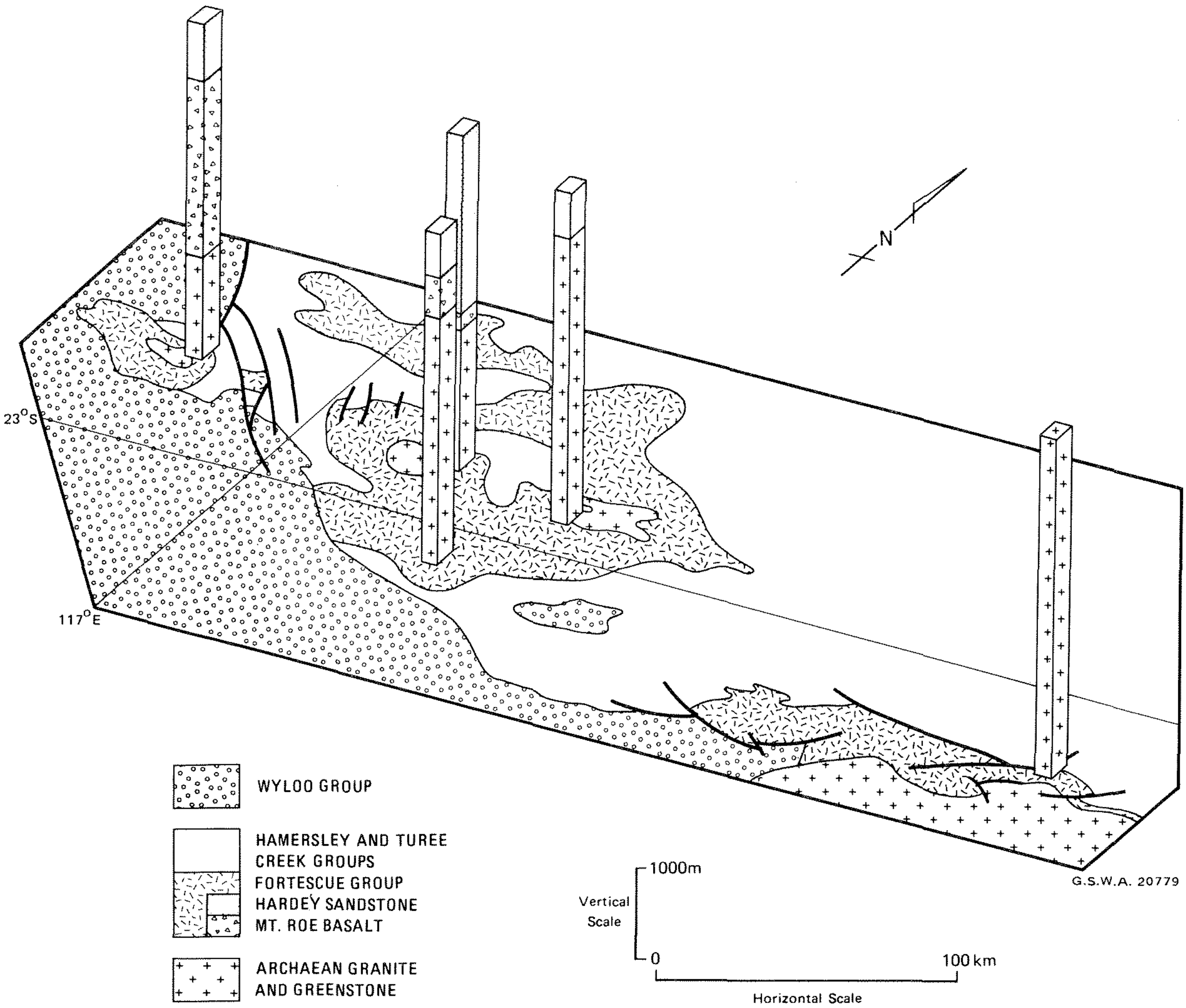


Figure 23 Columns showing thickness of the lower Fortescue Group in the southern Hamersley Basin. The method of measuring thickness is described in the text

high price of gold during 1980 stimulated activity from local prospectors, particularly in the Rocklea and Milli Milli Domes. Workers from the iron-ore-mining towns of Tom Price and Paraburdoo engaged in recreational prospecting, working known alluvial or 'dry blown' patches. Gold nuggets of the order of 200 g are rumoured to have been found near Milli Milli Springs. These 'dry blown' patches are shown on Plate 2 A & B. Production records are not kept for these operations.

Four kilometres north of Paraburdoo, a gold prospect within Archaean conglomerate in the Bellary Dome has been examined by a number of companies. The mineralization appears to be associated with authigenic pyrite. Gold values to 22 g/t (Zeelanberg, 1976) have been recorded although the average value is much lower (0.2-0.7 g/t). The conglomerate strikes over a length of 2-3 km and is about 2 m thick.

Fortescue Group

Two abandoned gold mines, and one former copper mine, are located within the Wyloo Dome in Fortescue Group rocks. These are Paulsen (or Melrose), Belvedere, and Blacks (or Belfry, or Metawandy). Descriptions of these mines can be found in Blockley (1971) and Marston (1979). The Paulsen and Belvedere mines are quartz-vein deposits associated with faults. The Belvedere mine is within Mount Roe Basalt, and the line of working follows a northeasterly trending fault (Fig. 2). Country rocks at this mine are mafic and felsic volcanics and arenite. Lead-isotope ratios reported by Richards and others (1981) indicate that the mineralization may be late Proterozoic, but this conclusion is equivocal. The Paulsen mine is located just to the west-northwest of the Belvedere mine, around the boundary of the Mount Jope Volcanics and the underlying Hardey Sandstone. The country rock is basalt and arenite. Production from these two mines is given in Table 2.

No production has been reported from the Belfry mine. An adit has been driven into mafic and felsic volcanics, which are stained green with copper minerals.

