Proposed stratigraphic subdivisions of the Marra Mamba Iron Formation and the lower Wittenoom Dolomite, Hamersley Group, Western Australia

by

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Abstract

A total of four new members is erected within the Wittenoom Dolomite and Marra Mamba Iron Formation in the lower part of the Hamersley Group, in the northwest of Western Australia. Where possible, fresh diamond drillcore has been used to define the type sections of the members. The new definitions formalize, and slightly vary, previous schemes in use by companies mining iron ore in the Hamersley Basin.

The West Angela Member contains a sequence of interbedded dolomite and shaly dolomite. It is now regarded as being in the lower part of the Wittenoom Dolomite, although some earlier stratigraphic schemes place its leached, weathered equivalent at the top of the underlying Marra Mamba Iron Formation.

The Mount Newman Member forms the uppermost subdivision of the Marra Mamba Iron Formation and consists of thick macrobands of banded iron-formation (BIF) separated by thinner macrobands of mixed shale, chert and carbonate. The central part of the Marra Mamba Iron Formation, made up of interbedded shale, chert, carbonate and iron-formation, is named the MacLeod Member. A sequence of poddy, minnesotaite-rich BIF, chert and shale constituting the lower part of the Marra Mamba Iron Formation is defined as the Nammuldi Member.

Individual macrobands within the Mount Newman Member and the upper part of the MacLeod Member can be correlated over a wide area of theHa mersley Basin. However, stratigraphic ontinuity becomes less pronounced in the lower part of the MacLeod Member and has not been established for the Nammuldi Member.

KEYWORDS: Banded iron-formation, Hamersley Basin, Hamersley Group, iron ore, MacLeod Member, Marra Mamba Iron Formation, Mount Newman Member, Nammuldi Member, stratigraphy, West Angela Member, Wittenoom Dolomite.

Introduction

The Marra Mamba Iron Formation is the lowest unit of the 2500 Ma old Hamersley Group within the Hamersley Basin[4] in the northwest of Western Australia (MacLeod et al., 1963; Trendall and Blockley, 1970). It conformably overlies the Jeerinah Formation in the upper Fortescue Group, and is in turn conformably overlain by the Wittenoom Dolomite[5]. The geological setting of the formation and its main outcrop areas are indicated on Figure 1.

The unit attained economic importance around 1971 when it was found to contain large deposits of high-grade, secondary iron ore which were low in deleterious impurities such as phosphorus and alumina. Subsequent evaluation by a number of companies of this essentially stratabound mineralization led to the setting up of several different informal stratigraphic subdivisions of the formation, some of which included units more properly forming part of the overlying Wittenoom Dolomite. These various schemes are reported to have led to some confusion amongst potential buyers of Marra Mamba iron ore, and geologists working in this area saw a need to standardize their nomenclature. This need was accentuated when the industry began to computerize drill logs and saw advantages in adopting uniform designations for the stratigraphic units that they were exploring.

The stratigraphic subdivisions proposed in this paper have been agreed to by the Geological Survey of Western Australia (GSWA), the Commonwealth Scientific and Industrial Research Organization (CSIRO), and the principal iron ore mining and exploration companies sponsoring an Australian Mining Industry Research Association iron ore project on the iron ores and BIFs of the Hamersley Group. The elements of the scheme have already been adopted by industry and some names have already appeared in print (e.g. Kneeshaw, 1984).

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4 Although the term Hamersley Basin is used here as the name for the repository of the Hamersley Group and related sedimentary and volcanic rocks in accordance with current GSWA practice, it should be noted that Morris and Horwitz (1983) interpret the site of deposition as a platform.
5 The term Wittenoom Dolomite has been replaced by Wittenoom Formation in the paper by Simonson et al. in this volume.

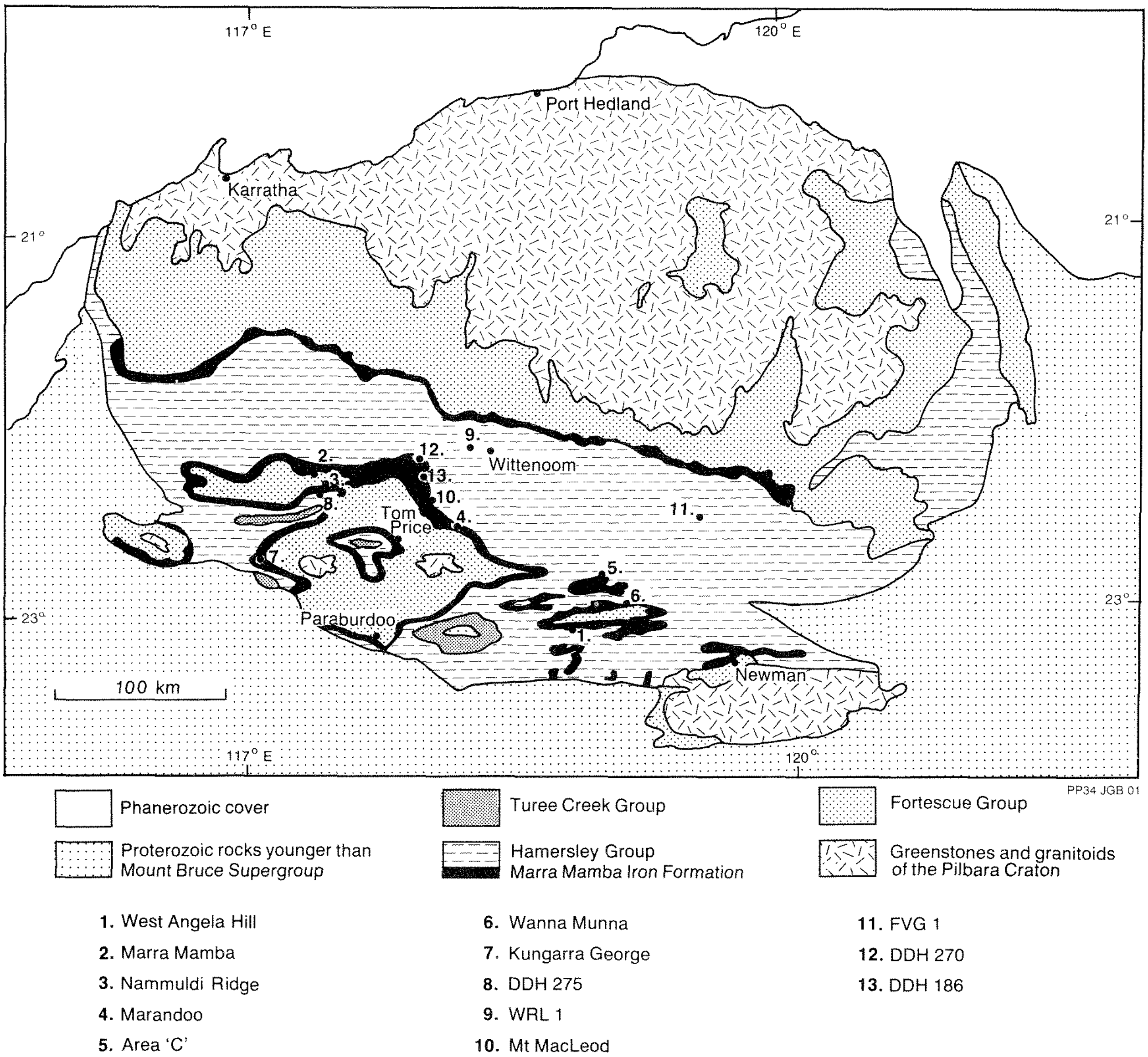

Figure 1. Simplified geological map of the Hamersley Basin showing main outcrop areas of the Marra Mamba Iron Formation and localities mentioned in the text

Previous stratigraphic subdivisions

The earliest attempt to create internal stratigraphic subdivisions within the Marra Mamba Iron Formation was made during an investigation by Ryan and Blockley (1965) of crocidolite deposits within the formation. This study resulted in the naming of two informal members and several crocidolite horizons. While some of the crocidolite horizons were able to be matched over distances of tens of kilometres, the presence of fibre was almost always a prerequisite for successful correlation. Away from the fibre seams no useful correlations were achieved and a composite section published by Blockley (1967), based on measurements of weathered exposures, has been superseded by later drillhole data.

