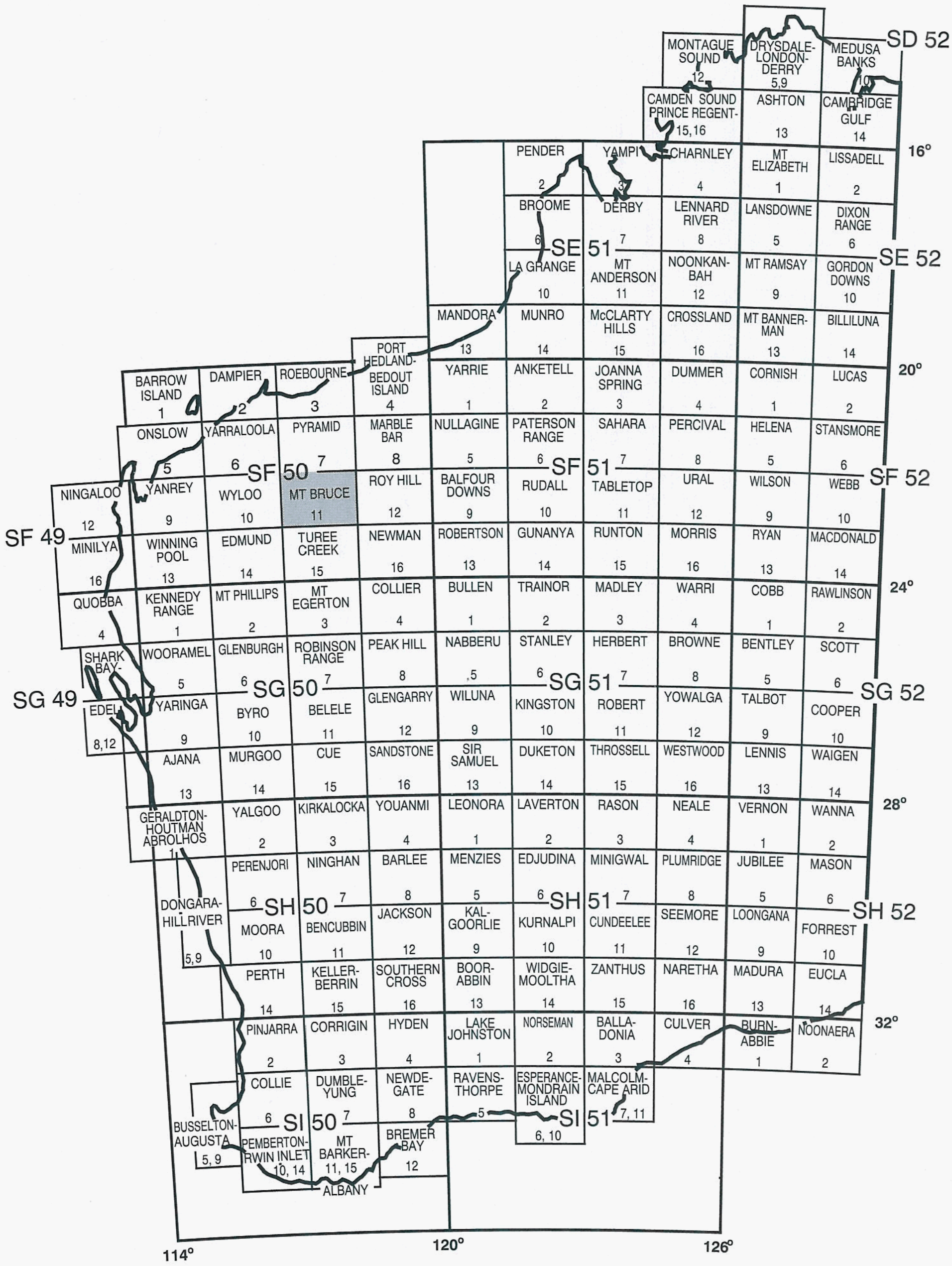
EXPLANATORY NOTES

GEOLOGY OF THE ROCKLEA 1:100 000 SHEET

by A. M. Thorne and I. M. Tyler

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY



MOUNT BRUCE SF50–11

JEERINAH 2353	McRAE 2453	WITTENOOM 2553
ROCKLEA 2352	MOUNT LIONEL 2452	MOUNT BRUCE 2552

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Cover photograph:

Columnar jointing in a single submarine pyroxene spinifex-textured basalt flow, Pyradie Formation, northwestern Rocklea Dome. Columns in upper and lower parts of the flow are oriented perpendicular to the flow surfaces and are separated by a narrow zone of smaller, disorganized columns and loose blocks. The height of the section is approximately 6 m.

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Geology of the Rocklea 1:100 000 sheet

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Introduction

The ROCKLEA* 1:100 000 map sheet (SF50-11-2352) is bounded by latitudes 22°30' and 23°00'S and longitudes 117°00' and 117°30'E. There are no towns on ROCKLEA, the nearest large settlements are the mining centres of Tom Price and Paraburdoo, with populations of about 3600 and 2000 respectively. The sealed Nanutarra–Paraburdoo road crosses the southern part of the map sheet and joins an unsealed road which links ROCKLEA to Wittenoom and the nearby Karijini National Park.

The climate is arid; annual rainfall is between 200 and 300 mm. Most rain falls from January to June. Summers are very hot: January maxima range from 36 to 44°C; minima from 24 to 28°C. Winters are mild: July maxima range from 20 to 25°C; minima from 6 to 11°C. Evaporation from a free water surface is about 3600 mm per year.

Most of ROCKLEA, except for the extreme southwest corner, forms part of the Fortescue Botanical District (Beard, 1975). Granitic rocks in the core of the Rocklea Dome are colonized by sparse shrubs, mainly mulga (*Acacia aneura*) and snakewood (*A. xiphophylla*), and buck spinifex (*Triodia wiseana*). Elsewhere, outcrops of basaltic rock are characterized by a mosaic of *A. aneura, A. pyrifolia, and Triodia*, with *Eucalyptus brevifolia* on the steepest, rockiest areas. Iron-formations of the Hamersley Range are covered by the *E. brevifolia–T. wiseana* association, and *E. gamophylla* is present locally. Most of the valley plains carry *A. aneura*; *E. camaldulensis* occurs along the major watercourses.

The remainder of ROCKLEA forms part of the Ashburton Botanical District (Beard, 1975). Mudstone and sandstone of the Ashburton Formation are colonized by species of *Cassia, Eremophila,* and stunted *Acacia*. Other rock units, colluvium and Cainozoic gravel are characterized by *A. aneura, A. xiphophylla,* and *A. victoriae;* they may be associated with small shrubs such as *Eremophila cuneifolia, Bassia divarica* and *Atriplex inflata*.

ROCKLEA can be divided into three main physiographic zones corresponding broadly to the areas of granite–greenstone basement, Hamersley Basin, and Ashburton Basin rocks.

Granite–greenstone basement rocks form an area of low, rounded hills and ridges, and sandy valleys in southeast central ROCKLEA. Maximum elevation in this region is about 500 m Australian Height Datum (AHD) and local relief is less than 100 m. Hamersley Basin rocks underlie most of the remaining map sheet area and give rise to a rugged topography of high, rounded hills and strike ridges. The highest point on ROCKLEA (Mount Turner,1014 m (AHD), AMG 436892) is in this area, and local relief ranges up to 450 m. Ashburton Basin rocks are confined to the southwestern part of ROCKLEA. Here, areas of folded sandstone, basalt, and dolomite give rise to a strike-ridge topography of low to moderate relief. Gently undulating hills of low to moderate relief characterize those areas where folds are open, or where the proportion of basalt or mudstone is high.

Early geological investigations in the area are summarized in the first edition explanatory notes for the MOUNT BRUCE 1:250 000 geological sheet (de la Hunty, 1965). These Notes discuss more recent work.

Tectonic setting

The main tectonic features of ROCKLEA are shown in Figure 1. The map sheet covers part of the northern margin of the Capricorn Orogen (Gee, 1979), a major zone of deformed, low- to high-grade metamorphic rocks and granitoid intrusions formed during continental crustal collision between the Pilbara and Yilgarn cratons about 2000–1700 Ma (Myers, 1990a; Tyler and Thorne, 1990; Thorne and Seymour, 1991).

Pilbara Craton granite–greenstone basement (older than 2800 Ma) outcrops in the Rocklea Dome in southeast central ROCKLEA. These rocks are unconformably overlain by 2765–2470 Ma supracrustal deposits of the Hamersley Basin which outcrop in the northern part of ROCKLEA. Hamersley Basin rocks are unconformably overlain by the c. 2000–1800 Ma rocks of the Ashburton Basin, which developed during the early stages of the Capricorn Orogen. Subsequent deformation of the Ashburton Basin took place during the final stages of the Capricorn Orogeny, at about 1800 Ma.

* Capitalized names in these Notes refer to standard map sheets.