Green secondary copper staining was found in highly cleaved metabasalt (Mount Roe Basalt) 4 km south of Four Mile Bore. Daniels (1970) also records

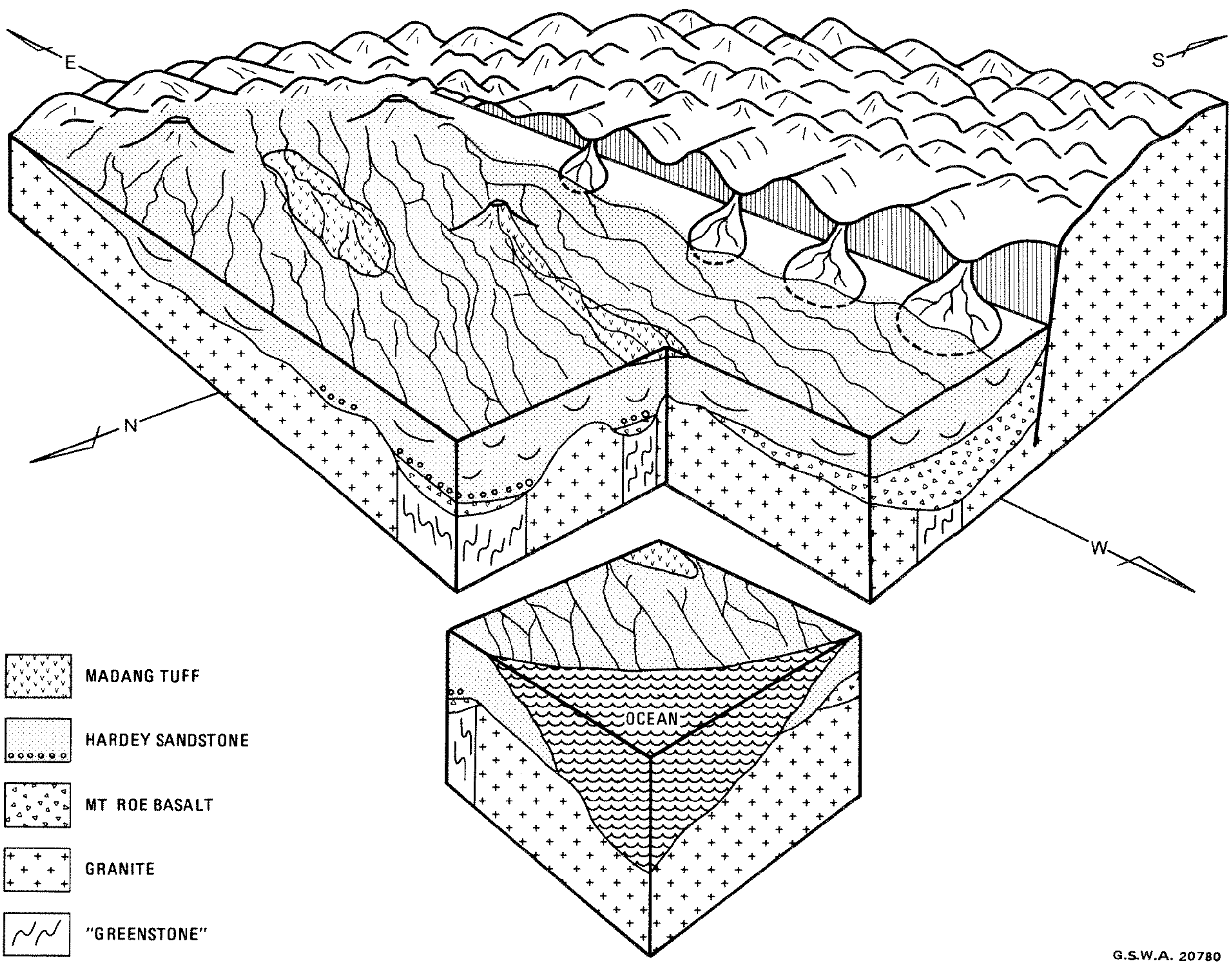


Figure 24 Block diagram illustrating potential environments of deposition of the Hardey Sandstone in the southwestern Hamersley Basin. The sand was laid down on a fluviatile braidplain fed from high ground in the eastern part of the Hamersley Basin and receiving additional input from streams

the occurence of copper mineralization at the western end of the Wyloo Dome near Mindle Bore. At the western end of the Rocklea Dome, secondary copper mineralization is disseminated through a coarse-grained arkosic unit of the Hardey Sandstone.

TABLE 2. PRODUCTION FROM THE PAULSEN AND BELVEDERE MINES

	Belvedere		*Paulsen*	
	Ore	*Metal*	*Ore*	*Metal*
Gold	1 584 t	13 864.1 g	2 955 t	28 549.6 g
Silver	—	3 568.5 g	—	271.5 g
Copper	1.32 t	0.19 t	8.45 t	1.40 t
Lead	—	1.77 t	—	—

In the Wyloo Dome, 8 km southeast of Mount de Courcey, a large gossan-like cap crops out over about 100 m. It is thought to cover a thin (< 20 m) black shale within basalt. Analyses reveal anomalous copper (235 ppm) and zinc (> 1 000 ppm) values, but the high manganese content (1 000-2 000 pm) of the samples suggests that the base metals may have been 'scavanged' from sources outside of the gossan by molecular sorption.

Approximately 4.5 km east-southeast of Horse Well, on the northern side of the Wyloo Dome, galena was noted in quartz veins within the Mount Roe Basalt.

Lead and mercury mineralization are associated with quartz veins on the southern side of the Milli Milli Dome immediately west of Coppin Pool. Galena and cerrusite with traces of cinnabar occur in an east-trending quartz vein that is totally contained within a dolerite sill in the Hardey Sandstone. J. R. Richards (written comm., 1982) dated the lead at 2.4 Ga.

Fibrous chrysotile asbestos was noted at several localities, in particular within the Rocklea Dome. In all cases, this material was associated with the pyroxenite sills intruding Hardey Sandstone. Fibres up to 0.2 m long were observed; these are regarded as having formed in dilation seams by hydrothermal alteration of the enclosing ultramafic material.

While all known mineral occurrences are small, their very presence should be viewed with optimism, because they show that ore-concentrating mechanisms have operated in these rocks.