At a later stage of the crocidolite investigations, Trendall and Blockley (1970) recognized a central shaly unit within the formation. This led to an informal threefold subdivision of the Marra Mamba Iron Formation as follows:

Unit	Thickness (m)
upper BIF member	60
middle shaly member	35
lower BIF member	135

A narrow transition zone of interbedded dolomitic, manganese-bearing shale and chert between the upper BIF member and the first massive dolomite unit within the overlying Wittenoom Dolomite was also recognized but not assigned specifically to either unit. The two informal members named by Ryan and Blockley (1965) were abandoned and it was stated that any scheme of formal nomenclature within this poorly exposed unit should await the availability of drillcore.

Similarly, although the two BIF members of the formation were recognized as being composed largely of alternating iron-formation and shale units, no attempt was made to subdivide these into numbered macrobands as had been done for the Dales Gorge Member of the Brockman Iron Formation (Trendall and Blockley, 1970).

Throughout most of its outcrop area the Marra Mamba Iron Formation ranges in thickness from about 180 m to 230 m, but marked thinning of the unit to the north and northeast is recorded by Trendall and Blockley (1970, p. 84).

During the early to mid-1970s, drillcore and downhole natural gamma-ray logs became available from a number of iron ore exploration projects within the Marra Mamba Iron Formation. By 1975, most operators had established their own stratigraphic divisions of the formation and had achieved correlations of individual macrobands over considerable distances, particularly in the upper BIF member.

The different schemes used by individual operators between about 1971 and the early 1980s are compared in Table 1. Essentially, all schemes recognized the three informal members proposed by Trendall and Blockley (1970). However, four also included a fourth, uppermost shaly member corresponding to, but generally thicker than, Trendall and Blockley's transition zone.

Apart from the small differences in terminology used in the various schemes, detailed correlations of measured sections and gamma-ray logs indicated that some boundaries between members had been placed at different positions (Blockley, 1979). For example, the 'upper banded iron member' of the Mount Newman Mining scheme (Slepecki, 1981) embraced a sequence of shale and chert which other operators included in their uppermost shaly member.

Goldsworthy Mining differed from the other companies in using the contact between ore and unenriched BIF as the stratigraphic boundary between its upper and middle members (Neale, 1975). While this contact does show stratigraphic persistence in some areas, it is certainly transgressive on a regional scale, and the general concept contravenes accepted stratigraphic principles.

Another discrepancy between the schemes is the status accorded to the upper shaly member. This unit is a feature of the subdivisions set up in the central and eastern parts of the basin by Robe River Mining Associates, Texasgulf/Hanwright (now CRA/Hanwright) and Mount Newman Mining (now BHP Iron Ore Ltd), but was omitted from the scheme used by Hamersley Exploration Pty Ltd (Hamex) working in the better exposed westerly part of the basin. In this area, the shale was interpreted by Hamex Senior Geologist, John Evans (1977, pers. comm.) as being derived by leaching of laterally equivalent Wittenoom Dolomite.

Proposed stratigraphic scheme

General principles

The stratigraphic scheme proposed in this paper recognizes and formalizes all four members which have gained currency in the industry, but assigns the uppermost shaly member to the Wittenoom Dolomite rather than to the Marra Mamba Iron Formation as drillcore and fresh natural exposures show it to consist mainly of dolomite and dolomitic shale. It should be noted that Simonson et al. (1993) uses the names Bee Gorge and Paraburdoo Members for the upper and middle parts respectively of the Wittenoom Dolomite, and also suggests that the name of the unit be changed to Wittenoom Formation because of its high content of non-carbonate lithologies. His new nomenclature has not been used in this paper.

The four new members proposed here, from youngest to oldest, are:

Wittenoom Dolomite

West Angela Member

Marra Mamba Iron Formation

Mount Newman Member
MacLeod Member
Nammuldi Member

Definitions of the three members proposed here for the Marra Mamba Iron Formation are based largely on detailed study of the core of DDH 275 drilled by Hamex at 117° 21.5'E and 22° 25.6'S, about 6.7 km northeast of the Mount Brockman trigonometric station. Additional information on the lowest member has been obtained from the core of DDH 186 drilled by Hamex at 117° 55'E and 22° 24'S

Repository of cores

The core of DDH 275 is stored at the CSIRO Exploration Geoscience Laboratory, Floreat Park, Western Australia. A set of streak prints prepared by the method of Morris and Ewers (1978) is also held at the CSIRO laboratory to provide a convenient means of examining the lithology of the core.

Core from WRL 1 is stored at the CRA Exploration Pty Ltd depot in Anderson Road, Karratha.

The partial intersection of the Nammuldi Member obtained in DDH 186 is held by the Geological Survey of Western Australia in its core library.

Wittenoom Dolomite

West Angela Member

Derivation of name

The West Angela Member is named after West Angela Hill near the West Angelas iron ore deposits held under a State Agreement by Robe River Mining Associates.

Type section

The type section of the West Angela Member is herein defined as that part of the core from hole WRL 1 between

Table 1. Comparison of stratigrapic schemes formerly in use by exploration companies

'Natural' Lithological Subdivisions	*Newman (a)*	*CRA/Hanwright (b)*	*Cliffs*	*HAMEX*	*Hamersley Iron*	*Goldsworthy*
Interbedded shale, chert, BIF ± dolomite. Thickest where overlying ore in eastern part of basin. Contains iron and manganese concentrations. (Trendall & Blockley's (1970) transition zone)	**Upper shale member** Typically 30 m thick. 16 shale bands recognized (A1 to A16)	**Upper shale member** Typically 40 m thick. Some informally named marker beds used.	**Upper shale member** 30 to 40 m thick. 3 shale bands recognized (480, 490 and 500).	**Not recognized** (considered to be leached Wittenoom Dolomite)	**Upper shale member** 10 m thick where unmineralized. Not subdivided but some marker horizons used.	**Not recognized**
BIF interbedded with shale–chert carbonate units weathering to thin shaly partings. Commonly mineralized to powdery hematite–goethite ore, particularly in upper part.	**Upper BIF member** Typically 50 m thick (unmineralized). 11 shale bands recognized (B1 to B8 plus U1 to U3)	**Upper banded iron member** About 46 m thick where unmineralized. 8 shale bands recognized. (F1, F2, G, H, H1, I, J, K).	**Upper banded iron** Typically 80 m thick where unmineralized. 7 shale bands recognized (numbered 510 to 570 by tens).	**Upper BIF member** About 30 m thick where mineralized. 4 shale bands recognized (upper, twin shales and lower).	**Upper BIF member** 80 m thick where unmineralized 8 shale bands recognized (M1 to M8)	**Upper member** Hematite-goethite ore with up to 10 numbered shale bands.
Interbanded shale, chert, BIF and carbonate. Commonly weathers to form a strike valley. Rarely mineralized.	**Middle BIF and shale member** Typically 24 m thick, 15 shale recognized (C1 to C15).	**Intermediate shale member** About 32 m thick. 14 shale bands recognized (L to W plus V1 and and W1)	**Intermediate shale member** Typically 45 m thick where unmineralized. 16 shale bands recognized (580 to 730 by tens).	**Median shale member** Not subdivided	**Median shale member** Thickness ranges from 25 m (mineralized) to 37 m. Not subdivided.	**Middle member** Cherty BIF over interbedded shale and chert. No subdivisions recorded.
Cherty BIF and chert with numerous shaly bands. Podded yellow chert bands (after minne-sotaite) are a feature of most outcrops.	**Lower BIF member** Typically 70 m thick, but thins to 40 m. 18 shale bands recognized (D1–D18).	**Lower banded iron member** Thickness not established. No shale band nomenclature.	**Lower banded iron member** Full thickness not established. 10 shales recognized in upper 50 m. (740 to 830 by tens).	**Lower BIF member** Not subdivided, but distinctive podded chert beds ('Potato beds') near top are used as a marker.	**Lower BIF member** 90 to 115 m thick. Subdivisions noted but not named, except for 'potato beds'.	**Lower member** 125 m thick. No subdivisions recorded