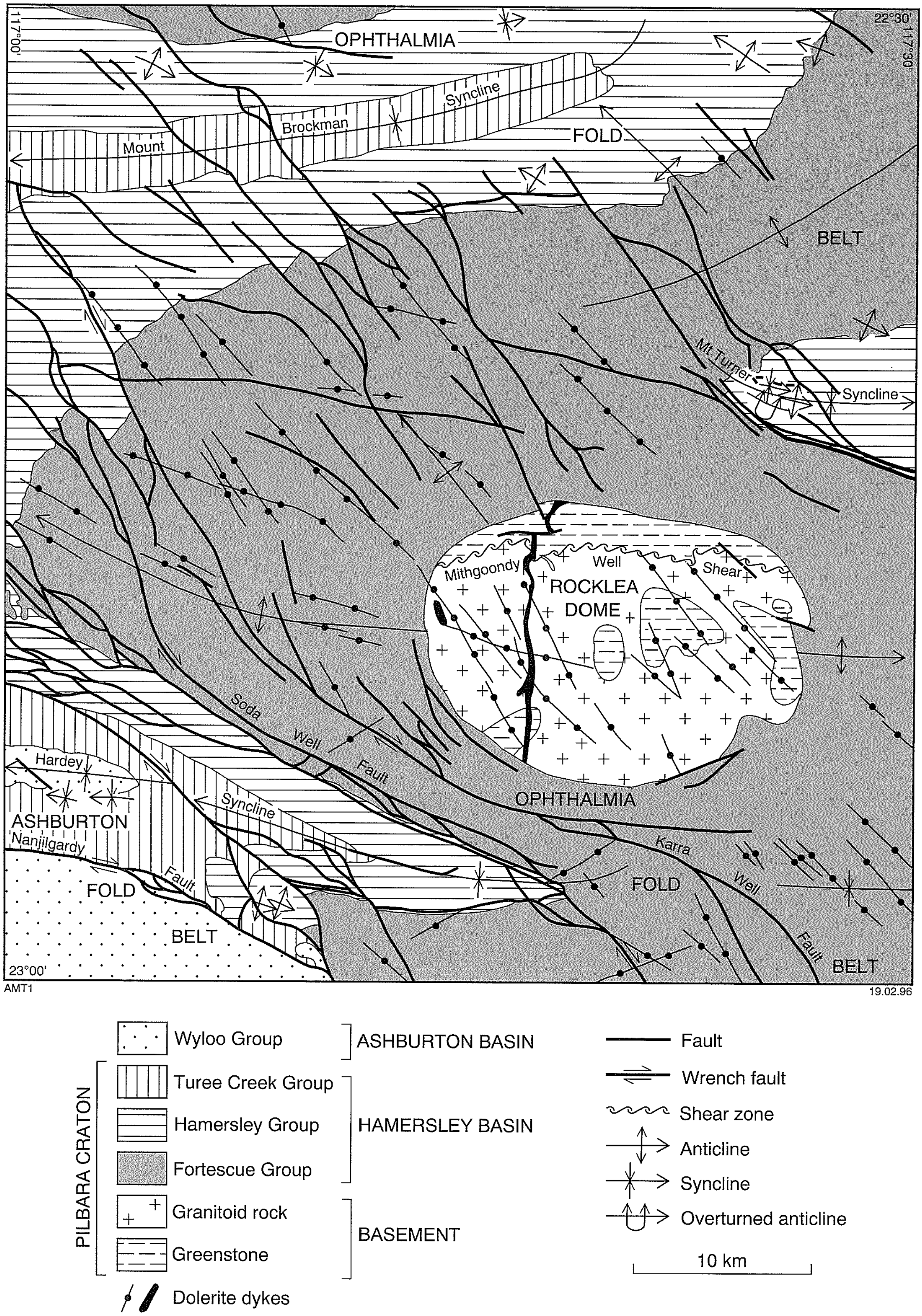

Figure 1. Simplified geological map of ROCKLEA showing the main tectonic units

Terminology

Rocks of the Hamersley and Ashburton Basins have been subjected to lower greenschist facies metamorphism. However for the sake of brevity, the prefix 'meta' will not be used in the following descriptions.

Pilbara Craton granite–greenstone rocks

Pilbara Craton granite–greenstone rocks are confined to the core of the Rocklea Dome and comprise metabasalt and metamorphosed pyroxene spinifex-textured basalt; quartzofeldspathic and quartz–chlorite schists; chert; metamorphosed biotite monzogranite; metadolerite dykes; and minor pegmatite dykes. On ROCKLEA, the minimum age of these rocks is fixed by the 2765 Ma age of the overlying lower Fortescue Group. Their maximum age is unknown, although comparison with similar granite–greenstone assemblages on the northern Pilbara Craton (Hickman, 1990) indicates they formed between 3500 and 2900 Ma.

Granite–greenstone rocks on ROCKLEA have been subjected to lower greenschist facies metamorphism (Blight, 1985).

Metabasalt (*Ab*) and metamorphosed pyroxene spinifex-textured basalt (*Abm*)

Metabasalt and metamorphosed pyroxene spinifex-textured basalt occur in small, irregularly shaped outcrops in the central, southern, and southeastern Rocklea Dome. Contact relationships show that these rocks have been intruded by biotite monzogranite, and also by pegmatite and dolerite dykes.

Metabasalt forms massive, generally non-vesicular flows, interbedded with pyroxene spinifex-textured basalt and minor basaltic breccia. Most basalts are aphyric and comprise a felted mass of tremolite, epidote–clinozoisite, plagioclase, and chlorite, together with subordinate white mica and quartz. Plagioclase-phyric varieties, with porphyroblasts up to 1 mm long, are also recorded.

Metamorphosed spinifex-textured basalts are non-vesicular, and consist predominantly of randomly oriented, acicular relict pyroxene, interlayered with thin seams in which the pyroxene needles are aligned normal to the flow boundaries. As is the case with the basaltic rocks, the present mineralogy of these rocks reflects the lower greenschist facies metamorphism and comprises recrystallized acicular tremolite in a finer grained matrix of chlorite, epidote–clinozoisite, talc, and sphene.

Quartzofeldspathic schist and quartz–chlorite schist (*Al*)

Quartzofeldspathic schist, quartz–chlorite schist, and talc–fuchsite schist outcrop in the northern part of the Rocklea Dome and are separated from less-deformed monzogranite and basaltic rocks to the south by an easterly trending belt of strongly foliated monzogranite and quartz–feldspar mylonite. Within this northern belt, contacts between the different schist types are generally subparallel to the strong S_1 foliation, although several quartz–chlorite schist bodies that show sharp contacts are strongly discordant to this trend.

Relict textures preserved within quartzofeldspathic schist indicate these rocks are formed from two separate protoliths: biotite monzogranite, and felsic volcanic rock. The former consists of equant to flattened porphyroclasts of potassic feldspar and quartz aggregate in a fine-grained, sericitic quartzofeldspathic matrix. Schist derived from felsic volcanic rock is fine to medium grained and shows rounded to angular beta quartz, sericitized feldspar phenocrysts, and rhyodacitic lithic fragments, in a sericitized quartzofeldspathic matrix.

Quartz–chlorite schist is generally fine to medium grained and contains lenticular, or ribbon-like porphyroclasts of recrystallized quartz set in a matrix of strongly aligned chlorite and leucoxenized opaques. Many quartz–chlorite schists are strongly carbonated. The mineralogy of this rock suggests a mafic igneous origin whereas the strongly discordant relationships shown by some quartz–chlorite schist bodies suggest they represent former dolerite dykes.

Friable talc–carbonate schist, the least abundant schistose lithology, is generally very fine grained and is probably derived from former ultramafic rock.

Chert (*Ac*)

Grey and white banded, fine-grained chert forms a laterally persistent marker unit within quartzofeldspathic schist and quartz–chlorite schist in the northern part of the granite–greenstone outcrop. Centimetre-scale banding within the chert reflects variations in quartz crystal grain size. The darker layers are composed mostly of 10–20 μm crystals, whereas grains in the coarser layers are generally 50–100 μm across. Isoclinal folds, with hinge lines and axial surfaces parallel to the bounding surfaces of the chert, are observed in some areas, and deformation of cross-cutting quartz veins points to considerable flattening of the chert unit locally.

Metamorphosed biotite monzogranite (*Agm*)

Medium-grained, homogeneous, metamorphosed biotite monzogranite forms the dominant rock type in the south-central Rocklea Dome. Typical mineralogy is quartz, plagioclase (now albitic), microcline, and minor biotite with secondary sericite, epidote, and chlorite. Closer to the boundary with the quartzofeldspathic schist and quartz–chlorite schist, the monzogranite develops a blastomylonitic texture in which porphyroclasts of plagioclase and microcline lie in a fine-grained matrix of quartz, feldspar, biotite, and secondary white mica.

Metamorphosed mafic dykes (d_1) and pegmatite dykes

North-trending metamorphosed mafic dykes, including the prominent intrusion extending northward from AMG 293692, cut all granite–greenstone rocks in the core of the Rocklea Dome. These dykes are unconformably overlain by the lower Fortescue Group and are correlated with the earliest suite (d_1) of dykes in the Sylvania Inlier (Tyler, 1991).

Small, discontinuous pegmatite dykes (≤4 m thick) intrude basaltic greenstones in the southeastern part of the Dome. These show no systematic trend and are not shown on the accompanying map sheet. Their relationship to both the d_1 dolerite dykes and the Fortescue Group is unknown.

Granite–greenstone structure

In northern parts of the Dome, a pervasive, broadly eastward-trending, northward-dipping foliation is developed in the biotite monzogranite and adjacent quartzofeldspathic schists and quartz–chlorite schist. The foliation grades into the Mithgoondy Shear Zone, an easterly trending fault zone showing a range of blastomylonitic to ultramylonitic textures. In this zone a prominent stretching lineation plunges 25–45° toward 300° and sense-of-shear criteria indicate oblique dextral movement.

The foliation and associated lineation within the monzogranite and schistose rocks are deformed locally by small- to large-scale open folds of various orientations (e.g. at AMG 280770 and 430800). These open folds are cut by the northward-trending dyke suite (d_1) which in turn is displaced by an easterly trending pre-Fortescue Group dextral wrench fault at AMG 297810. Localized dextral C–S fabrics, observed within schistose rocks in this area are probably related to this structure.

A northwest-trending set of near-vertical fractures, with centimetre-scale dextral offsets, cuts the prominent chert unit at AMG 358825. These fractures are parallel to, and show the same shear sense as, the main fault system in the nearby cover rocks, and were probably formed during the D_{2a} event of the Capricorn Orogeny.

Hamersley Basin

The Hamersley Basin is a late Archaean to early Proterozoic (2765–2470 Ma) depositional basin which is exposed over most of the southern part of the Pilbara Craton. Three major stratigraphic units (collectively referred to as the Mount Bruce Supergroup) are recognized within the basin; these are, in ascending order, the Fortescue, Hamersley, and Turee Creek Groups.

Fortescue Group

The Fortescue Group is the lowermost stratigraphic unit of the Hamersley Basin and rests with angular unconformity upon granite–greenstone basement. It is exposed over a large part of Rocklea and consists of about 6.4 km of low-grade volcanic and sedimentary rocks. The Fortescue Group was deposited between 2765 and 2687 Ma (Arndt et al., 1991). Six major stratigraphic units are recognized on ROCKLEA; they are, in ascending order, Mount Roe Basalt, Hardey Formation, Boongal Formation, Pyradie Formation, Bunjinah Formation, and Jeerinah Formation.

Mount Roe Basalt (*AFr*)

The Mount Roe Basalt is confined to the southeastern limb of the Rocklea Dome and has a maximum thickness of about 100 m. The unit consists of basalt flows interbedded with thin beds of basaltic breccia. A thin feldspathic sandstone, coarsening upward into pebbly sandstone and conglomerate occurs locally at the base of the formation.

Basalt flows range in thickness from 3–30 m. Most are massive in the lower to middle parts of the flow but display strongly vesicular or amygdaloidal flow tops. The basalt consists of altered plagioclase phenocrysts in a carbonated and chloritized matrix; amygdales are infilled by carbonate, quartz, and feldspar. Thin beds of flow-top breccia locally separate the basalt flows.

Hardey Formation (*AFh*)

The Hardey Formation unconformably overlies the granite–greenstone basement over most of the Rocklea Dome, except for the eastern limb where it disconformably overlies the Mount Roe Basalt. The Hardey Formation has a maximum thickness of about 1.8 km on ROCKLEA; however up to 500 m of the stratigraphy consists of dolerite and layered sills. The non-intrusive component consists of sandstone, siltstone, mudstone, conglomerate, volcaniclastic rock, basalt, and chert.

Trough cross-stratified feldspathic quartz sandstone and minor quartz-pebble conglomerate (*AFhs*) dominate the lowermost 250–300 m of the Hardey Formation. Troughed sets range from 0.1 to 1.3 m thick and trough axes indicate a general palaeoflow toward the southwest and west. Mudstone and siltstone occur interbedded with upward-coarsening feldspathic sandstone units in middle to upper parts of the stratigraphy.