Cainozoic

The Tertiary limonite valley fill (T) is, elsewhere in the Hamersley Ranges, an important source of iron ore. The limonite in the area covered by this study has been well explored, and although promising material was found in the Rocklea Dome, tonnages and grades were not sufficient to compete with existing iron-ore deposits elsewhere in the Hamersley Ranges.

MINERALIZATION MODELS

Volcanogenic deposits

Within any volcanic terrain, there must be potential for volcanogenic sulphide deposits. There are a number of different types of such deposits but all require certain common factors: a source of metal ions and a hydrothermal 'plumbing system'.

The source of metal ions in such deposits is regarded as either the volcanic rocks themselves, or the underlying basement. Hydrothermal systems are set up by the heat generated from the volcanic activity. In continental settings, the hydrothermal system is recharged by meteoric waters from adjacent highlands; in oceanic settings, the system is supplied by either convective circulation of seawater (Solomon and Walshe, 1979) or, where there is a rapid build-up of sediment, by expulsion of connate waters by intrusive sills (Einsele and others, 1980).

Massive sulphide deposits of the Noranda type have usually been regarded as being associated with calc-alkaline volcanic rocks. However, recent data presented by Fox (1979) and MacGeehan and MacLean (1980) show that such deposits are not restricted to calc-alkaline associations but may be hosted by rocks showing a variety of iron content. This concept clearly upgrades many terrains previously thought to be unprospective. The association of acid volcanic rocks and massive sulphides has long been recognized, *e.g.* Hopwood (1976). It is generally held that acid volcanism represents the last extrusive phase of a particular volcanic event and that metal sulphides in a hydrothermal system were formed in the waning stages of the volcanic event. Thus felsic volcanic piles of tholeiitic or calc-alkaline affinity should be regarded as potential sites for the accumulation of massive sulphide deposits. Within the Mount Roe Basalt, such a lithological association exists and is best displayed in the Wyloo Dome, where felsic pyroclastics are interlayed with basalt of probable tholeiitic affinity.

However, the majority of massive sulphide deposits are recognized as having been formed in an oceanic environment. As the Mount Roe Basalt formed in a sub-aerial to shallow-water environment, this may mitigate against its potential to host a volcanogenic massive sulphide deposit.

Because new evidence suggests that the base of the Fortescue Group is about 2 750 Ma old (Trendall, 1983), a geochronological correlation with the metallogenically important Archaean 'greenstones' of the Yilgarn Block further south can be made. Speculation that the Fortescue Group represents a platform equivalent of these 'greenstones' would enhance the possibility of the Fortescue Group also being mineralized.

Smith (1975a, 1975b, 1976) has discussed in some detail the similarity between the Fortescue Group and Keweenawan basalts in the Michigan copper province of North America. There, mineralization is thought to have occurred where copper, leached from basalts by connate waters, was expelled during metamorphism and subsequently redeposited in suitable sites because of changes in physico-chemical conditions. These suitable sites may be brecciated lava flow tops or sediments. Because of Smith's exhaustive treatment of this topic it is not pursued further.

Black Shale

As mentioned earlier, gossanous material southeast of Mount de Courcey, which shows anomalous copper and zinc values, is presumed to overlie black shale. Thought could be given to the possibility that more of this type of mineralization may be interlayered within the mafic volcanics of the Mount Roe Basalt, or perhaps within the Mount Jope Volcanics. It is likely that any such inter-basalt black shale would be relatively thin and would, therefore, host only small metal deposits.

Sedimentary gold and uranium

The Fortescue Group, and in particular the Hardey Sandstone, has been considered a potentially suitable unit to host gold and uranium mineralization of the Witwatersrand or Elliot Lake type (Pretorius, 1981). In fact, auriferous conglomerate has been exploited in a small way in the northern part of the Hamersley Basin. Near Nullagine, there has been a small production of gold from the Beatons Creek Conglomerate, which, locally, is the basal member of the Hardey Sandstone (Hickman, 1983). West of Marble Bar at the 'Just-in-Time' workings some gold has been won from a local basal conglomerate member of the Mount Roe Basalt (Button, 1976; Hickman & Lipple, 1978).

There is an extensive literature regarding this type of deposit, but most is in relation to South African examples. Early accounts of the genesis of this type of deposit polarized between ideas proposing an epigenetic origin and those proposing a syngenetic origin. Recent research, in particular studies of associated pyrite morphologies (Utter, 1977; Simpson and Bowles, 1979; Dimroth, 1977; Clemmey, 1981), has shown that the mineralization in this type of deposit is likely to take one of three forms:

(a) detrital allogenic material including rounded grains of gold and uraninite that are in hydraulic equivalence with the enclosing material and concentrated on foresets in scour planes and in coarse fractions (Minter 1976; Smith and Minter 1979);

(b) gold and brannerite associated with allogenic, rounded, porous pyrite grains that are regarded as having been derived diagenetically from muds within the alluvial system and subsequently reworked; and

(c) gold and uranium that are associated with carbonaceous material and regarded as having formed diagenetically where suitable precipitates were trapped by algal growths (Zumberge and others, 1978).

The allogenic type of mineralization is likely to be concentrated in the proximal high-energy conglomerate-facies of an alluvial system (Simpson and Bowles, 1977) although Pretorius (1981) regards conglomerate of palaeovalley-fill type as being less prospective than the fluvial-fan type. The diagenetic type of mineralization is more likely to occur in the low-energy, distal parts of the system (Simpson and Bowles, 1977).

During the mapping programme, much of the Hardey Sandstone in the mapped areas was tested for radioactivity by hand-held scintillometer. In only a few places was an anomalous count (4 to 8 times background) obtained. These areas were all in the northern section of the Bellary Dome and were in the stratigraphically lower sections of the Hardey Sandstone. In every case, the anomalous reading was obtained from a pebbly or conglomerate horizon. Material from the two most highly radioactive locations was analyzed (Table 3).