(a) Now BHP Iron Ore
(b) Formerly Texasgulf/Hanwright

420.4 m and 524.6 m. The upper part of the member is marked by a transition from predominantly massive dolomite to interbedded dolomite and shaly dolomite. This change is reflected in the gamma-ray and caliper logs of the hole (Fig. 2).

The core is stored at the premises of CRA Exploration Pty Ltd at Karratha and the core log, extracted from Meakins (1987), is tabulated in Appendix 1.

As noted above, the near-surface expression of the member may vary quite markedly from that seen in drillcore.

Type areas

Relatively fresh exposures of the West Angela Member are seen at Radio Hill near Paraburdoo and in tributaries of Duck Creek. Cored intersections of the member were also obtained in holes DDH 275 and FVG 1 (Fig. 1).

Typical lithologies of the weathered member can be seen at Newman, particularly in the openpit on Mount Newman Mining's Orebody 29. Other accessible exposures are present at the portal of an exploratory adit on the West Angelas deposits and at the entrance to the test pit at Marandoo.

Description

The dominant lithologies of the fresh West Angela Member are dolomite and shaly dolomite. Chert is a minor component of the upper part of the member, but becomes more common lower down. Near the base of the member there is a 10 to 20 m thick sequence of interbedded chert, BIF and shale that gives rise to three characteristic gamma-ray peaks (Fig. 2). These peaks have been identified wherever the member has been examined in detail and are designated AS1 to AS3 in company logs (Fig. 2).

The dolomite units logged in WRL 1 (Meakins, 1987) are massive and crystalline, laminated with shaly partings, or brecciated with shale fragments. They may exhibit soft-sediment deformation structures and stylolites. The shaly dolomite comprises thinly bedded, grey crystalline dolomite interbedded with carbonaceous shale and siltstone. Sedimentary features noted include inverted graded bedding and flame structures. Pyrite occurs in shale beds as blebs, stringers parallel to bedding, and fracture fillings.

The lower boundary of the member is marked by a sharp contact between shale or shaly dolomite, and a thick unit of podded, magnetite-bearing BIF at the top of the Marra Mamba Iron Formation. It is clearly defined in outcrop and drill logs, and can be traced throughout the greater part of the Hamersley Basin. However, the upper boundary of the member is transitional and, although it can be clearly identified in the geophysical logs of the various core holes that penetrate it, we recognize that there are difficulties in establishing its position in most areas. For this reason it is difficult to estimate the normal thickness of the member.

The West Angela Member is best known where it is found in proximity to iron ore deposits developed in the underlying Mount Newman Member of the Marra Mamba Iron Formation. In these situations the carbonate content of the member is almost always leached, leaving a rock composed mainly of poorly bedded shale with chert bands or breccias. The shales are striped due to alternating bands of manganese and iron oxide enrichment. Locally, manganese oxide concentrations can be high (up to 25% MnO), particularly along a cherty horizon (near the base of the member) which commonly forms a stratigraphic marker known as the 'Manganese Band'. In the Newman pit on Orebody 29, the shale is typically light and porous, and contains secondary gypsum.

Stratigraphic continuity

Lateral persistence within the West Angela Member is best demonstrated by the sequence of interbedded chert, BIF and shale near its base. Above this sequence it is difficult to establish lateral correlations within the member. Comparison of the logs of holes WRL 1 (Meakins, 1987) and FVG 1 (Andrew, 1985) suggests that the member becomes more shaly in the eastern part of the basin. Such a facies change could account for the more prominent development of residual shale at Newman and West Angelas compared with that at Nammuldi and Paraburdoo.

Marra Mamba Iron Formation

General features

Detailed descriptions including mineralogy, petrography, and geochemistry of cores from the Marra Mamba Iron Formation were presented by Davy (1975) for the upper 4 m of the Mount Newman Member at Millstream; Ewers and Morris (1980) for DDH 270, upper Mount Newman Member at Marlathanna bore; Davy (1985) for the lower 88 m of the Nammuldi Member in DDH 186 (about 13 km south of DDH 270); and Morris (1991) for the two upper members and the top 12 m of the Nammuldi Member in DDH 275, at Nammuldi. Klein and Gole (1981) gave a detailed mineralogical and chemical breakdown of four representative 12.5 cm lengths of core from DDH 270 and 182.

The three members of the Marra Mamba Iron Formation differ in their basic features though they have many points in common.

The Mount Newman Member shows a marked subdivision into two major rock types, forming an alternating macroband pattern somewhat similar to that in the Dales Gorge Member. The dominant macrobands consist of magnetite-rich, oxide-type banded iron-formation (BIF) with a significant silicate–carbonate content. The intervening narrower macrobands consist of varying proportions of ferroan dolomite and limestone, with shaly intercalations and occasional chert beds. These horizons are defined as SCC macrobands (silicate–carbonate–chert) following a convention established by CSIRO workers. SCC macrobands show