Clast-supported, polymictic, pebble to boulder conglomerate (*AFhc*) forms lenticular bodies near the base of the Hardey Formation along the eastern and northern limbs of the Rocklea Dome. In the eastern limb, the basal conglomerate contains a high proportion of Mount Roe Basalt fragments in addition to clasts of monzogranite, vein quartz, and chert. Conglomerate exposed on the northern margin of the dome is dominated by clasts of quartz–chlorite schist, chert, and quartzofeldspathic schist from the underlying greenstone succession.

Fine- to coarse-grained mafic volcaniclastic rock and basalt flows occur locally in the Hardey Formation, but are most abundant in middle to upper parts of the stratigraphy (*AFh*) around the eastern and western closures of the Rocklea Dome. Volcaniclastic layers contain lithic and vitric fragments of basaltic and andesitic composition, mixed with xenocrystic quartz and K-feldspar. The quartz and feldspar are generally well rounded and probably represent detritus from a pre-existing granitoid source. Volcaniclastic units display a variety of internal structures including trough cross-stratification, parallel-stratification, current and wave-ripple cross-lamination, convolute lamination, and small slump folds. Basalt flows are typically 2–5 m thick with irregular, vesicular flow tops.

Boongal Formation (*AFo*)

The Boongal Formation conformably overlies the Hardey Formation in the central and southeastern part of ROCKLEA. The formation has a maximum thickness of about 1 km and consists mainly of massive mafic lava and tube- or sack-like pillow lava. Fine- to very coarse-grained hyaloclastite breccia, and mafic volcaniclastic rock (*AFob*) are abundant locally. The altered mafic lavas are fine to medium grained, and may contain phenocrysts of plagioclase and tremolite. The matrix consists of chlorite, epidote, altered feldspar, and actinolite. Beds of sand- to silt-sized volcaniclastic rock exhibit parallel-lamination or ripple cross-lamination and many fine upwards.

Pyradie Formation (*AFp*)

The Pyradie Formation conformably overlies the Boongal Formation and is up to 1 km thick on ROCKLEA. The formation is characterized by a suite of pyroxene spinifex-textured flows and pillow lavas, interbedded with hyaloclastite breccia, sand- to silt-sized volcaniclastic rock, mudstone, and minor chert. There is a prominent serpentinized komatiite flow in the middle of the Pyradie Formation around the southeastern and northwestern limbs of the dome.

Pyroxene spinifex-textured basalt flows range in thickness from 2 to 50 m. Many of the thicker flows show a structured zonation in which random blades and needles of former pyroxene in the lower part of the flow pass up into a unit containing vertically aligned pyroxene sheaves interlayered with random pyroxene blades and needles. Flow bases are sharp and planar; flow tops are brecciated, in some cases vesicular, and are commonly transitional upwards into hyaloclastite breccia. Columnar jointing is present in several flows.

Komatiite (*AFpk*) is restricted to Pyradie Formation outcrops to the south and southwest of Rocklea Homestead (AMG 459690) and west of the Beasley River in the area of AMG 330870. The komatiite flow is about 100 m thick and shows a sharp, planar base and an irregular flow top, which is transitional into the overlying bed of hyaloclastite breccia. Internal flow structure comprises a lower unit of massive pyroxene cumulate overlain successively by porphyritic and massive olivine orthocumulate, pyroxene spinifex-textured rock, and finally by fine-grained flow-top material. Komatiite mineralogy has been modified by low-grade metamorphism: olivine is replaced by antigorite, chlorite, and magnetite, whereas pyroxene has altered to tremolite. Interstitial material in the pyroxene-rich units consists largely of various combinations of tremolite–actinolite, leucoxene, saussuritized and albitized plagioclase, and quartz.

Sand- to silt-sized volcaniclastic rock, mudstone, and minor chert (*AFps*) are interbedded with spinifex-textured basalt, particularly in the extreme southeast corner of ROCKLEA. Most beds of sand- to silt-sized volcaniclastic rock range in thickness from 10 to 200 mm and exhibit parallel-lamination or ripple cross-lamination. Thin- to medium-bedded chert units are generally less than 2m thick and show fine to coarse, parallel planar to undulatory lamination.

Bunjinah Formation (*AFu*)

The Bunjinah Formation conformably overlies the Pyradie Formation and has a maximum thickness of about 900 m. This unit is very similar lithologically to the Boongal Formation, except that upper parts of the formation are represented by highly vesicular basalt flows interbedded with hyaloclastite breccia. Thick accumulations of hyaloclastite breccia and sand- to silt-sized volcaniclastic rock (*AFub*) characterize the formation in southwest ROCKLEA.

Jeerinah Formation (*AFj*)

The Jeerinah Formation conformably overlies the Bunjinah Formation and outcrops along the flanks of the Hardey and Mount Brockman Synclines. Present maximum thickness of 1.8 km is the result of extensive intrusion by dolerite and gabbro sills, and the depositional thickness of the formation was probably about 900 m. The remainder of the stratigraphy consists of massive and pillowed basaltic lava flows, basaltic breccia, mudstone and siltstone, chert, and sandstone. The Jeerinah Formation is conformably overlain by the Marra Mamba Iron Formation of the Hamersley Group.

Massive and pillowed basaltic lava flows make up most of the non-intrusive Jeerinah Formation stratigraphy on ROCKLEA. They form thin, lenticular units interlayered with dolerite and sedimentary rocks and also form thicker, laterally persistent units (*AFjl*) in the middle of the formation. Discontinuous beds of hyaloclastite breccia are commonly associated with the lava flows. Most of the remaining thickness of the Jeerinah Formation consists of parallel-laminated, carbonaceous or ferruginous mudstone and siltstone, interbedded with finely laminated chert.

Mafic (*AFd*) and layered (*AFl*) sills in the Fortescue Group

Mafic and layered sills are an important component of the Fortescue Group, particularly in the Hardey and Jeerinah Formations. Massive, mafic sills range from discontinuous bodies only a few metres thick to laterally persistent intrusions with a thickness of several hundred metres. Most are doleritic to gabbroic and have a relict subophitic to poikilitic texture. Their present mineralogy of actinolite, chlorite, epidote, altered plagioclase, and subordinate interstitial quartz, opaques, and apatite reflects the superimposed regional lower greenschist facies metamorphism.

Layered sills are typically 50–200 m thick and show an upward gradation from pyroxenite to leucocratic gabbro or dolerite. Lower levels of the sill have a medium- to coarse-grained cumulate texture and a mineralogy of tremolite–chlorite pseudomorphs after orthopyroxene in a matrix of chlorite, tremolite, talc, serpentine, and sphene. Locally, a thin serpentinite occurs at the base of the intrusion.

Hamersley Group

Marra Mamba Iron Formation (*AHm*)

The Marra Mamba Iron Formation is the lowest unit of the Hamersley Group, and conformably overlies the Jeerinah Formation. It has been divided into three members (Kneeshaw, 1984; Blockley et al., 1993); however, because of the generally poor quality of exposure of this formation on ROCKLEA this subdivision is not shown on the map sheet.

The Nammuldi Member is the lowest unit and is estimated to be about 100 m thick in the Rocklea area. It consists of alternating yellow to yellow-brown chert and brown to black iron-formation mesobands. Podding of the banding is common. The overlying MacLeod Member, about 45 m thick, comprises interlayered thin shale, chert, and banded iron-formation (BIF). The contact between the Nammuldi Member and the MacLeod Member is marked by a distinctive chert pod layer known as the 'potato bed'. The uppermost division, the Mount Newman Member, is estimated to be 60 m thick and consists predominantly of banded iron-formation with thin shale intervals.

Wittenoom Formation (*AHd*)

The Wittenoom Formation (formerly Wittenoom Dolomite) is one of the most heterolithic units within the Hamersley Group but is not well exposed on ROCKLEA, where it is estimated to be between 275 and 350 m thick. Elsewhere within the Hamersley Basin the formation is subdivided into 3 members: a lower West Angela Member, a middle Paraburdoo Member, and an upper Bee Gorge Member (Simonson et al., 1993; Blockley et al., 1993).

The presence of the West Angela Member has not been confirmed on ROCKLEA. Elsewhere in the Hamersley Basin the unit has a maximum thickness of about 100 m and consists primarily of dolomite and dolomitic argillite. Chert is abundant in lower parts of the member but only a minor component towards the top. Sedimentary structures within the argillaceous beds include reverse graded-bedding and flame structures. Pyrite occurs in argillite beds as blebs and bedding-parallel stringers, and as fracture fillings (Blockley et al., 1993).

The Paraburdoo Member (Simonson et al., 1993), probably about 175–200 m thick on ROCKLEA, consists of thin- to thick-bedded dolomite with minor amounts of chert and argillite, and almost everywhere displays even, tabular bedding. Most dolomite beds are a few centimetres to several decimetres thick; the thinner argillite layers range from sub-millimetre partings to thin beds up to a few centimetres thick.

The Bee Gorge Member (Simonson et al., 1993) is estimated to be about 75 m thick in the map sheet area. Thinly laminated graphitic argillite is the main lithology, together with subordinate thicknesses of carbonate, chert, volcaniclastic rock, and iron-formation. Many of the non-argillite rock types display clastic textures and current-formed structures.

Mount Sylvia Formation and Mount McRae Shale (*AHs*)

The Mount Sylvia Formation conformably overlies the Wittenoom Dolomite and consists of shale, dolomitic shale and three prominent BIFs. BIFs mark both the top and the bottom of the unit. The upper BIF is the distinctive Bruno's Band. Bourn and Jackson (1979) estimate the formation is 30 m thick.

The Mount McRae Shale conformably overlies the Mount Sylvia Formation and is 55 m thick (Bourn and Jackson, 1979). The lower 43 m comprise interlayered chert and shale, while the upper 12 m include BIF.

Brockman Iron Formation (*PHb*)

The Brockman Iron Formation is the main iron-formation within the Hamersley Group and forms prominent strike ridges within the Mount Turner and Mount Brockman Synclines. The unit has been described in detail by Trendall and Blockley (1970) and consists of four members: the Dales Gorge Member, the Whaleback Shale Member, the Joffre Member, and the Yandicoogina Shale Member.

The Dales Gorge Member (*PHbd*) consists of an alternating sequence of 17 BIF macrobands and 16 argillite layers (Trendall and Blockley, 1970). Where it is unmineralized the member is about 150 m thick. Compston et al. (1981) reported a U–Pb zircon age of 2490 ± 20 Ma from the S13 macroband of the Dales Gorge Member.