The anomalous radioactivity is due to thorium, not uranium. Thin-section examination of the rock samples indicated the presence of small, subrounded, uniaxial positive, high relief, highly birefringent, tetragonal crystals in the matrix. These have been tentatively identified as zircon or xenotime, and are regarded as the source of the anomalous radioactivity. Their presence indicates that a fluvial mechanism for the concentrating of heavy resistates was in operation at the time of deposition of the Hardey Sandstone.

TABLE 3. ANALYSES OF RADIOACTIVE CONGLOMERATES WITHIN THE HARDEY SANDSTONE NORTH OF PARABURDOO

Sample No.	*Locality*	*U (ppm)*	*Th (ppm)*	*Au (ppm)*
70924	23°06'40" S 117°34'30" E	15	130	<0.2
70942B	23°03'20" S 117°35'25" E	25	370	<0.2

Analysed by Government Chemical Laboratories.

Apart from the two previously mentioned gold workings in the northern part of the Hamersley Basin, and some other minor uranium occurrences, the Fortescue Group is not known to contain sedimentary gold and uranium deposits. This may, in part, be a function of the limited amount of exploration for this type of deposit. In the southern Hamersley Basin, it may also reflect the composition of the source area. As previously discussed, the current-direction data for the Hardey Sandstone in that area indicates a source to the east (*i.e.* the southeastern part of the Pilbara Craton). Exposures of the craton (*i.e.* basement) in the eastern part of the Hamersley Basin are chiefly granite (Geological Map of Western Australia, 1979); greenstones make up only a small portion. If this apparent dominance of granitic material is representative, then it may account for the lack of gold within the Hardey Sandstone. At the time of deposition there may have been little suitable source material available.

Another factor which may have limited the accumulation of gold in the Fortescue Group across the entire Pilbara region may be that the first rocks of the Pilbara Block to be covered were greenstones in palaeovalleys (Fig. 24). Thus the updoming granitoid rocks, which formed the highlands during this time would provide much of the detrital material for the Fortescue Group, lessening the likelihood of large qantities of gold being deposited in the Hamersley Basin.

Despite this possibility, and until such time as the Hardey Sandstone has been extensively prospected, it must remain as a potential host to Witwatersrand type gold-uranium mineraliz-ation.

CONCLUSIONS

(a) The Fortescue Group was deposited unconformably on the adamellite-greenstone terrain of the Pilbara Craton.

(b) The predepositional topography was controlled to some extent by the geological features of the underlying Pilbara Block inasmuch as greenstones commonly floor palaeovalleys.

(c) The Mount Roe Basalt is present in only the Wyloo and Bellary Domes, and part of the Rocklea Dome, and was initially deposited in palaeovalleys.

(d) The lower part of the Mount Roe Basalt is a mixture of clastic sediments and felsic and mafic pyroclastic volcanics, whereas the upper section is a homogeneous amygdaloidal basalt. This homogeneous upper facies has been recognized as far north and northeast as Roebourne and Nullagine.

(e) The overlying Hardey Sandstone is interpreted as a braidplain whose proximal, or conglomerate, facies is confined to palaeovalleys. Current-direction data and isopachs indicate a source from the east.

(f) A new volcanic member of the Hardey Sandstone, the Madang Tuff Member, is recognized, described, and defined.

(g) Pyroxenite and dolerite sills intrude the Hardey Sandstone. These are thought to be comagmatic with the overlying Mount Jope Volcanics.

(h) A model of the depositional environment of the Lower Fortescue Group in the southern Hamersley Basin has been inferred from the above data. This model suggests a continental environment of deposition for these units in a roughly west-northwesterly trending half-graben, confined on the south-southwest and deepening to the west-northwest.

(i) In view of the known styles of mineralization, the lower Fortescue Group of the southern Hamersley Basin is thought to have low economic potential. The continental nature of the deposition mitigates against volcanogenic sulphide deposits, and the apparent lack of a suitable source area may have prohibited the formation of a gold deposit of the Witwatersrand type. However, further exploration is required to examine this possibility.

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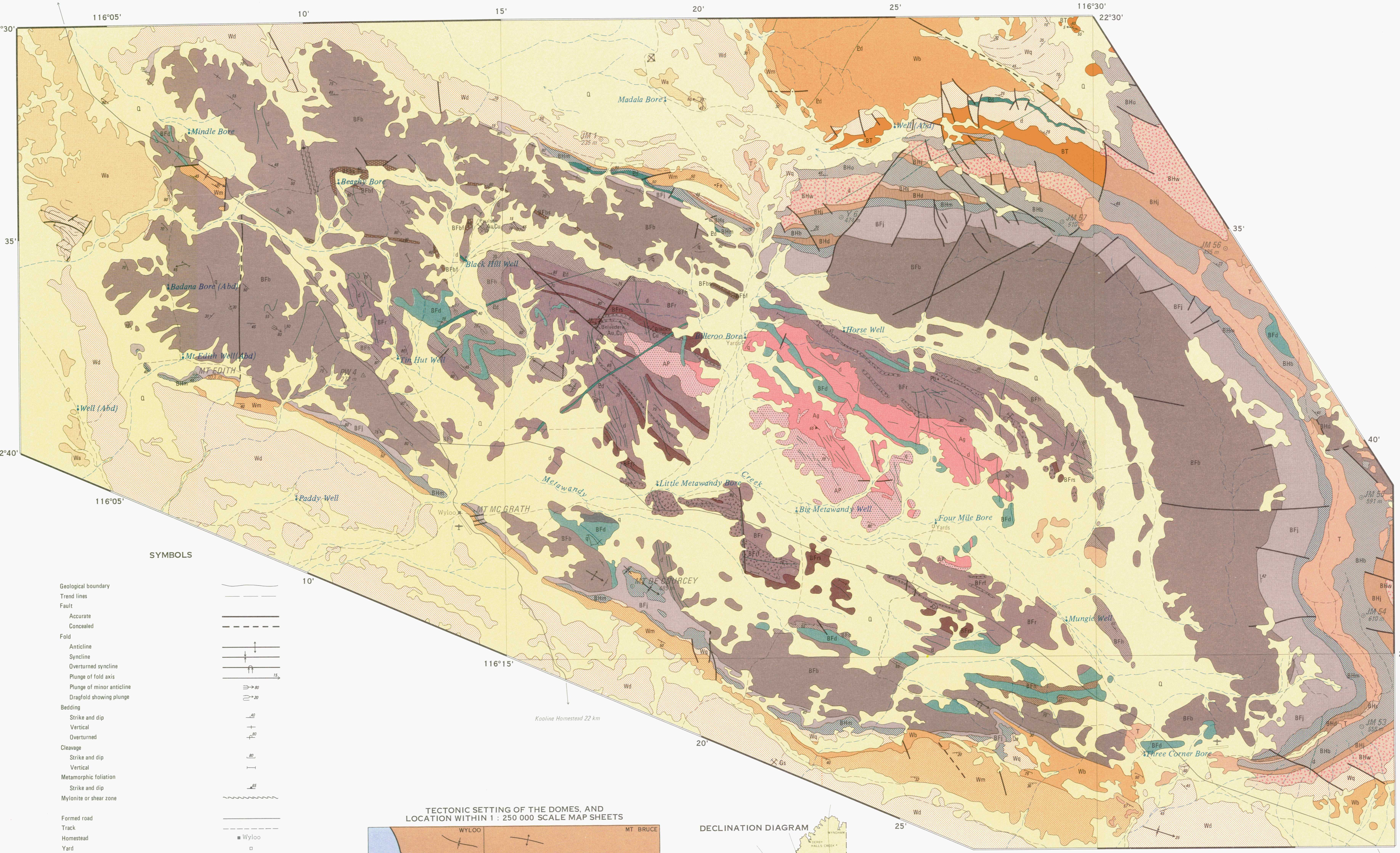