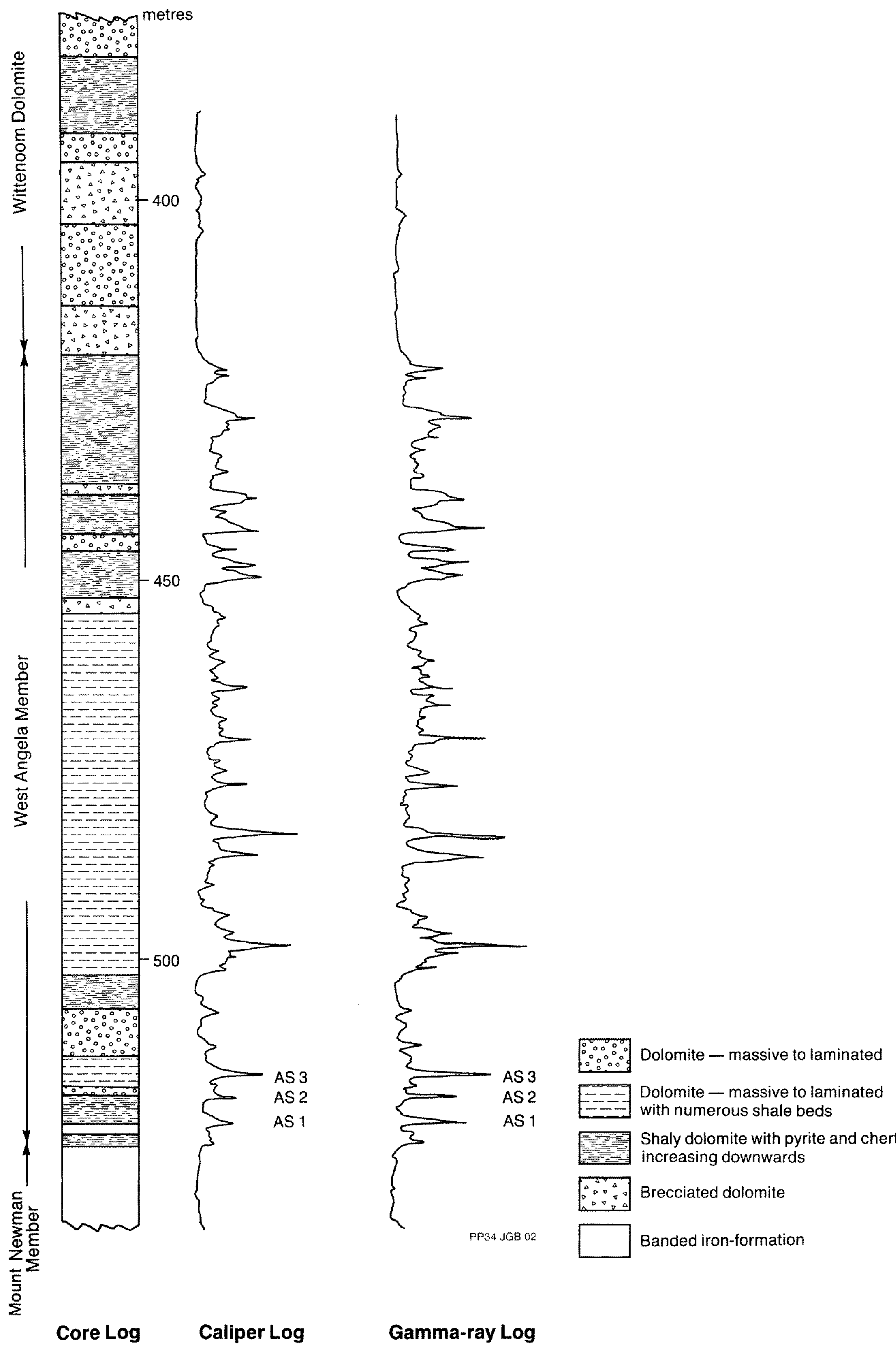

Figure 2. Lithological, gamma-ray and caliper logs of the type section of the West Angela Member in hole WRL 1

little similarity to the S macrobands of the Dales Gorge Member (except for the purely shale horizons) and most closely resemble the lithology of the overlying Wittenoom Dolomite (Ewers and Morris, 1980; Morris, 1991) but with significant iron in the carbonate. The geochemistry of the shales and the occasional shard bands suggest derivation from mainly volcaniclastic components, modified by reaction with iron-bearing marine waters. The SCC macrobands are generally referred to as 'shales' because of their appearance in weathered and enriched exposures.

The upper part of the middle shaly unit, the MacLeod Member, also shows this type of macroband subdivision but with a significantly higher silicate content in the BIF. The limestone–dolomite sequence decreases down the member and, towards the base, it becomes difficult to clearly distinguish shaly BIF from cherty shale.

Macrobanding is poorly defined in the Nammuldi Member which is predominantly silicate–carbonate BIF sequence, with some resemblance to the BIF of the S macrobands, but with a varying magnetite content (Davy, 1985).

The mesobanding of the Marra Mamba Iron Formation is more varied than in the Dales Gorge Member and reflects the significantly higher content of silicates and carbonates of the unit. The mineralogy, though relatively simple, is not easily determined with the microscope, owing to the complex fine-grained mineral intergrowths. The major components are quartz (chert), magnetite, and minnesotaite, with ferroan talc, calcium–magnesium carbonates varying from dolomite to ankerite, abundant ferroan and normal calcite in the SCC macrobands, siderite (particularly in the MacLeod Member), stilpnomelane, riebeckite, chlorite, ?greenalite, phlogopite and undetermined 'mica'. Among the less prominent minerals are widespread pyrite, and very erratic pyrrhotite which, when concentrated, is usually associated with chalcopyrite, sphalerite, and rarely galena and arsenopyrite. Authigenic alkali feldspars, albite, orthoclase, and untwinned microcline, are common in some alumina-rich bands, but are most readily recognized in carbonate zones. Ilmenite, tourmaline and pyrite are commonly associated in narrow bands in the shale zones. Carbon, and rarely graphite, are most easily seen in carbonate areas, commonly associated with stylolites, and as the colouring matter (commonly with pyrite) in black shale.

A significant feature is the absence of well-defined BIF-varves or aftbands (originally called microbands) from the Marra Mamba Iron Formation, despite their prominence in the Dales Gorge Member cores. Nevertheless, some mesobands do show a type of thick, regular banding but lack the well-defined iron-rich and silica–carbonate-rich alternations of the Dales Gorge Member. Instead, variations in the minnesotaite and ankerite distribution in chert, or of stilpnomelane with carbonate, are the most common (Morris, 1991). A much finer, though rarely regular banding results from 'rafts' of magnetite forming fine laminae which alternate with intergrown chert–silicate–carbonate.

Alteration and mineralization

Oxidized and weathered BIF generally retains the original mesobanding, and the outcrop is typically stained yellow as a result of the breakdown of the abundant carbonate and silicate components. The oxidized shale bands include significant kaolinite, goethite and gibbsite. They usually occur as either well-bedded, white, pink and red-banded horizons or massive khaki units with goethite pods.

The bulk of the potentially commercial iron ores within the Marra Mamba Iron Formation occurs within the Mount Newman Member, although in places mineralization extends upwards into the lowermost part of the West Angela Member of the Wittenoom Dolomite and downwards, normally only for a short distance, into the MacLeod Member. Typically the mineralized zone extends stratigraphically downwards from the top of the member so that there is usually a downward transition from ore to weathered BIF at some variable horizon within the sequence. For example, in Orebody 29 at Newman, the whole of the member is mineralized whereas at Nammuldi, mineralization typically stops at the level of shale NS2.

The enrichment processes are described in detail by Morris (1980, 1985, 1987) and Slepecki (1981). The ore, which consists of goethite, ochreous goethite, and hematite is considered to have been formed by supergene enrichment of BIF followed by variable leaching of the replacement goethite. Original banding within the BIF and many other structures are well preserved, as is the characteristic gamma-ray profile of the member. The transition from iron-formation to ore involves a reduction in thickness by about 35%; subsequent processes, which include metamorphism (rare in the Marra Mamba Iron Formation) and further leaching, can increase this to about 50%.

As a result of the pseudomorphing by goethite of the high silicate and carbonate content of the BIF, and the post-enrichment differential leaching of this goethite, iron ore formed within the Mount Newman Member is typically softer and more friable than that developed within the Brockman Iron Formation. The ore in Orebody 29 at Newman, for example, ranges from weakly cemented biscuit ore to iron ore dust being scaled from 0063 to 0073 in the Pilbara Iron Ore Classification (PIOC) (Kneeshaw, 1984). At Marandoo the ore in the upper 'hardcap' zone is competent (0033) with a biscuit ore (0063) appearing at depth.