The Whaleback Shale Member (*PHbw*) overlies the Dales Gorge Member and is composed predominantly of interlayered chert and shale with two BIF bands near the base. The thickness of the member on ROCKLEA is about

75 m. The Joffre Member (*PHbj*) overlies the Whaleback Shale and consists of 280 m of BIF with minor thin shale layers. A prominent dolerite sill (*PHt*) intrudes the upper part of the Joffre Member in the northern part of ROCKLEA. The 40 m-thick Yandicoogina Shale Member overlies the Joffre Member and comprises alternating chert and thin shale, intruded by dolerite sills. The Yandicoogina Shale Member is grouped with the Joffre Member on ROCKLEA.

Weeli Wolli Formation (*PHj*)

The Weeli Wolli Formation (600 m thick) conformably overlies the Brockman Iron Formation and is conformably overlain by the Woongarra Rhyolite. This unit is 5 to 10 m thick and consists typically of jaspilitic iron-formation, together with shale and chert. The formation has been intruded by several dolerite sills giving a distinctive, broadly striped appearance to the outcrops.

Woongarra Rhyolite (*PHw*)

The Woongarra Rhyolite (formerly Woongarra Volcanics) is 800 m thick at Woongarra Pool (AMG 105694) and is described by Trendall (1995). It consists of massive medium-grained quartz- and/or feldspar-phyric rhyolitic to rhyodacitic igneous rocks. The top of the unit is generally marked by a tuffaceous horizon that displays features consistent with the margin of a sill intruded into wet sediment (Trendall, 1995). Within the unit there is a distinctive but discontinuous jaspilitic BIF horizon which may be up to 5 m thick.

Compston et al. (1981) reported a multi-grain zircon U–Pb age of 2470 ± 30 Ma for the Woongarra Rhyolite.

Boolgeeda Iron Formation (*PHo*)

The Boolgeeda Iron Formation is the uppermost formation of the Hamersley Group and has a maximum thickness of 250 m. This unit conformably overlies the Woongarra Rhyolite and is itself conformably overlain by the Turee Creek Group. The Boolgeeda Iron Formation is subdivided into a lower unit comprising massive black to dark yellow-brown BIF, a poorly exposed central shaly unit, and an upper unit characterized by purple-black, thinly bedded and fissile BIF.

Turee Creek Group

The Turee Creek Group conformably overlies the Boolgeeda Iron Formation in the Hardey and Mount Brockman Synclines. It has an estimated maximum thickness of about 4 km in the Hardey Syncline and is here overlain unconformably by the Wyloo Group (Seymour et al., 1988; Powell and Li, 1991). Middle levels of the Turee Creek Group in the Hardey Syncline are intruded by medium- to coarse-grained dolerite sills (*PTUd*).

Trendall (1979) defined and described the Turee Creek Group in the Hardey Syncline and adjacent parts of Wyloo. He included within it the thick basal Kungarra Formation and a number of unnamed overlying units. Trendall's (1979) nomenclature for the lower Turee Creek Group is adopted for these notes and, in addition, the middle and upper part of the stratigraphy is subdivided into two newly named formations: the Koolbye Formation, which conformably overlies the Kungarra Formation, and the Kazput Formation, which conformably overlies the Koolbye Formation and forms the uppermost part of the Turee Creek Group.

Kungarra Formation (*PTUk*)

The Kungarra Formation is about 2.8 km thick and its base is marked by a gradational, conformable contact with the underlying Boolgeeda Iron Formation. Above this contact the remainder of the formation comprises mostly mudstone and siltstone, interbedded with thin-bedded sandstone. Mudstone and fine-grained siltstone are parallel-laminated, whereas coarse-grained siltstone and fine-grained sandstone are either parallel-laminated or ripple cross-laminated. Coarser grained sandstone forms tabular to lenticular beds, which are either structureless or normally graded. Some are parallel-laminated with current ripple-laminated tops. The depositional setting of the Kungarra Formation is considered to be a deep-marine shelf.

The Meteorite Bore Member (*PTUkm*) is a distinctive pebble to cobble argillite and sandstone unit that outcrops in the upper part of the Kungarra Formation, on the southern side of the Hardey Syncline (AMG 026653) (Trendall, 1976). Most of the unit is massive, apart from local thick lithic sandstone beds. Pebbles and cobbles of sandstone and felsic volcanic rock are the dominant clast type, together with minor chert, carbonate rock, and vein quartz. A small proportion of these cobbles are faceted and striated; a feature which prompted Trendall (1976) to suggest this deposit may be glacial in origin.

Koolbye Formation (*PTUo*)

The 130 m-thick Koolbye Formation (named after Koolbye Well, AMG 081568) is confined to the Hardey Syncline where it is equivalent to the unnamed quartzite unit 1 of Trendall (1979). It apparently conformably overlies the Kungarra Formation and consists largely of fine- to coarse-grained quartz sandstone, and minor argillite and conglomerate. Topographically, the formation forms a prominent strike ridge within the outcrop area of middle Turee Creek Group argillaceous rocks.

The type section for the Koolbye Formation is at AMG 035667. Here, the base of the formation is marked by a thin, discontinuous pebbly sandstone which is overlain by thin- to thick-bedded coarse-grained quartz sandstone. The remainder of the unit is dominated by tabular to lenticular beds of fine- to medium-grained quartz sandstone with thin argillite interbeds. Internal structure of the sandstone is varied and includes small- to medium-scale trough cross-strata, parallel planar to undulatory lamination, and ripple cross-lamination. Straight-crested symmetrical ripples are preserved on many bedding surfaces. The depositional environment of the Koolbye Formation is interpreted as coastal to shallow marine.

Kazput Formation (*ꞒTUa*)

The Kazput Formation (named after Kazput Pool, AMG 195590) is also confined to the Hardey Syncline where it has an estimated thickness of about 1.1 km. Although this formation outcrops in the extreme southwest of ROCKLEA, its stratigraphy is best developed on adjacent parts of HARDEY, near AMG 970680. Here, the formation is equivalent to the combined unnamed carbonate and shale unit, and quartzite units 2 and 3 of Trendall (1979). The Kazput Formation is conformable upon the Koolbye Formation and is unconformably overlain by the Beasley River Quartzite.

The type area for the Kazput Formation is in the Hardey Syncline on southeast HARDEY at AMG 970680. Here the succession consists largely of fine- to coarse-grained quartz sandstone, argillite, conglomerate, dolomite, and minor basalt and banded iron-formation. Argillaceous rocks form areas of low topo-graphy in the core of the Hardey Syncline; sandstone and conglomerate are more resistant and give rise to rounded hills and ridges.

On ROCKLEA the Kazput Formation is exposed a short distance below the Wyloo Group unconformity at AMG 001678. Here the succession comprises a lenticular body of grey, recrystallized dolomite, underlain by a thin unit of ferruginous argillite and iron-formation (*ꞒTUac*). Little surface detail is present in the dolomite other than a diffuse, irregularly sinusoidal banding of light and dark layers.

Metamorphism

It was thought initially that rocks in the Hamersley Basin were little affected by regional metamorphism (Trendall and Blockley, 1970). A study by Smith et al. (1982) however, established a zonal pattern of very low- and low-grade metamorphism, based mainly on assemblages observed in mafic volcanics from the Fortescue Group.

On ROCKLEA, most Hamersley Basin rocks lie within the highest grade (prehnite)–epidote–actinolite zone, which represents lowermost greenschist facies conditions. The northeastern corner of the sheet is in the lower grade prehnite–pumpellyite–epidote–actinolite zone representing the pumpellyite–actinolite facies. A narrow strip along the southwest margin is in the lower grade prehnite–pumpellyite–epidote–actinolite zone also. The overall pattern observed by Smith et al. (1982) showed that grade increased towards the southern margin of the Hamersley Basin. This is coincident with a general increase in stratigraphic thickness of Hamersley Basin sedimentary rocks, and the zonal pattern was interpreted as the product of a regional burial metamorphism (M_h). The appearance of lower grade rocks at the southern margin of the basin was explained by Smith et al. (1982) as the result of local thickening of the Fortescue Group and thinning of the Hamersley Group, however Tyler (1991) considered their presence to be the result of later burial metamorphism beneath the Ashburton Basin.

The isograds and zones identified by Smith et al. (1982) are based on assemblages in the Fortescue Group, which is at the base of the Mount Bruce Supergroup. Stratigraphically higher units reached correspondingly lower grades (Smith et al., 1982, fig. 3). When all the units in the Hamersley Basin are considered, the isograd pattern is more complex than that interpreted by Smith et al. (1982) and appears to reflect the fold pattern, with lower grade rocks in the synclines and higher grade rocks in anticlines. Metamorphic conditions were between 300°C at 120 MPa and 470°C at 250 MPa (Smith et al., 1982).

Ashburton Basin

The Ashburton Basin (Thorne, 1990; Thorne and Seymour, 1991) corresponds to the present-day outcrop of the Wyloo Group. It is exposed in the extreme southwestern part of ROCKLEA and comprises a 12 km-thick succession of sedimentary and volcanic rocks that have been metamorphosed at low grade.

Wyloo Group

The Wyloo Group was informally established and subdivided by MacLeod et al. (1963) and subsequently revised by Trendall (1979), Horwitz (1980), and Thorne and Seymour (1991). Felsic tuff in the upper part of the Wyloo Group on WYLOO gave a U–Pb zircon age of 1843 Ma (Pidgeon and Horwitz, 1991); whereas lead isotopes reported by Richards (1986) for galena in the Ashburton Formation on YARRALOOLA gave a model lead age of about 2.0 Ga. There are no published determinations for the lower part of the stratigraphy.

On ROCKLEA, the Wyloo Group is subdivided (in ascending order) into: Beasley River Quartzite, Cheela Springs Basalt, Mount McGrath Formation, Duck Creek Dolomite, and Ashburton Formation.

Beasley River Quartzite (*ꞒWq*)

The Beasley River Quartzite is exposed along the axis and southern limb of the Hardey Syncline. It is 200–250 m thick and rests unconformably on the Turee Creek Group (Seymour et al., 1988; Powell and Li, 1991).

The formation consists mainly of cream- or white-weathering fine- to coarse-grained quartz sandstone, intruded locally by dolerite sills (*ꞒWo*). The sandstone forms 0.05–1.5 m thick tabular to lenticular beds showing a complex organization of internal stratification in which undulatory and planar parallel lamination pass vertically and laterally into sets showing trough or planar cross-stratification. Locally, symmetrical ripples are preserved on bedding surfaces. No reliable regional sediment transport directions were obtained from this unit, which is characterized by palaeocurrent data of highly varied orientation (*see* Horwitz and Powell, 1992, figs 5, 8). In contrast, a more consistent, west-northwestward palaeoflow was obtained from an assemblage of stacked sets of large-scale trough cross-stratification at AMG 030678. Thorne and Seymour (1991) interpret these quartz sandstones as shallow marine, tidal channel and sand-bar facies.

Up to 90 m of parallel-laminated and cross-laminated argillite, interbedded with subordinate amounts of ferruginous sandstone and jaspilitic BIF-derived conglomerate (*EWqs*) characterize the lowermost Beasley River Quartzite along the axis of the Hardey Syncline. Horwitz and Powell (1992, fig. 9a) record a broad northeastward palaeoflow from the jasper-bearing unit at one locality on the southeastern flank of the Hardey Syncline; however, this could not be confirmed by our own observations at this locality.