REFERENCE

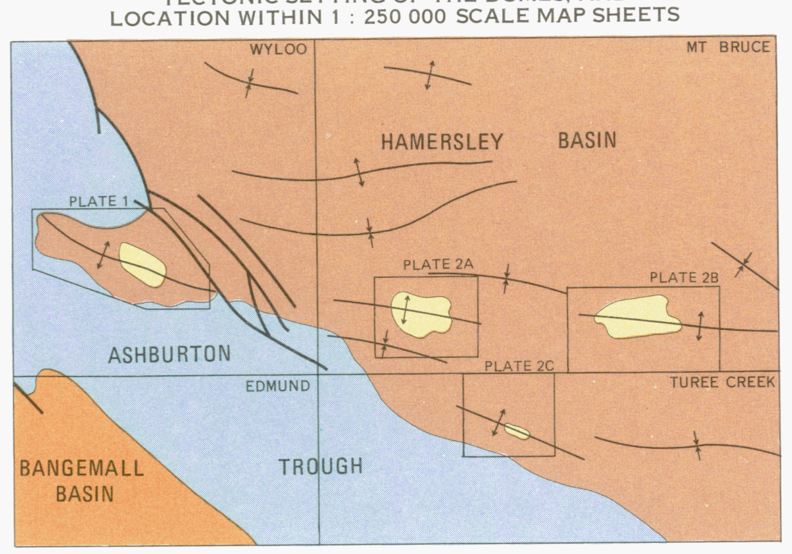
QUATERNARY		Q	Alluvium and colluvium
TERTIARY		T	Hematite and goethite capping, colluvium and calcrete deposits with some ROBE PISOLITE
PROTEROZOIC		Ɐd	Olivine gabbro to granogabbro, in dykes
		d	Dolerite, in dykes
		q	Quartz, in veins
	Wyloo Group	Wa	ASHBURTON FORMATION : chiefly clastic turbidites
		Wd	DUCK CREEK DOLOMITE : grey to buff dolomite with some shale. Contains stromatolites
		Wm	MOUNT McGRATH FORMATION : chiefly clastic sediment including shale, arenite and conglomerate with some dolomite containing stromatolites
		Wb	CHEELA SPRINGS BASALT : massive basalt some amygdular
		Wq	BEASLEY RIVER QUARTZITE : quartzite commonly with basal **Three Corner Bore Conglomerate Member**
	Mount Bruce Supergroup — Turee Creek Group	BT	TUREE CREEK GROUP : chiefly clastic sediment with some dolomite
	Mount Bruce Supergroup — Hamersley Group	BHo	BOOLGEEDA IRON FORMATION : purplish flaggy siltstone, banded iron-formation and shale
		BHw	WOONGARRA VOLCANICS : acid volcanic, some tuffaceous
		BHj	WEELI–WOLLI FORMATION : banded iron-formation, chert and shale. Intruded by dolerite sills
		BHb	BROCKMAN IRON FORMATION : banded iron-formation and shale
		BHs	MOUNT McRAE SHALE : shale siltstone, dolomitic shale with banded iron-formation and chert. Includes MOUNT SYLVIA FORMATION
		BHd	WITTENOOM DOLOMITE : grey dolomite with some chert and shale
		BHm	MARRA MAMBA IRON FORMATION : banded iron-formation and chert
	Mount Bruce Supergroup — Fortescue Group	BFd	Dolerite Intrusive sills, somewhat transgressive
		BFj	JEERINAH FORMATION : shale, chert, jaspilite, mudstone quartzite and dolomite
		BFb	MOUNT JOPE VOLCANICS : chiefly pillow basalt with some pyroclastic and minor ultramafic flows
		BFbf	Acid volcanic, lapilli tuff and quartz-feldspar porphyry
		BFbs	Clastic sediment : medium to coarse-grained arenite
		BFbt	*Basaltic tuff, some pisolitic
		BFh	HARDEY SANDSTONE : coarse arkose with some pebble horizons, shale and tuff—fluvial sequence with abundant cross-bedding
		BFhm	***Madang Tuff Member** : intermediate vitric, lithic crystal tuff commonly containing poorly rounded clastic quartz grains
		BFhc	*Conglomerate : commonly occurs in paleovalleys and marks the base of the HARDEY SANDSTONE
		BFr	MOUNT ROE BASALT : vesicular basalt and basaltic agglomerate including some scoria
		BFrf	Acid volcanic : lapilli tuff and quartz-feldspar porphyry
		BFrs	Waterlain clastic sediment—diamictite, conglomerate, arenite and shale, minor basaltic tuff some with lapilli
ARCHAEAN		Ag	METAWANDY GRANITE : biotite bearing medium-grained adamellite
		AP	"Greenstone", undifferentiated. Part of PILBARA SUPERGROUP