Mount Newman Member

Derivation of name

The Mount Newman Member is the uppermost of the three members of the Marra Mamba Iron Formation. It is named after Mount Newman (latitude 23°16'S, longitude 119°34'E), a prominent peak in the Ophthalmia Range situated about 20 km northwest of the town of Newman. The Mount Newman Mining Company was one of the first to recognize the stratigraphic controls of iron ore within the Marra Mamba Iron Formation, and was the first to mine this ore type commercially.

Type section

The type section of the Mount Newman Member is defined as the interval of core in hole DDH 275 between the top of the member at 342.5 m and its base at 419.65 m. This section is presented in Figure 3, which includes a gamma-ray log showing the peaks typical of the member. A log of the core making up the type section is given in Appendix 2.

Type areas

The Mount Newman Member has been studied extensively by mining companies because of its concentrations of iron ore, and a number of typical exposures have been recorded. Probably the least weathered and most complete natural exposure is in Kungarra Gorge (Fig. 3) where the member is seen on both limbs of an anticline in a deeply dissected drainage. Other useful exposures are present in the Turner Syncline (latitude 22° 40.5'S, longitude 117° 26.6'E), in two gorges at Wanna Munna (latitude 23° 04.9'S, longitude 119° 9.2'E and latitude 23° 04.9'S, longitude 119° 08.2'E), and in 'Manganese Gorge' at Marandoo. The member is also well documented in exploration holes across the province, having been explored in detail at Paraburdoo, Tom Price, Nammuldi, Marandoo, Area 'C', Wanna Munna and Newman.

In addition to the core of DDH 275, a complete intersection of the member was also achieved in hole WRL 1 drilled near Wittenoom (Fig. 3) while DDH 270, drilled 38 km west of Wittenoom, cored the upper 34 m of the member (Ewers and Morris, 1980).

Enriched sections of the Mount Newman Member are well exposed in the opencut on Orebody 29 at Newman, and in various openings at West Angelas, Area 'C', Marandoo and Nammuldi.

The Mount Newman Member is made up of nine macrobands of BIF alternating with 8 SCC macrobands. These 'shale' bands are important stratigraphic markers and are referred to as shales NS1 to NS8, the numbering proceeding from the base of the unit. Other thinner, or less continuous 'shales' have been recorded but are less important as stratigraphic markers and have not been numbered. Similar subdivisions of the member have previously been published by Blockley (1979) and Slepecki (1981), although the presently defined boundaries of the member differ from those used by the earlier authors. Following the same principle, the BIF macrobands separating the shales are designated NB1 to NB9.

Cherts within the BIF macrobands of the Mount Newman Member are strongly podded and give the unit a characteristic wavy bedding locally referred to as 'pinch-and-swell' structure. The pods may be either flat and parallel to the main bedding planes, or inclined to the bedding in a manner reminiscent of the cross pods within the Dales Gorge Member (Trendall and Blockley, 1970, p. 155). Such cross pods commonly occur in stacks of three or four within stratigraphic intervals of 30 or 40 cm, each pod being slightly offset from the one below.

Stratigraphic continuity

The eight shale bands (NS1 to NS8) referred to above can be traced over the entire extent of the area in which exploration for iron ore has taken place (Blockley, 1979). Throughout this extent they are characterized by distinctive patterns in gamma-ray logs which, in mineralized sections, often provide more-reliable correlations than do the strongly altered lithologies.

Stratigraphic continuity on even finer scales can also be demonstrated. For example, within shale NS3 there is a thin band containing pyrite nodules up to 5 mm in diameter which become goethitic or hematitic in oxidized sections. This band, usually no more than 5 cm thick, has been identified in exposures as far apart as Newman and Nammuldi.

Another stratigraphic indicator of somewhat lesser importance is provided by a group of crocidolite bands commonly appearing within BIF macroband NB2. These bands have been noted in localities ranging from Kungarra Gorge in the west to Wanna Munna in the east. The stratigraphic interval containing these bands and associated massive riebeckite was referred to by Trendall and Blockley (1970) as the Vivash Riebeckite Zone. In most natural exposures the original crocidolite has been replaced by goethite or silica to form griqualandite or tiger eye.

MacLeod Member

Derivation of name

The MacLeod Member is named after Mount MacLeod, one of the higher peaks on the Hamersley Range and situated at latitude 22° 23.8'S, longitude 118° 01'E, about 28 km north-northwest of Marandoo camp.

Type section

The type section of the MacLeod Member is defined here as the drillcore from Hamex DDH 275 between the depths of 419.65 m and 465.8 m. A core log of the type section is given in Appendix 3.

Type areas

The MacLeod Member is very susceptible to erosion because of its high content of shaly beds; consequently, complete natural exposures are rare. Sections showing most of the member occur at Kungarra Gorge, in the Turner Syncline (latitude 22° 40.5'S, longitude 117° 26.6'E), and in two gorges at Wanna Munna.

The member has been extensively drilled during the search for iron ore and is generally better known from its gamma-ray logs than from outcrop. In addition to those illustrated from DDH 275 and WRL 1, complete gamma-