Cheela Springs Basalt (*EWb*)

The Cheela Springs Basalt was initially regarded as a member within the Mount McGrath Formation (MacLeod et al., 1963), but was elevated to formation status by Horwitz (1980). On ROCKLEA, the Cheela Springs Basalt outcrops in the area immediately southwest of the Hardey Syncline, where it conformably overlies the Beasley River Quartzite.

The formation has a thickness of about 1.7 km and comprises basalt flows interbedded with minor amounts of flow-top breccia and parallel-laminated dolomite. Basalt flows are generally amygdaloidal and range from 5–20 m thick. All basalt has undergone prehnite–pumpellyite to lower greenschist facies metamorphism and now consists of andesine and relict pyroxene (partly or completely replaced by tremolite and chlorite) phenocrysts set in a groundmass of andesine, actinolite, chlorite, sphene, epidote, pumpellyite, and iron oxide.

Mount McGrath Formation (*EWm*)

The Mount McGrath Formation was subdivided by de la Hunty (1965) and later redefined by Horwitz (1980) as 'the essentially clastic rocks that overlie disconformably the Cheela Springs Basalt and overlap unconformably onto older formations. It is conformably overlain by the Duck Creek Dolomite, which itself overlaps onto older units'. The Mount McGrath Formation has a maximum thickness of at least 1.2 km and occurs in discontinuous outcrops immediately south of the Hamersley Range.

The formation comprises ferruginous conglomerate and sandstone (often pebbly), quartz sandstone, argillite, dolomitic argillite, and dolomite. Ferruginous conglomerate and sandstone are most abundant in the middle part of the Mount McGrath Formation; the remaining rock types characterize lower and upper parts of the stratigraphy.

Conglomerate is generally clast supported and forms lenticular or tabular beds up to 4 m thick. Most beds are parallel-stratified and exhibit normal or inverse grading. The clasts are mainly of BIF, vein quartz, chert, quartz amygdales, and felsic igneous rock.

Sandstone and pebbly sandstone outcrop in lenticular units up to 20 m thick. They are either cross-stratified, parallel-stratified, or massive. Palaeocurrent data (axes of medium-size troughs) indicate that sediment transport was generally toward the south and southwest.

Quartz sandstone and siltstone are generally ripple cross-laminated or parallel-laminated; mudstone is parallel-laminated. Dolomite (including dolomitic mudstone) is generally parallel-laminated, but may also contain soft-sediment folds and thin beds of intraformational breccia.

Approximately 100 m of parallel-laminated ferruginous argillite and minor sandstone, conglomerate, and chert (*EWms*) occur locally at the base of the Mount McGrath Formation. Lower levels of this unit may contain cobble- to boulder-sized clasts of dolomite, similar to the dolomite found at the top of the underlying Cheela Springs Basalt.

The upper part of the Mount McGrath Formation is characterized by a thick succession of dolomitic argillite, dolomite, and minor ferruginous sandstone (*EWmd*). This unit is commonly partly concealed beneath a Cainozoic silcrete caprock.

Duck Creek Dolomite (*EWd*)

The Duck Creek Dolomite rests conformably upon the Mount McGrath Formation and has a maximum thickness of 1 km. The formation consists of thin- to thick-bedded, buff, grey, or mauve dolomite with local intense silicification.

Low and upper levels of the Duck Creek Dolomite consist of thin-bedded dolomite and nodular dolomite interlayered with thin- to very thick-bedded dolomitic conglomerate.

Thin-bedded dolomite is planar- to undulatory-laminated and commonly contains layers and nodules of red or black chert. Beds are generally interstratified with thin layers of chloritic or ferruginous mudstone, and may contain synsedimentary folds. Thin-bedded dolomite is transitional into nodular dolomite. This fabric ranges from a gentle pinch-and-swell in the dolomite layers to a complex network of interlocking nodules, which resembles a mechanical breccia.

Thin to very thick beds of both clast- and matrix-supported, pebble to boulder conglomerate consist of a chaotic mixture of dolomite fragments set in a matrix of mudstone, coarsely crystalline dolomite or sparry quartz.

The middle part of the Duck Creek Dolomite consists of stromatolitic dolomite interbedded with dolomitic grainstone. Stromatolites recognized include *Pilbaria perplexa, Pilbaria cf. perplexa,* and *Asperia ashburtonia* (Grey, 1985). These forms are locally associated with planar laminated stromatolitic dolomite and isolated domical stromatolites. Intraclast grainstones are generally massive and poorly sorted, and commonly contain fragments of stromatolitic dolomite.

Ashburton Formation (*ЕWa*)

The Ashburton Formation, the uppermost stratigraphic unit of the Wyloo Group, conformably overlies the Duck Creek Dolomite in the extreme southwestern corner of ROCKLEA. The formation has an estimated thickness of 5 to 12 km on neighbouring TUREE CREEK (Thorne and Seymour, 1991); however, only the lower part of this stratigraphy is exposed on ROCKLEA.

Feldspathic and lithic quartz sandstone, interbedded with variable amounts of argillite and minor conglomerate make up most of the Ashburton Formation on ROCKLEA. Two varieties of arenaceous deposit are recognized: thin- to medium-bedded sandstone, and massive sandstone. Sandstone beds of thin to medium thickness are laterally continuous, normally graded, and display a partial or complete development of the Bouma sequence of sedimentary structures. Massive sandstone is generally medium- to coarse-grained or pebbly, and occurs as tabular or lenticular beds, up to 5 m thick. Palaeocurrent data from Ashburton Formation sandstone suggest sediment transport was toward the west-northwest.

Chloritic and ferruginous argillite forms layers that range in thickness from a few millimetres to several metres. Silt-sized layers are either parallel-laminated or cross-laminated, mudstone is massive or parallel-laminated.

Capricorn Orogen structure and metamorphism

Structure

The boundary between the Hamersley Basin, deposited on granite–greenstone basement, and the Ashburton Basin in the southwestern corner of ROCKLEA (Fig. 1) also represents the boundary between the Archaean and earliest Proterozoic rocks of the Pilbara Craton, and the Early Proterozoic rocks of the Capricorn Orgogen (Gee, 1979; Tyler and Thorne, 1990). Available geochronological data, reviewed and summarized by Libby et al. (1986), suggest that the Orogen developed between 2200 and 1600 Ma (based on Sm–Nd and Rb–Sr data). A U–Pb zircon date of c. 1840 Ma for the June Hill Volcanics (Pidgeon and Horwitz, 1991) provides an age for the upper part of the Wyloo Group, regarded as syn-orogenic by Tyler and Thorne (1990, 1994). Early Proterozoic deformation is not restricted to the Ashburton Basin; it has also affected the Pilbara Craton rocks, producing large-scale folding and faulting. The timing of this folding and faulting, its relationship to the Capricorn Orogeny, and how many deformation events are represented has been the subject of some debate and is discussed below.

Previous interpretations of structural development in the southern Pilbara have been based on mapping of MacLeod et al. (1963), Halligan and Daniels (1964) and MacLeod (1966). In general, an increasing intensity of deformation was recognized from the Fortescue Valley southwards with two fold periods, the Ophthalmian and the Rocklean, inferred from the presence of large-scale dome-and-basin structures interpreted as fold interference patterns. Folding was regarded as passive, formed as a response to essentially vertical movements in the basement. The absence of small-scale folds that could be attributed to the Rocklean fold period led Gee (1979) to re-interpret the fold pattern as a single set of folds with curvilinear axes. Trendall (1979) documented an unconformity between the Wyloo Group and the Mount Bruce Supergroup. This enabled Gee (1979) to separate structures into two fold belts: the Ophthalmia Fold Belt, and the younger Ashburton Fold Belt (Fig. 1).

Tyler and Thorne (1994) and Thorne and Trendall (in prep.) have recognized the occurrence of two major sets of west-northwest trending faults, the Jeerinah–Sylvania Fault system and the Nanjilgardy Fault system, that were initiated as normal faults and controlled regional variations in stratigraphy and sedimentation patterns during deposition of the Fortscue Group. These structures are regarded as having controlled later deformation, being periodically re-activated as extensional faults, strike-slip faults, and thrusts.

In the southwestern part of the Hamersley Basin the Ophthalmia Fold Belt is characterized by broad-scale, open dome-and-basin structures having a mainly north-westerly trend, which corresponds to the central structural zone of MacLeod et al. (1963). Tyler (1991) identified a regional-scale foreland fold-and-thrust belt in the southeastern Hamersley Basin characterized by easterly trending, close to tight folds with short wavelengths, corresponding to the southern structural zone of MacLeod et al. (1963). As will be discussed, structural and stratigraphic relationships along the margin between the Ophthalmia and Ashburton fold belts suggest that these two groups of folds represent different events. Deformation to produce the dome-and-basin structures was attributed by Tyler (1992) to dextral transpression along the southern Pilbara margin during the early stages of the Capricorn Orogeny of Gee (1979). Horwitz and Powell (1992) and Blake and Barley (1992), however, have suggested that this deformation was related to the development of the McGrath Trough (Horwitz, 1982), which was initiated either as a foreland basin or a backarc compressive cratonic basin during a collision between the Pilbara Craton and an unknown southern continent sometime after c. 2440 Ma but before 1840 Ma.

Tyler (1991) and Tyler and Thorne (1990, 1994) interpreted the foreland fold-and-thrust belt in the southeastern Hamersley Basin as the result of an oblique collision between the Pilbara and Yilgarn Cratons at c. 1840 Ma, taking place in the east first and migrating westwards. Uplift of the Sylvania Inlier supplied granitic sediment to the Ashburton Formation in the Ashburton Basin. Initial deformation of the Ashburton Basin to form the Ashburton Fold Belt was attributed to thrusting. Associated uplift provided sediment to the Mount Minnie Group and the Capricorn Formation. Later deformation was related to a dextral wrench-fault system produced by the westward extrusion of material from between the two approaching craton margins.

In contrast Horwitz and Powell (1992) regarded the widespread occurrence of northwesterly oriented mafic dykes as evidence of a period of extension during upper Wyloo Group time, marked by the occurrence of mafic volcanics. The formation of both the dome-and-basin structures and the foreland fold-and-thrust belt was thought to have occurred contemporaneously, prior to the deposition of the upper Wyloo Group.

Ophthalmia Fold Belt

The earliest deformation that affects Hamersley Basin rocks within the Ophthalmia Fold Belt produced small-scale layer-parallel folds. This deformation — referred to as D_{1c} — was first recognized by Tyler et al. (1990) on the NEWMAN 1:250 000 map sheet area, where it is restricted to particular stratigraphic units. On ROCKLEA D_{1c} folds have been recognized at only one locality, within the lower part of the Boolgeeda Iron Formation at the eastern end of the Mount Brockman Syncline.