*Unit not on map but included in reference to indicate stratigraphic relationships

SYMBOLS

- Geological boundary
- Trend lines
- Fault
  - Accurate
  - Concealed
- Fold
  - Anticline
  - Syncline
  - Overturned syncline
  - Plunge of fold axis (15)
  - Plunge of minor anticline (80)
  - Dragfold showing plunge (20)
- Bedding
  - Strike and dip (40)
  - Vertical
  - Overturned (80)
- Cleavage
  - Strike and dip (80)
  - Vertical
- Metamorphic foliation
  - Strike and dip (65)
- Mylonite or shear zone
- Formed road
- Track
- Homestead — ■ Wyloo
- Yard
- Landing ground
- Locality — Metawandy
- Horizontal control
  - Major
  - Minor
- Watercourse (ephemeral)
- Well or bore with windpump
- Abandoned — (Abd)
- Mine
- Mineral occurrence
  - Copper — Cu
  - Gold — Au
  - Iron — Fe
  - Lead — Pb
  - Gemstone — Gm

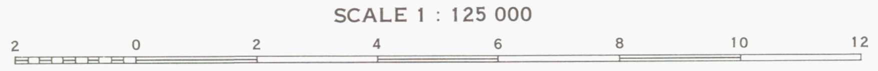
TECTONIC SETTING OF THE DOMES, AND LOCATION WITHIN 1 : 250 000 SCALE MAP SHEETS



DECLINATION DIAGRAM

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

SCALE 1 : 125 000

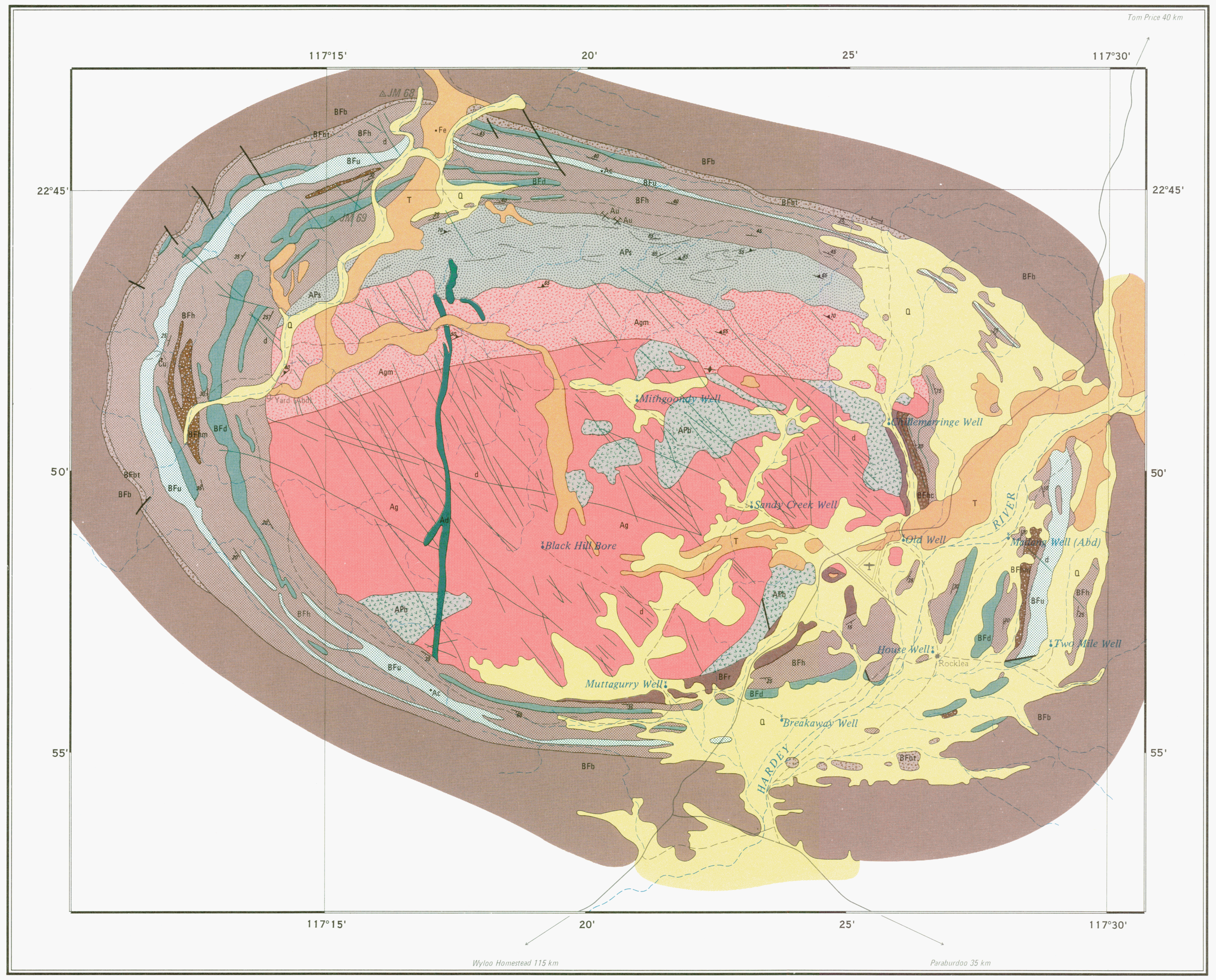


Geology by D.F. Blight and D.B. Seymour 1980

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF THE WYLOO DOME

PLATE 2A: ROCKLEA DOME



FORTESCUE GROUP REPORT 13 — PLATE 2B: MILLI MILLI DOME

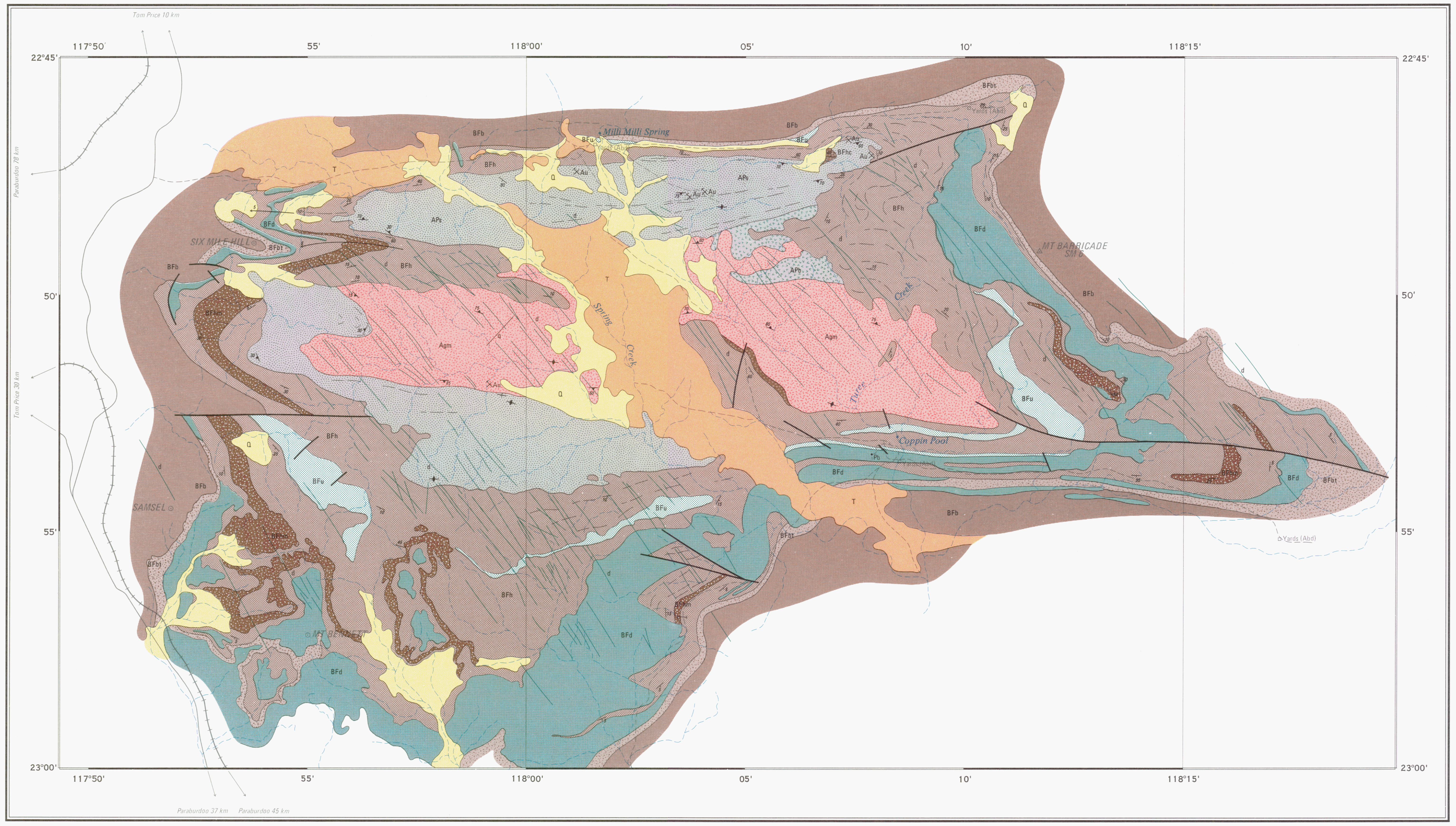
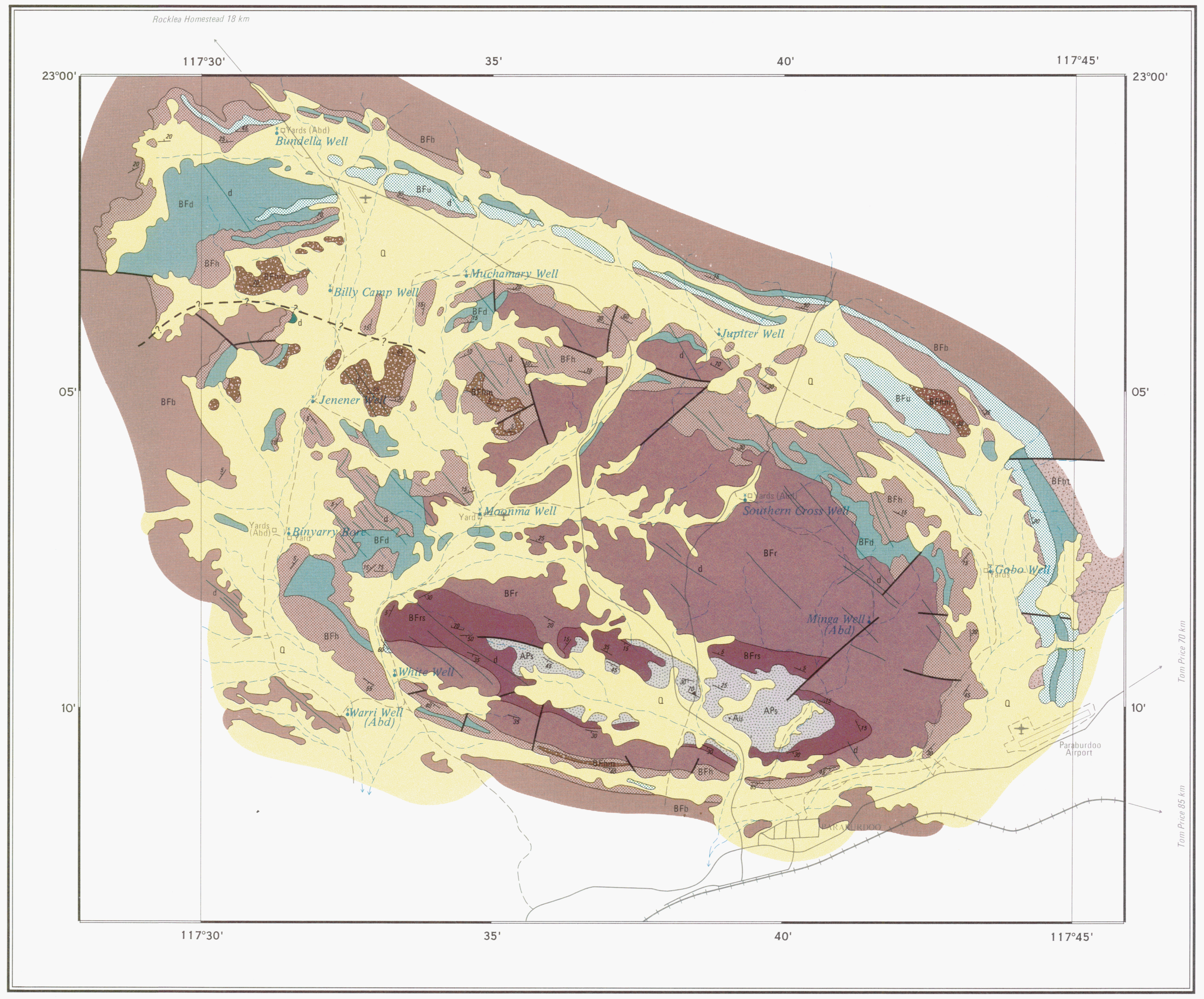