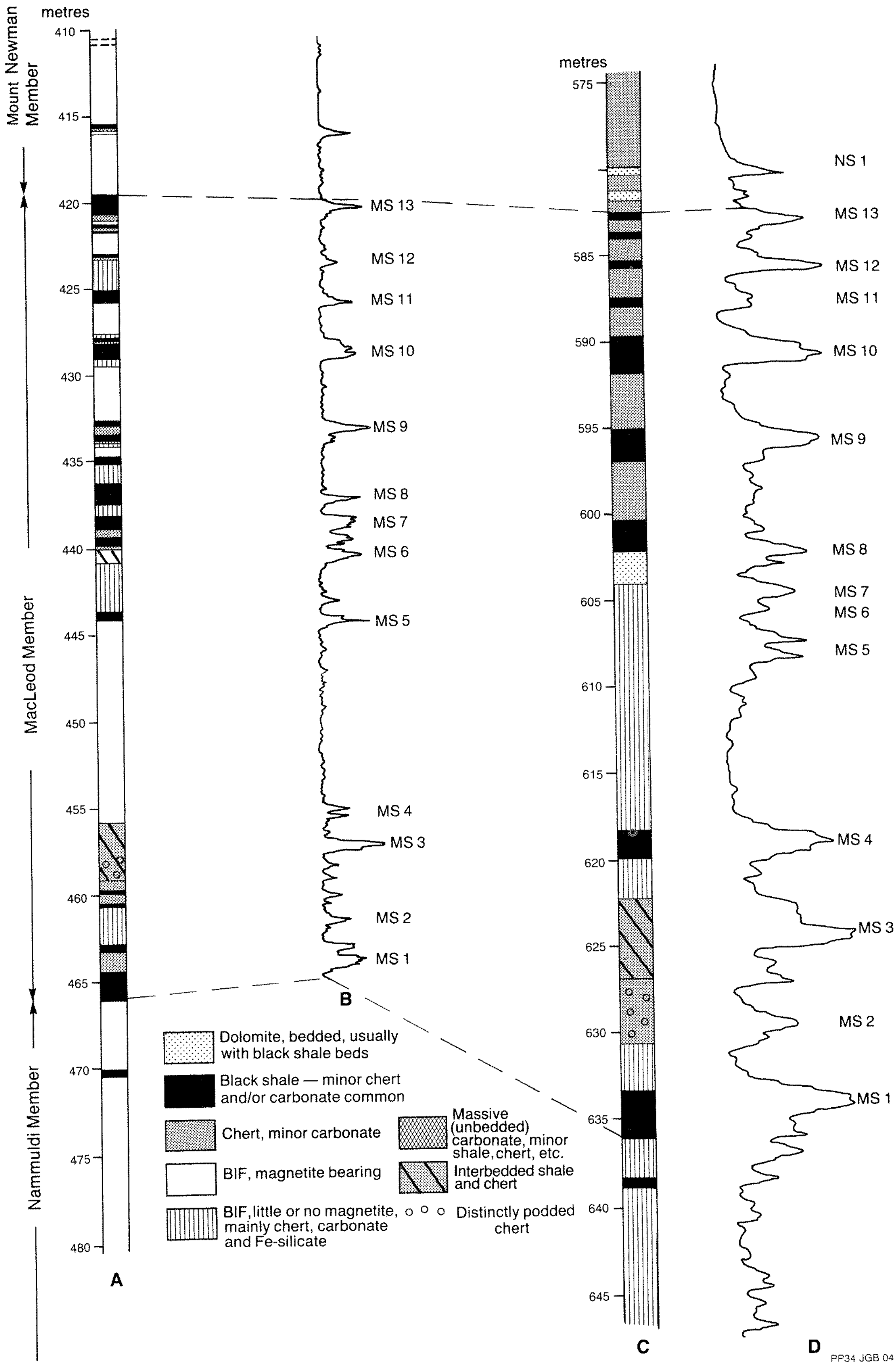

Figure 3. **Sections of the Mount Newman Member. A — Core log of the type section in DDH 275. B — Gamma-ray log of the type section in DDH 275. C — Core log of member in WRL 1. D — Section of member measured in Kungarra Gorge**

ray profiles are available from Tom Price, Newman, West Angelas and Marandoo. Another complete core of the unweathered member was obtained from hole WRL 1 near Wittenoom.

Description

In fresh drillcore the MacLeod Member consists of interbedded iron-formation, black shale and carbonate. The iron-formation contains chert, iron carbonates and a high proportion of iron silicates, with a variable content of magnetite. Much of this material, particularly toward the base of the member, is best classified as shaly iron-formation.

Weathered exposures of the member consist of shale, chert, and altered iron silicates with minor bands of hematite or goethite. Outcrop is generally poor, with the member typically forming small, strike-controlled gullies.

Gamma-ray logs of the member usually show 13 distinct peaks corresponding to shale bands, although these may be difficult to identify in outcrop. These peaks have been used as the basis for subdividing the unit into numbered shale and BIF bands for use in detailed borehole gamma-ray log interpretation (Fig. 4).

During field mapping the base of the member has commonly been placed at a prominent horizon of chert nodules referred to as the 'potato bed'. The chert pods within this marker vary in size from place to place. They are generally of an oblate spheroid shape, but in places have been deformed into ellipsoids. Internally they contain stellate cracks, usually filled with quartz or carbonate. However, as several chert horizons within the member are known to contain similar nodules, the use of the 'potato bed' to define the base of the member should be discontinued. Nevertheless, this distinctive unit remains a useful marker horizon in many localities. Until further information becomes available, the 'potato bed' is tentatively correlated with the band of chert nodules logged between 457 and 459 m in DDH 275 (Fig. 4). This band is 17 m above the base of the member as defined above.

The Dun Crocidolite Horizon of Trendall and Blockley (1970) is now considered to lie within the MacLeod Member, probably in BIF macroband MB9.

Iron mineralization within the member is minor and of lower grade compared with that in the Mount Newman Member. Near the top of the unit, the ore consists of interbedded goethite, martite (hematite after magnetite) and ferruginous shale, but lower in the section, hematite is absent. The ore is typically of PIOC type 0073 (Kneeshaw, 1984).

Nammuldi Member

Derivation of name

The Nammuldi Member is named after Nammuldi Ridge which is centred at 22° 25'S, 117° 24'E, and forms a low topographic rise to the north of Mount Brockman. The ridge contains a major deposit of Marra Mamba iron ore under tenure to Hamersley Iron Pty Ltd.

Type section

The type section of the Nammuldi Member is defined as the exposure on the east side of the gorge formed where the Hardey River cuts the Marra Mamba Iron Formation on the south limb of the Turner Syncline (latitude 22° 46.6'S, longitude 117° 30.9'E. A detailed description of the type section is set out in Appendix 4.

The base of the member is clearly defined by its contact with the underlying Roy Hill Shale Member of the Jeerinah Formation, which here is intruded by a dolerite sill at a short distance below the contact. At its top, the member is in contact with poorly exposed shale and chert of the MacLeod Member. The measured thickness of the type section is 125.5 m.

Type areas

No satisfactory section of the entire Nammuldi Member is preserved as drillcore. Hamex hole DDH 275 intersected the upper boundary of the unit at 465.8 m and stopped some way into the member at 480 m. The core from DDH 186 commenced within the member at 54 m and intersected the lower boundary at 141.95 m before passing into the conformably underlying Roy Hill Shale Member of the Jeerinah Formation. It is unlikely that these drill intersections overlap stratigraphically. Hole WRL 1 drilled by CRA Exploration at about 22° 12'S, 118° 13'E, intersected the complete Nammuldi Member from 638.9 to 678.9 m. However, the 40 m thickness indicated is appreciably less than that recorded in other parts of the basin, and there are also lithological differences which suggest that this intersection is not typical of the member as a whole.

Most of the prominent outcrops of the Marra Mamba Iron Formation consist largely of the Nammuldi Member. Reasonably accessible exposures can be seen at the old Marra Mamba crocidolite workings, Mount Lionel near Tom Price, and in the Chichester Range north of Wittenoom.

Thickness

The Nammuldi Member is typically about 130 m thick, but substantial variations have been recorded. The 40 m thickness recorded near Wittenoom is noted above, while the standard gamma-ray log reference section used by Mount Newman Mining indicates a thickness of about 60 m near Newman (Slepecki, 1981).

Description

In oxidized outcrop the member consists predominantly of yellow and brown chert with thin hematite bands. Chert is more predominant than in the Mount Newman Member. A distinctive feature of the Nammuldi Member is the extensive development of chert pods, particularly in the upper part of the unit. The pods are better developed and more numerous than those in the