The origin of D_{1c} structures is problematical. Although they occur throughout the Hamersley Basin, any one occurrence appears to be limited in its extent. Deformation is restricted to bedding planes, and ramping (in which the deformation cuts up or down the stratigraphy) is not seen. Movement directions are unknown and they could represent either extensional or compressional features. Horwitz and Powell (1992) suggested that these structures may be related to the formation of extensional features that are widespread in banded iron-formations of the Hamersley Basin (the cross-pods *of* Trendall and Blockley, 1970).

Mappable folds that belong to the Ophthalmia Fold Belt on Rocklea form broad-scale, open dome-and-basin structures with curvilinear trends that vary from west-northwest to east-northeast. The main structures are the Mount Brockman Syncline, the Mount Turner Syncline, the Rocklea Dome, and the Hardey Syncline (Fig. 1). The Mount Turner Syncline and an anticlinal structure separating it from the Mount Brockman Syncline die out from east to west across the sheet. A pervasive axial planar cleavage, similar to that developed in the southeastern Ophthalmia Fold Belt (Tyler et al., 1990; Tyler, 1991), is not developed on ROCKLEA. However, small- and medium-scale folding, and an associated cleavage, are present in pelitic units of the Hamersley Group and Turee Creek Group, particularly around the Mount Brockman Syncline.

In the Hardey Syncline, west-northwesterly trending open, steeply inclined to upright structures deform the Turee Creek Group (Trendall, 1979; Seymour et al., 1988; Powell and Li, 1991). The Beasley River Quartzite of the lower Wyloo Group lies unconformably on the folded Turee Creek Group (Seymour et al., 1988; Powell and Li, 1991) and this relationship is well illustrated 2 km north-northwest of Meteorite Bore (AMG 042646). Similar relationships are seen at the eastern end of the Wyloo Dome farther to the west on WYLOO (Horwitz, 1982; Seymour et al., 1988).

Tyler and Thorne (1990) and Tyler (1991) used these relationships as evidence that folding in the western part of the Ophthalmia Fold Belt predated the fold-and-thrust event in the southeast, which folds the lower Wyloo Group rocks that lie with apparent conformity on Turee Creek Group rocks in the core of the Turee Creek Syncline (Thorne et al., 1991). However, Powell and Li (1991) have pointed out that there are two fold phases in the Hardey Syncline, with the second post-dating the lower Wyloo Group. Based on the occurrence of only one cleavage that occurs in both the Turee Creek Group rocks and the lower Wyloo Group rocks, they interpreted the two sets of essentially co-planar folds as actually representing one set of west-northwesterly trending folds that started to form during Turee Creek Group times and continued to form after the Beasley River Quartzite was deposited. They correlated this continuous folding event with the fold-and-thrust event of Tyler and Thorne (1990) and Tyler (1991), and regarded it as evidence that the main fold structures throughout the Ophthalmia Fold Belt all formed at this time.

To the southeast of ROCKLEA on PARABURDOO and TUREE CREEK there is no evidence of folding taking place between the deposition of the Turee Creek Group and the Beasley River Quartzite, and the Beasley River Quartzite lies disconformably on the Weeli Wolli Formation of the Hamersley Group along the southwestern limb of the Bellary Dome, and with apparent conformity on the Turee Creek Group in the Mount Maguire area and in the core of the Turee Creek Syncline (Thorne et al., 1991; Tyler and Thorne, 1994). As has been discussed, palaeocurrent directions in the upper Turee Creek Group are consistent with uplift to the southwest. However, reliable (non-marine) palaeocurrent directions in the Beasley River Quartzite indicate derivation from the northwest and northeast (Thorne and Seymour, 1991), not from the southwest, as would be expected with the lower Wyloo Group foreland basin model.

Although Powell and Li (1991) and Horwitz and Powell (1992) correlated the post-Beasley River Quartzite folding in the core of the Hardey Syncline with the fold-and-thrust event in the southeast of the Ophthalmia Fold Belt, there is no evidence in the Wyloo Group succession on ROCKLEA that substantial folding or tilting of strata took place between the deposition of the Cheela Springs Basalt and the Mount McGrath Formation. Farther to the west, the Mount McGrath Formation lies unconformably on Hamersley Basin rocks around the southwestern and western margins of the Wyloo Dome (Horwitz, 1982; Seymour et al., 1988) indicating uplift did occur locally during D_{2c}. To the southeast the Mount McGrath Formation lies unconformably on Hamersley Basin rocks along the southern limb of the Turee Creek Syncline (Thorne et al., 1991).

Ashburton Fold Belt

The Ashburton Fold Belt has been described by Thorne and Seymour (1991) and affects Wyloo Group and Hamersley Basin rocks in the southwestern corner of ROCKLEA, which covers the northern structural zone of the fold belt and is dominated by large-scale, open to tight D_{2a} folds. Early, recumbent D_{1a} folds are restricted to the southern and central zones of the fold belt and are not recognized on ROCKLEA. The separation in this marginal zone of Ashburton Fold Belt structures from those of the Ophthalmia Fold Belt can be difficult as folding is essentially co-planar, with the later deformation tightening up pre-existing folds and reactivating earlier formed faults.

The northeast margin of the Ashburton Fold Belt is marked by a set of west-northwest to northwest orientated faults and associated quartz veins (*q*) of D_{2a} age (Fig. 1). On ROCKLEA faulting is represented by the Nanjilgardy and Soda Well Faults in the southwest of the sheet, and also occurs within the Ophthalmia Fold Belt, being well developed along the southern limb of the Mount Turner Syncline. Faulting has taken place parallel to the regional strike of bedding along the northeastern limb of the Hardey Syncline, and units including the Wittenoom Dolomite, the Marra Mamba Iron Formation, and parts of the Jeerinah Formation have been removed. Horwitz and Ramanaidou (1993) attributed this to syndepositional slumping. However, the faults can be traced out into northwesterly trending structures that cut across the nose of the fold, and are linked to faults with similar relationships but which cut Wyloo Group rocks and show dextral offsets of up to 7.5 km along the southern limb of the Bellary Dome on PARABURDOO and TUREE CREEK (Tyler, 1991; Thorne et al., 1991; Tyler and Thorne, 1994). The faults are linked also to prominent dextral strike-slip faults along the eastern margin of the Wyloo Dome to the west (Seymour et al., 1988).

Along the southwestern limb of the Hardey Syncline a prominent cleavage is developed within Wyloo Group rocks including Cheela Springs Basalt and adjacent Mount McGrath Formation. This fabric is therefore regarded as D_{2a} in age and, as there is no evidence of the development of a crenulation cleavage, is regarded as the same fabric that occurs in the Turee Creek Group and Beasley River Quartzite in the core of the syncline. Horwitz and Powell (1992, fig. 3a) regarded a northwesterly trending fold structure as younger, refolding the core of the Hardey Syncline. This structure is parallel to a fault located to the west of Meteorite Bore. Here, the S_{2a} fabric becomes more intense towards the fault and tails are developed on pebbles within the Meteorite Bore Member. Again there is no evidence of the development of a crenulation cleavage. The relationship between northwesterly trending folds and faults and west-northwesterly trending folds (Fig. 1) is consistent with dextral strike-slip faulting (Wilcox et al., 1973), and is similar to relationships between folding and faulting in Wyloo Group rocks to the southeast of Mount Maguire on PARABURDOO and TUREE CREEK (Thorne et al., 1991; Tyler and Thorne, 1994).

The curvilinear trend of the major folds within the Ophthalmia Fold Belt on ROCKLEA can be attributed to clockwise rotation of the fold axes during D_{2a} dextral strike-slip faulting, similar to the interpreted rotation of the D_{2c} Turee Creek Syncline (Tyler and Thorne, 1990; Tyler, 1991). However, the eastern end of the Mount Brockman Syncline has been folded about northwesterly trending axes to produce a type 3 'hooked' refolded fold, consistent with a northeast–southwest compression (Ramsay and Huber, 1987). Horwitz and Powell (1992) noted that the fold pattern in the western Ophthalmia Fold Belt was the result of interference between west-northwesterly trending folds and northwesterly trending folds. They regarded dextral strike-slip faulting as a younger event.

Metamorphism

Throughout the Ashburton Basin on ROCKLEA the metamorphic grade is low, with the quartz–chlorite–sericite assemblage typical of much of the fold belt.

In terms of the known stratigraphic and structural sequence, metamorphism in the Ashburton Fold Belt is a separate event (M_a) from the burial metamorphism recognized in the Hamersley Basin. Tyler and Thorne (1990) regarded peak metamorphism in the Wyloo Group as the product of overthrusting during the D_{1a} deformation, with retrogression taking place during the later higher level D_{2a} event.

Mafic dykes

Four mafic dyke swarms, trending north (d_1), west-northwest (d_4), northwest (d_5), and northeast (d_7), are identified on ROCKLEA. All the dykes are dolerite and consist of pyroxene and feldspar with minor quartz, hornblende, and biotite.

The d_1 swarm is the oldest dyke suite; it cuts Pilbara Craton granite–greenstone rocks in the core of the Rocklea Dome but is overlain by the basal Fortescue Group. Dykes of this suite are also cross-cut by the three other swarms.

West-northwesterly (d_4) and northwesterly (d_5) trending mafic dykes (Tyler, 1991) are seen to cut Hamersley Basin rocks, with the northwesterly set, equivalent to the Round Hummock Suite of Hickman and Lipple (1978), also cutting the Beasley River Quartzite in the core of the Hardey Syncline. On PARABURDOO mafic dykes that post-date D_{2c} folding (Tyler, 1991; Thorne et al., 1991; Tyler and Thorne, 1994) are thought to pre-date the major period of iron-ore formation (Morris, 1980).

The west-northwesterly trending dykes are restricted to the southern margin of the Pilbara Craton (Tyler, 1990) and are cross-cut by the younger northwesterly trending swarm in the Sylvania Inlier (Tyler, 1991). The north-westerly trending dykes are more extensive, occurring throughout the Pilbara Craton. Northwesterly trending dykes are particularly well developed in the northeast part of ROCKLEA. Both sets typically infill pre-existing joint and faults (Baldwin, 1975; Bourn and Jackson, 1979). Horwitz and Powell (1992) noted that northwesterly trending small- and medium-scale folds around the Mount Turner Syncline, here regarded as D_{2a} in age, were localized along the margins of the northwesterly trending dykes, suggesting that dyke emplacement occurred pre- to syn-D_{2a}.

The northeast-trending (d_7) swarm is equivalent to the Mundine Well Suite of Hickman and Lipple (1978) and the Mundine dyke swarm of Myers (1990b). Dykes are continuous over long distances and their intrusion post-dates deformation of the Bangemall Basin on southern TUREE CREEK. (Thorne et al., 1991). A dyke belonging to this suite causes recrystallization of hematite ore at Channar on PARABURDOO (Bourn and Jackson, 1979).