PLATE 2C: BELLARY DOME



REFERENCE

QUATERNARY

Q — Alluvium and colluvium

TERTIARY

T — ROBE PISOLITE : pisolitic limonite deposits along old river channels and OAKOVER FORMATION ; limestone and calcareous gravel with opaline silica

PROTEROZOIC

d — Dolerite, in dykes

q — Quartz, in veins

Fortescue Group

BFd — Dolerite; BFu — Pyroxenite: Intrusive sills, somewhat transgressive

BFj — * JEERINAH FORMATION : shale, chert, jaspilite, mudstone, quartzite and dolomite

BFb — * MT JOPE VOLCANICS : chiefly pillow basalt with some pyroclastic and minor ultramafic flows

BFbt — Basaltic tuff, some pisolitic

BFh — HARDEY SANDSTONE : coarse arkose with some pebble horizons, shale and tuff — fluvial sequence with abundant cross-bedding

BFhm — **Madang Tuff Member** : intermediate vitric, lithic crystal tuff commonly containing poorly rounded clastic quartz grains

BFhc — Conglomerate — commonly occurs in palaeovalleys and marks the base of the HARDEY SANDSTONE

BFr — MT ROE BASALT : vesicular basalt and basaltic agglomerate including some scoria

BFrs — Waterlain clastic sediment — diamictite, conglomerate, arenite and shale, minor basaltic tuff some with lapilli

ARCHAEAN

Ad — Dolerite, in dykes

Ag — Granite — medium-grained and biotite bearing

Agm — Heterogeneous marginal facies of granite, gneissic to blastomylonitic texture

Pilbara Supergroup

APs — Metasediments — shale, banded iron-formation and acid tuff

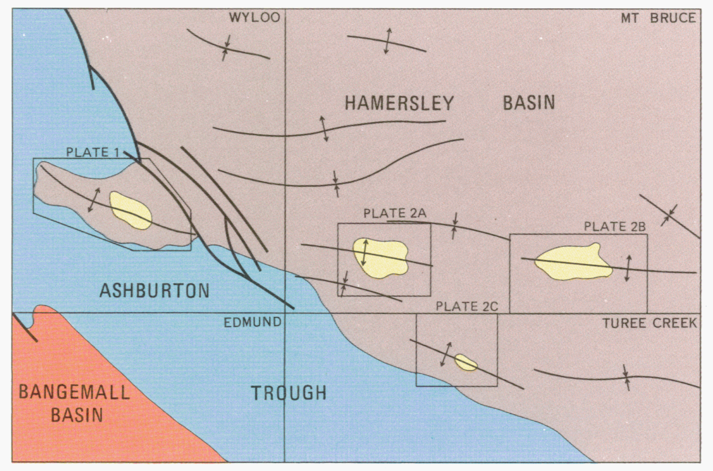
APb — Metavolcanic — chiefly basaltic

* Unit not on maps but included in reference to indicate stratigraphic relationships

SYMBOLS

Geological boundary	
Trend line	
Fault	
Accurate	
Concealed or inferred	– –?– – –?–
Fold	
Plunge of fold axis	5
Bedding	
Strike and dip	10
Vertical	
Cleavage	
Strike and dip	70
Vertical	
Metamorphic foliation	
Strike and dip	30
Vertical	
Formed road	
Track	
Railway	
Horizontal control	
Major	
Minor	
Homestead	■ Rocklea
Yard	
Landing ground	
Watercourse (ephemeral)	
Well or bore with windpump	
Abandoned	(Abd)
Mine	
Alluvial gold workings ("dry blown" patches)	Au
Mineral occurrence	•
Chrysotile (asbestos)	Ac
Copper	Cu
Gold	Au
Iron	Fe
Lead	Pb

TECTONIC SETTING OF THE DOMES, AND LOCATION WITHIN 1 : 250 000 SCALE MAP SHEETS



DECLINATION DIAGRAM

The lines indicate magnetic declination, 1980 + means declination is east and correction must be added to compass bearing to give true bearing − means declination is west and correction must be subtracted from compass bearing to give true bearing

Annual change is − 2' westerly

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

SCALE 1 : 125 000

2 0 2 4 6 8 10 12
KILOMETRES

Geology by D.F. Blight 1981

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF THE ROCKLEA, MILLI MILLI AND BELLARY DOMES