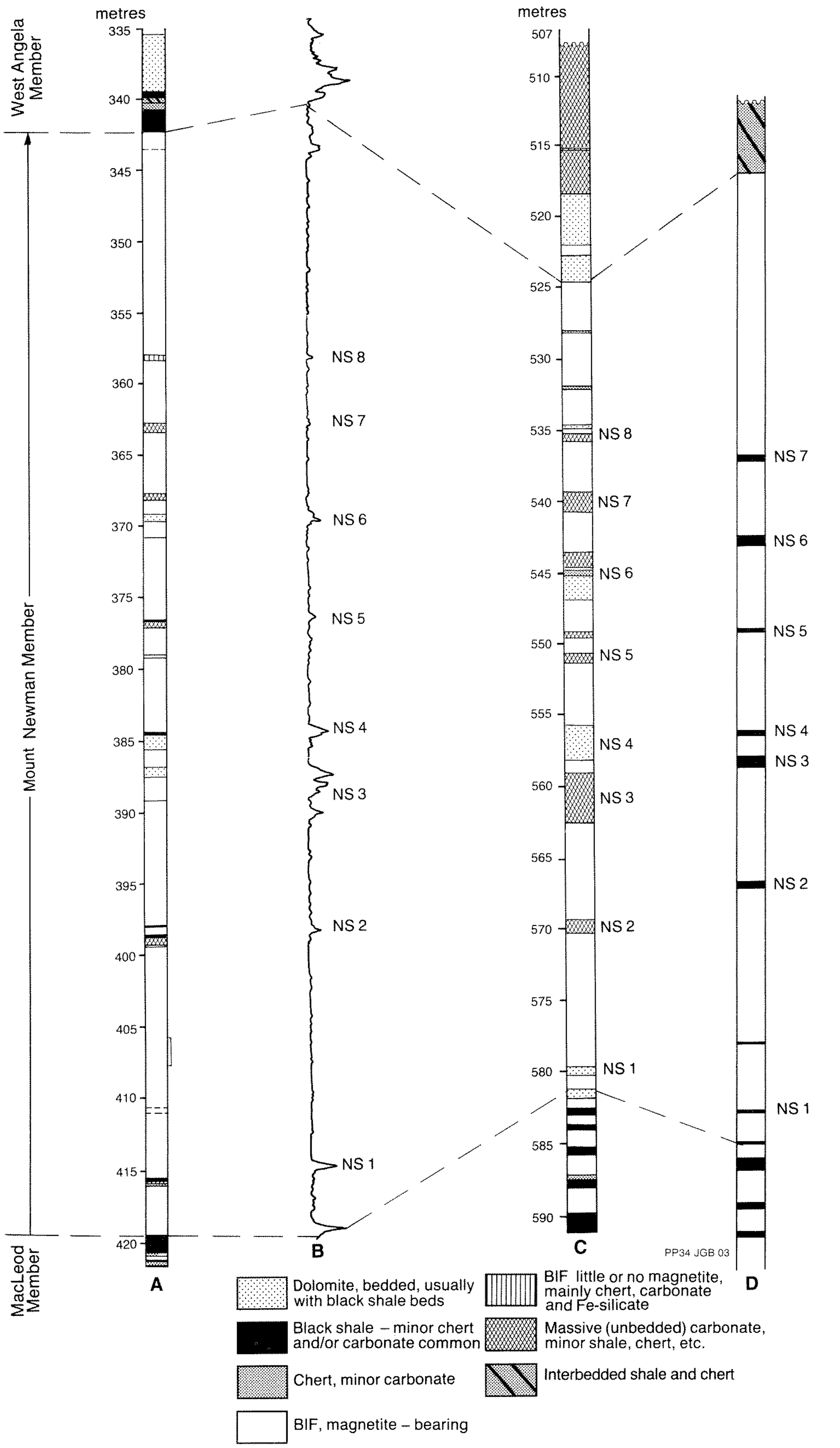

Figure 4. Sections of the MacLeod Member. A — Core log of the type section in DDH 275. B — Gamma-ray log of the type section in DDH 275. C — Core log of member in WRL 1. D — Gamma-ray log of member in WRL1

Mount Newman Member or in any other BIF unit in the Hamersley Group. In many localities, pods are elongated parallel to the axes of regional folds, suggesting an overlap between diagenesis and tectonic deformation. Gamma-ray logs and drillcores of the Nammuldi Member indicate that a significant proportion of it consists of shaly material; however, shale is rarely seen in outcrop, its position being indicated by breaks in exposure.

The upper part of the member in DDH 275 consists of unoxidized magnetite-bearing BIF with minor stilpnomelane, riebeckite and pyrite. Davy (1985) described the lithology of the lower part of the member in DDH 186 as predominantly dark-coloured BIF and interbedded green minnesotaite and stilpnomelane with minor carbonates and quartz. Magnetite decreases with depth and is totally absent from the bottom 9 m which is shaly and transitional into the underlying Roy Hill Shale Member. The pyrrhotite content of the core increases towards the base of the member.

Davy and Hickman (1988) note that while the BIF is banded, the banding is not entirely regular, and the rock varies from laminated to massive. Subdivision of the member depends more on the differences in the proportions of the minerals present (represented visually by colour differences) than on totally different lithologies. There are no macrobands of radically different composition.

The core of the Nammuldi Member in WRL 1 contains very little magnetite, iron being expressed in minerals such as minnesotaite, stilpnomelane, ferroan carbonate and pyrrhotite. Macrobanding and mesobanding are poorly developed. Some sedimentary features, such as tuff beds, scouring and possible cross-bedding have been recognized in the core (Meakins, 1987). Stylolites are common in chert–carbonate horizons.

Although the Nammuldi Member contains numerous shale bands, it has not been possible to establish regional correlations of these beds, although some local correlation has been obtained in the Newman area. As a result, no numbering scheme for the shales is proposed in this paper.

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Appendix 1

Core log of type section of the West Angela Member: Hole WRL 1 (after Meakins, 1987)

420.40–428.62 (m) Shaly dolomite

A medium-to pale-grey, medium-crystalline dolomite, intercalated with numerous thin carbonaceous shale and siltstone beds and laminations. Carbonaceous shale beds towards the top of the sequence show inverse graded bedding, otherwise shale horizons occur as thin discrete bands. Occasional flame structures associated with the shale horizons, as are rare pyrite stringers. Notable divisions as follows:

422.15–422.80: grey, medium- to coarse-grained massive dolomite which is distinctive as it is coarser textured and contains a significant amount of non-carbonate (?carbonaceous) matter.

423.37–423.61: brecciated sequence hosting dolomitic fragments containing calcite veins. The matrix consists of dark carbonaceous matter, and the breccia is mainly clast supported, with well-developed stylolite contacts.

428.62–437.40 Shaly dolomite

Thin carbonaceous shale interbeds and laminations are located within significantly coarser grained dolomite containing large amounts of dark, fine, non-carbonate fragments. Carbonaceous shale beds become thinner but more closely spaced up sequence. Rare pyrite stringers occur within the shale horizons. Basal contact is well defined.

437.40–438.73 Brecciated dolomite

A thin, brecciated unit consisting of grey, coarsely crystalline massive dolomite containing common, fine, carbonaceous shale fragments and clasts. Shale fragments are particularly abundant near the base of the unit. Extensive, irregular calcite veining present throughout the unit. The basal and upper contacts are well defined.

438.73–443.99 Shaly dolomite

Numerous wavy to planar carbonaceous shale beds (to 5 cm thickness) and laminations are intercalated in a sequence of medium to coarsely crystalline 'dirty' dolomites. The dolomite is laminated to massive and contains abundant fine carbonaceous matter. Only minor calcite veining present in the unit. Blebs and stringers of pyrite are more common in shales than in previous units.

443.99–445.87 Massive dolomite

A pale-grey, medium-crystalline massive to poorly laminated dolomite characterized by extensive soft-sediment deformation and common well-developed stylolite contacts. The unit contains only rare shale partings. The dolomite is considerably cleaner than overlying units.

445.87–451.80 Shaly dolomite

A medium-grey, medium- to occasionally fine-crystalline, laminated dolomite with abundant interbedded carbonaceous shale and siltstone beds (up to 13 cm thickness) and laminations. The unit contains minor calcite, vein-associated brecciation and a few cavities near the base. Notable divisions include:

451.56–451.80: a very pale-grey, finely crystalline, massive dolomite, which is distinctly clean carbonate containing only minor carbonaceous material.