Cainozoic geology (*Cz*) and (*Q*)

A prominent feature of the Cainozoic geology of the Pilbara region is the Hamersley Surface (Macleod et al., 1963; Campana et al., 1964; Twidale et al., 1985), an elevated and dissected peneplanation surface, probably of late Mesozoic to early Tertiary age. Residual deposits (*Czr* and *Czl*) that formed as part of this surface are lateritic and may be ferruginous. On banded iron-formation, surficial iron enrichment produces local deposits of hematite–goethite ore (Morris, 1980, 1985; Kneeshaw, 1984).

An early stage in the dissection of the Hamersley Surface produced extensive valley-fill deposits. These take the form of partially consolidated and cemented colluvium (*Czc*), and alluvium (*Cza*), and calcrete (*Czk*). In addition, the Robe Pisolite (*Czp*) is a pisolitic limonite, 15–45 m thick, that now forms elevated terraces and mesas. It contains limonite and hematite pisoliths, generally small amounts of terrigenous detritus, and scattered fragments of fossil wood. Hocking et al. (1987) suggested a Late Eocene age for the Robe Pisolite.

Areas of sheetwash plain (*Qw*) occur within the Hardey and Mount Brockman Synclines. Alluvium (*Qa*), comprising unconsolidated silt, sand and gravel, was deposited along the present drainage channels and colluvium (*Qc*) forms recent talus slopes adjacent to outcropping bedrock. Small areas of wind-blown sand (*Qs*) occur in the Hardey Syncline and Rocklea Dome.

Economic geology

Gold

Small amounts of gold have been recovered from Cainozoic deposits overlying granite–greenstone and Fortescue Group rocks on ROCKLEA. Total production reported to the Department of Minerals and Energy (to the end of 1994) amounted to 2.2 kg, most of this having been obtained from alluvial workings on the northern limb of the Rocklea Dome. Here, the source of this alluvial gold is thought to be either sheared quartz–chlorite schist (*Al*) or basal Hardey Formation conglomerate (*AFHc*).

Iron

Hamersley Group rocks on ROCKLEA lie within the Hamersley Iron Province of MacLeod et al. (1963). The presence of major hematite ore bodies on Rocklea was recognized during the 1960s (de la Hunty and Jones, 1964), the principal associations being with BIF in the Brockman and Marra Mamba Iron Formations, and also Cainozoic valley-floor deposits, particularly the Robe Pisolite and some ferruginous gravels (*Czr*).

The formation of hematite ore bodies in BIF has been discussed by Morris (1980, 1985). The occurrence of hematite pebbles containing microplaty hematite (a form of hematite characteristic of the major ore bodies) in the Mount McGrath Formation near Paraburdoo restricts the age of ore formation to early Proterozoic (c. 2000 Ma, the age of the Wyloo Group). The close association of high-grade hematite deposits with areas of structural complexity suggests hydrothermal fluid flow along large-scale Capricorn Orogen (D_{2a}) faults was also an important element in the iron-ore enrichment process (*see* Sibson, 1987). The principal ore types are martite–hematite and martite–(hematite)–goethite (Kneeshaw, 1984).

Demonstrated resources of high-grade ore (>60% Fe) from the Brockman Iron Formation on ROCKLEA stand at 412 Mt, while the equivalent figure for the Marra Mamba Iron Formation is 224 Mt. In addition, ROCKLEA has demonstrated resources of 400 Mt of high-grade pisolitic ore (>55% Fe), associated with the Robe Pisolite.

Asbestos

Several small deposits of crocidolite are associated with the Marra Mamba Iron Formation in the Mount Brockman and Mount Turner Synclines (Trendall and Blockley, 1970). The largest of these is at Vivash Gorge (AMG 030880) where a number of very thin, fibrous seams occur in a 3 m-thick section of folded BIF.

Minor occurrences of fibrous chrysotile asbestos occur locally within the Fortescue Group on ROCKLEA (Blight, 1985). In all cases this material fills fractures in layered sills and ultramafic flows within the Hardey and Pyradie Formations.

Copper

Minor anomalous copper values are reported from the Hardey Formation in the western Rocklea Dome (Marston, 1979). The anomalies are associated with the Beasley River prospect (AMG 204787) in carbonate-bearing, weakly pyritic feldspathic sandstone, and graphitic shale. Surface mineralization is present in a north trending 60 x 30 m area. Two diamond drillholes (total length 280 m) intersected 1.6 m assaying 0.13% Cu and 2.4 m assaying 0.19% Cu.

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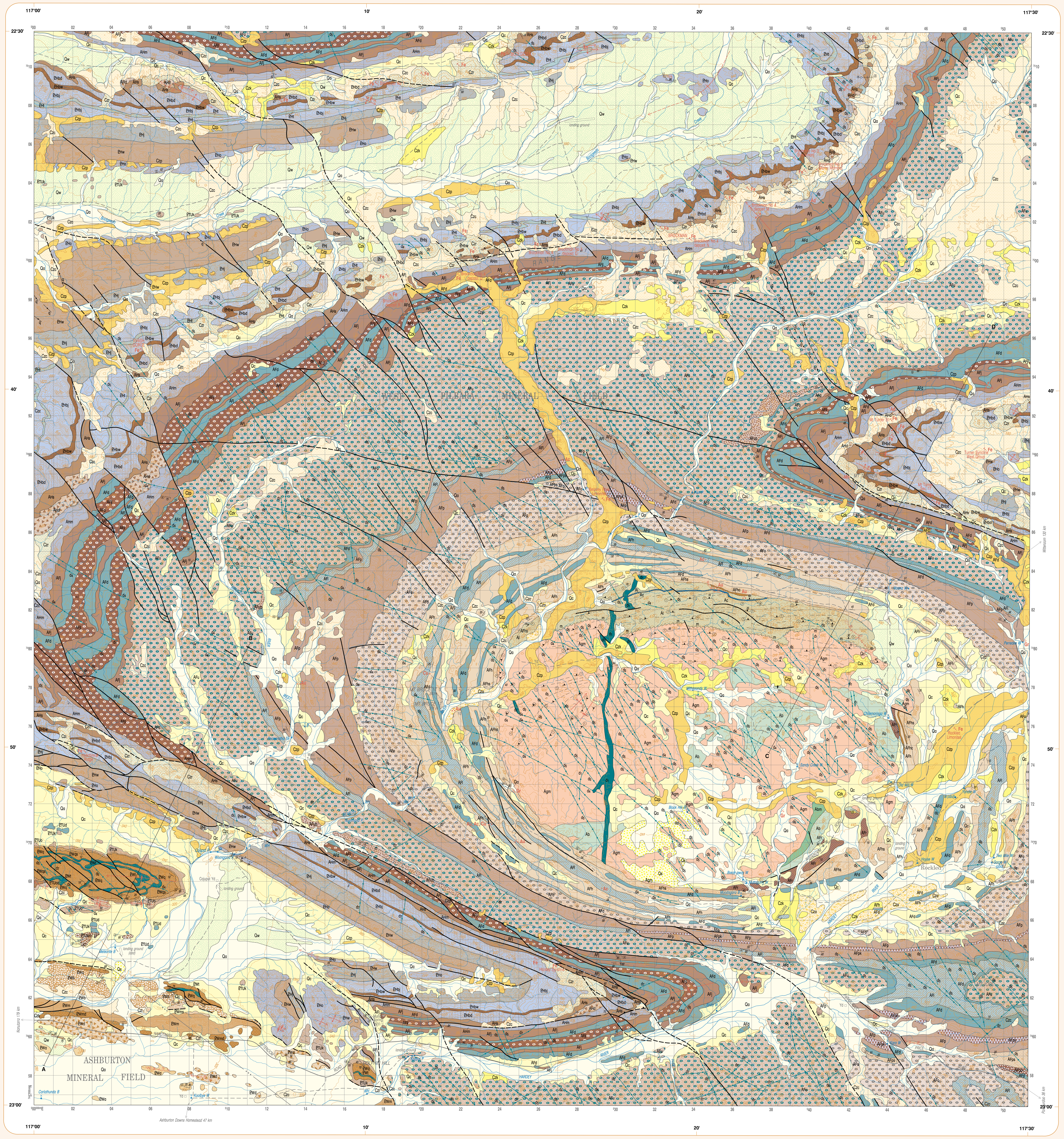
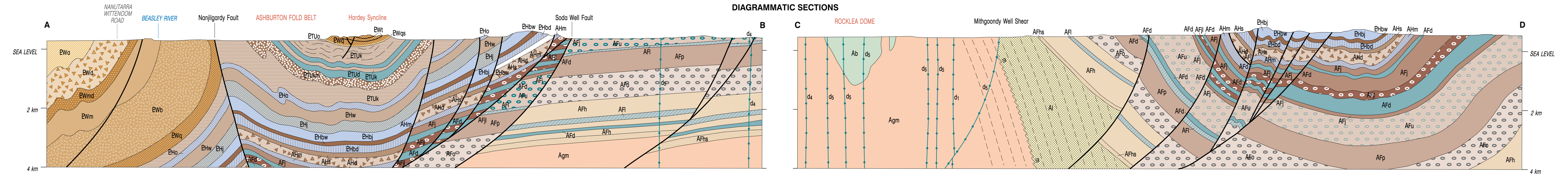
ROCKLEA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

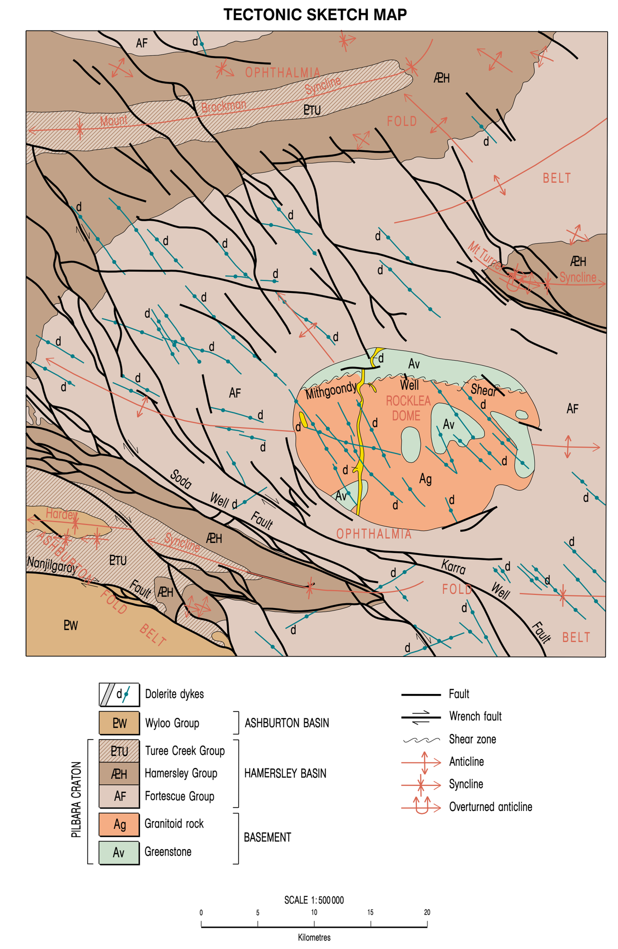
SHEET 2352



DIAGRAMMATIC SECTIONS



TECTONIC SKETCH MAP



PHANEROZOIC — CAINOZOIC

QUATERNARY

- Qa — Alluvium — unconsolidated silt, sand, and gravel
- Qs — Eolian sand — in dunes and sheets
- Qw — Alluvium and colluvium — red-brown sandy and clayey soil
- Qc — Colluvium — unconsolidated quartz and rock fragments in soil

- Cza — Alluvium — partly consolidated silt, sand, and gravel
- Czc — Colluvium — partly consolidated valley-fill deposits
- Czl — Laterite — massive and pisolitic limonite deposits developed along river channels
- Czr — Hematite-goethite deposits on banded iron-formation and adjacent cemented scree deposits
- Czp — **ROBE PISOLITE** — pisolitic limonite deposits developed along river channels
- Czk — Calcrete — sheet carbonate; found along major drainage lines

- q — Quartz veins
- d_5, d_7 — Dolerite dykes, sills, and small intrusions

PROTEROZOIC

Wyloo Group (ASHBURTON BASIN) — *c.* 1840 Ma

- ᵽWa — **ASHBURTON FORMATION:** thin- to thick-bedded metasandstone, pelite, and local metaconglomerate
- ᵽWd — **DUCK CREEK DOLOMITE:** thin- to thick-bedded, locally stromatolitic metadolomite; metadolorudite; minor chert and pelite
- **MOUNT McGRATH FORMATION:**
  - ᵽWmd — Dolomitic pelite, metadolomite, pelite, and metasandstone
  - ᵽWm — Ferruginous metasandstone and metaconglomerate, pelite, and metadolomite
  - ᵽWms — Pelite; minor metasandstone and metaconglomerate
- d_4 — Metadolerite dykes
- ᵽWt — Fine- to medium-grained metadolerite sills and small intrusions
- ᵽWb — **CHEELA SPRINGS BASALT:** amygdaloidal metabasalt and metabasaltic breccia, pelite, metasandstone, and metadolomite
- ᵽWq — **BEASLEY RIVER QUARTZITE:** fine- to medium-grained quartzitic metasandstone, ferruginous metasandstone and metaconglomerate, and pelite; intruded by metadolerite sills
  - ᵽWqs — Pelite; minor metasandstone and metaconglomerate

Turee Creek Group (PILBARA CRATON — HAMERSLEY BASIN)

- ᵽTUd — Medium- to coarse-grained metadolerite sills intruded into Turee Creek Group
- ᵽTUa — **KAZPUT FORMATION:** pelite, metasandstone, and metaconglomerate
  - ᵽTUac — Grey, recrystallized metadolomite, and thin beds of banded iron-formation
- ᵽTUo — **KOOLBYE FORMATION:** fine- to coarse-grained quartzitic metasandstone; minor pelite and metaconglomerate
- ᵽTUk — **KUNGARRA FORMATION:** pelite and subordinate thin- to thick-bedded metasandstone
  - ᵽTUkm — **Meteorite Bore Member:** diamictite; clasts comprise metamorphosed felsicvolcanic rock, chert, and sandstone

Hamersley Group — *c.* 2490 Ma

- ᵽHt — Fine- to coarse-grained metadolerite sills intruded into Hamersley Group
- ᵽHo — **BOOLGEEDA IRON FORMATION:** fine-grained, finely laminated iron-formation; pelite and chert
- ᵽHw — **WOONGARRA RHYOLITE:** metamorphosed rhyolite. rhyodacite, rhyolite, breccia, and banded iron-formation
- ᵽHj — **WEELI WOLLI FORMATION:** banded iron-formation (commonly jaspilitic), pelite, and numerous metadolerite sills
- ᵽHb — **BROCKMAN IRON FORMATION:** banded iron-formation, chert, and pelite
  - ᵽHbj — **Joffre Member:** banded iron-formation, chert, and minor pelite; overlain by **Yandicoogina Shale Member** in places
  - ᵽHbw — **Whaleback Shale Member:** pelite, chert, and minor banded iron-formation
  - ᵽHbd — **Dales Gorge Member:** banded iron-formation and pelite

ARCHAEAN

- AHs — **MOUNT McRAE SHALE and MOUNT SYLVIA FORMATION:** pelite, chert, and banded iron-formation
- AHd — **WITTENOOM FORMATION:** thin- to medium-bedded metadolomite, dolomitic pelite, chert, and metamorphosed volcanic sandstone
- AHm — **MARRA MAMBA IRON FORMATION:** chert, banded iron-formation, and pelite

Fortescue Group — *c.* 2690 Ma … *c.* 2765 Ma

- AFd — Medium- to coarse-grained metadolerite sills intruded into Fortescue Group
- AFl — Layered sills intruded into Fortescue Group; sills generally consist of a coarse-grained pyroxenite base, overlain by leucocratic metagabbro or metadolerite; serpentinite occurs locally at the base of some sills
- AFj — **JEERINAH FORMATION:** pelite, metasandstone, chert, metabasaltic pillow lava and breccia; intruded by numerous metadolerite sills
  - AFjl — Pillowed and massive metabasaltic flows and metabasaltic breccia
- AFu — **BUNJINAH FORMATION:** pillowed, massive, and amygdaloidal metabasalt flows; metabasalt breccia; metamorphosed volcanic sandstone, and pelite
  - AFub — Metabasaltic breccia
- AFp — **PYRADIE FORMATION:** metamorphosed, pyroxene spinifex-textured basalt flows and pillow lava; metamorphosed volcanic sandstone and minor chert
  - AFps — Pelite, chert, and metamorphosed volcanic sandstone
  - AFpk — Metakomatiite flow
- AFo — **BOONGAL FORMATION:** pillowed and massive metabasalt, metabasaltic breccia, pelite, and minor chert
  - AFob — Metabasaltic breccia
- AFh — **HARDEY FORMATION:** pelite, metasandstone, and metaconglomerate
  - AFhs — Feldspathic metasandstone, pebbly metasandstone, metaconglomerate, and minor pelite
  - AFhc — Metaconglomerate and metasandstone
- AFr — **MOUNT ROE BASALT:** amygdaloidal metabasaltic flows, and metabasaltic breccia

PILBARA CRATON BASEMENT

- d_1 — Metadolerite dykes
- Agm — Metamorphosed biotite monzogranite; weakly to strongly foliated
- Ac — Chert, grey and white banded
- Al — Quartzo-feldspathic schist, quartz-chlorite schist, talc-carbonate schist, quartzitic mylonite, and foliated felsic volcanic rock
- Ab — Metabasalt and metamorphosed, pyroxene spinifex-textured basalt
- Abm — Metamorphosed, pyroxene spinifex-textured basalt

Symbols

Geological boundary
- accurate

Fault
- accurate
- concealed
- reverse; concealed
- mylonite zone

Major fold, showing direction of plunge
- anticline
- syncline; concealed
- overturned anticline

Minor fold, showing strike and dip of axial surface, direction of plunge, and nature of vergence (Z, S, or M profiles)
- Capricorn Orogeny
  - Ashburton Fold Belt, D_{2a}
    - inclined
    - vertical
  - Ophthalmia Fold Belt
    - inclined
- Pre-Fortescue Group
  - inclined
- locality of superposed folds

Bedding, showing strike and dip
- inclined
- overturned
- strike and dip estimated from aerial photographs
  - 0 — 15°
  - 15 — 45°
  - 45 — 90°
  - trend of bedding

Way-up indicator
- sedimentary structure

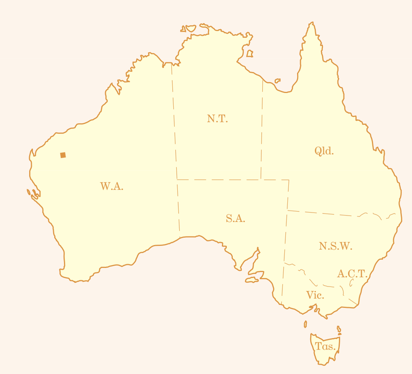
Foliation, showing strike and dip
- Pre-Fortescue Group
  - inclined, measured
  - inclined, interpreted from aerial photographs
- trend of foliation, interpreted from aerial photographs

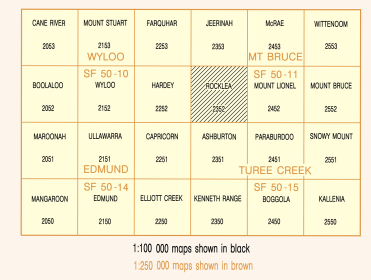
Cleavage, showing strike and dip
- Capricorn Orogeny
  - Ashburton Fold Belt, D_{2a}
    - inclined
    - strike coincident with bedding
    - C—S fabric
  - Ophthalmia Fold Belt
    - inclined
    - vertical
- Pre-Fortescue Group
  - inclined

Lineation, showing direction of plunge
- axis of crenulation
- bedding-cleavage intersection

- Major road
- Formed road
- Track
- Homestead — Rocklea
- Building
- Yard — Yd
- Horizontal control, minor
- Watercourse, ephemeral
- Pool — P
- Bore — B
- Well — W
- Windpump
- Abandoned — (abd)
- Contour line, 20 m interval — 420

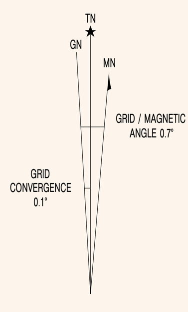
- Mineral field boundary
- Mining locality — BROCKMAN
- Quarry
- Alluvial workings
- Prospect — Brockman
- Mineral occurrence
  - Asbestos (chrysotile) — Ac
  - Asbestos (crocidolite) — Ad
  - Copper — Cu
  - Gold — Au
  - Gravel — Gr
  - Iron — Fe
  - Manganese — Mn





1:100 000 maps shown in black

1:250 000 maps shown in brown



True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 1994 and moves easterly by about 0.1° in 7 years.

DEPARTMENT OF MINERALS AND ENERGY
HON. GEORGE CASH, J.P., M.L.C.
MINISTER FOR MINES
K.R. PERRY, DIRECTOR GENERAL

PIETRO GUJ
DIRECTOR, GEOLOGICAL SURVEY
OF WESTERN AUSTRALIA

SCALE 1:100 000

1000 0 1 2 3 4 5 6 7 8 9 10

Metres — Kilometres

TRANSVERSE MERCATOR PROJECTION

Grid lines indicate 1000 metre interval of the Australian Map Grid Zone 50

Geology by: D.F. Blight 1981, A.M. Thorne 1989-92, I.M. Tyler 1992

Edited by: C. Strong, B. Ramsey, B. Williams

Cartography by: C. Bartlett, G. Loan

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Topographic base supplied by the Department of Land Administration and modified from geological field survey

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ROCKLEA

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