451.80–454.01 Dolomite breccia

A pale- to medium-grey, medium crystalline massive dolomite containing occasional laminated dolomite and shaly dolomite fragments with common, fine carbonaceous shale fragments and infillings. Bedding crudely defined in a few locations by scattered carbonaceous shale fragments. Occasional stylolite contacts and rare calcite veining and vugs near the top of sequence. Unit is formed on a mainly carbonaceous shale base (453.41–453.88). Very rare pyrite blebs.

454.01–465.41 Laminated dolomite

A grey, medium- to fine-crystalline, well to poorly laminated dolomite intercalated with numerous black carbonaceous shale and siltstone laminations. Intervals between shale laminations are relatively consistent, whilst shale bedding thickness does not exceed 612 cm. The bedding pattern is generally wavy. The dolomites appear to contain more carbonaceous material down sequence. Stylolite contacts are common whilst calcite veining is rare.

465.41–475.71 Laminated dolomite

A variable sequence consisting of grey to dark-grey, medium- to coarse- crystalline, well-laminated carbonaceous dolomite with occasional planar to wavy subhorizontal carbonaceous shale beds (to 5 cm maximum thickness). Most of the shale beds occur as discrete structureless units. fine, dark ?carbonaceous fragments are present in varying concentrations throughout and often serve to accentuate dolomite laminations which are distinctly wavy in outline. Rare, smeared pyrite occurs along slickenside shale partings. Well-formed stylolite contacts are common. Notable divisions include:

470.60–470.65: a very thin, dull-grey, extremely fine-grained horizon containing pale, scattered and altered crystals to 1–2 mm. Possibly represents distal ashfall tuff horizon.

475.31–475.61: a well-defined, dark-grey carbonaceous sequence containing a thick interbedded shale horizon located near base. Stained positive for K-feldspar.

475.71–502.25 Laminated to massive dolomite

A thick, pale- to dark-grey, medium- to coarse-crystalline, laminated to massive dolomite with irregular, wavy carbonaceous shale laminations. The shale units contain rare blebs and laminations of pyrite. The unit is characterized by common well-developed stylolitic contacts. The sequence can be subdivided on the amount of carbonaceous, and possibly clastic material present as follows:

475.71–483.04: mostly pale-grey, poorly laminated to massive dolomite with wavy carbonaceous shale laminations. Although the dolomite is occasionally carbonaceous most of the material is cleaner than overlying units. Vague laminations are wavy in outline possibly reflecting soft-sediment deformation.

483.04–502.25: This unit is very similar in style and content to 475–483.04 m. The basal contact is well defined. Bedding trends at 70° to core axis.

502.25–506.60 Shaly dolomite with thin chert bands

Grey, fine- to medium- crystalline dolomite interbedded with thin carbonaceous shale and thicker, green and black chloritic chert bands. Chert beds are numerous from 504.00–504.46, 504.76–505.27 and 505.64–506.44 m and are very finely laminated and contain very fine, disseminated pyrite. Bedding trends at 60–70° to core axis whilst bedding contacts are irregular with load cast features present. Dolomites contain variable carbonaceous material. A few thin, nonmagnetic, pink-coloured beds of undetermined mineralogy are present from 503.68–503.72 m. No magnetite was detected in the unit. Shale stained positive for K-feldspar.

506.60–512.87 Massive dolomite

A mainly pale-grey, medium- crystalline massive dolomite containing numerous well-formed stylolitic contacts and occasional carbonaceous shale beds and laminations. Shale bedding contacts are highly irregular, probably reflecting soft-sediment deformation. Contacts are reasonably well defined. Notable divisions include:

508.90–509.13: dark green to black, chloritic, finely laminated chert with some carbonaceous shale. The chert contains very finely disseminated pyrite.

512.87–516.92 Laminated dolomite

Mostly medium- to occasionally dark-grey, medium-crystalline, well-laminated dolomite containing numerous carbonaceous shale beds and laminations. Typically laminations are sinuous and wavy in outline. Also present are occasional beds and irregular clots and aggregates of carbonaceous dolomite. Bedding trends at 90° to core axis.

516.92–518.03 A mainly massive dolomite

A pale-grey to medium-grey medium- crystalline, massive to occasionally laminated dolomite sequence also containing minor chert bands. Chert dolomite contacts have been deformed following compaction. Pods and stringers of pyrite occur within chert bands. The unit contains very well-developed stylolite contacts but only rare carbonaceous shaly horizons.

518.03–521.84 Laminated dolomite, shale and BIF

An extremely variable unit consisting of medium-crystalline, pale-grey, mostly laminated dolomite with thin carbonaceous shale beds interbedded with chert and magnetite rich bands. Bedding orientations range from horizontal to 60° to the core axis, whilst bedding contacts may be planar, wavy or deformed with load casting and sedimentary dykes (at 520.13 m). Calcite and quartz veins are restricted to chert bands. Notable divisions include:

520.22–521.38: laminated dolomites
521.38–521.53: deformed cherts
521.53–521.84: laminated dolomites

521.84–522.73 BIF

A well-defined sequence of interbedded dark-green to black, mostly massive cherts with black, medium-crystalline magnetite bands and minor red-brown jasper horizons. The magnetite bands in particular are sinuous and wavy in outline and pinch and swell. Contacts with adjacent dolomite units are well defined.

522.73–524.60 Laminated to shaly dolomite

A grey, medium-crystalline laminated to massive dolomite containing common wavy carbonaceous shale laminations. Soft-sediment deformation present between 523.58–523.73 m and a few stylolites occur throughout unit. Blebs and stringers of pyrite associated with thicker shale beds. Basal contact well defined.

Marra Mamba Iron Formation
(524.60–678.90)

Appendix 2

Core log of type section of the Mount Newman Member: Hole DDH 275

339.38–339.82 (m)	Weathered shale, some iron oxide near the top
339.82–340.22	Interbedded chert and shale with some BIF in the lower few centimetres
340.22–340.70	Chert with minor BIF and shale

340.70–342.29	Dark shale, somewhat weathered near top; thin chert bands
342.29–343.50	BIF, silicate-rich in part, and chert. Core broken biscuit fashion

Top of Mount Newman Member

343.50–350.20	More continuous core of podded BIF. Appreciable magnetite in chert matrix but not commonly as distinct mesobands at first, although these appear later
350.20–357.90	Podded BIF with disseminated sulfides (?pyrite) at 350.2 m and 352 m
357.90–358.30	Chert, carbonate and minor shale; non-magnetic
358.30–362.80	BIF with carbonate mesobands and some scattered pyrite cubes; less podded than previously
362.80–363.40	Massive carbonate band with 5 cm of shale at top
363.40–367.75	Cherty BIF with two sets of bunched pods but generally fairly evenly banded
367.75–368.15	Massive carbonate with thin silicate bands
368.15–369.15	Cherty BIF, thickly banded
369.15–369.70	Well-bedded dolomite and shale
369.70–370.84	Massive carbonate with some stylolites; last 10 cm fairly well bedded
370.84–376.60	Generally flat-podded BIF; some chert mesobands 10 to 15 cm thick
376.60–377.10	15 cm black shale then massive carbonate
377.10–379.05	Evenly banded BIF with minor podding
379.05–379.25	Carbonate band
379.25–384.45	Well-mesobanded BIF with some small ovoid pods and occasional piled pods
384.45–385.65	5 cm white chert, 15 cm black shale, then interbedded carbonate and shale
385.65–386.90	BIF comprising mainly chert matrix and carbonate bands
386.90–387.65	Interbedded carbonate and shale
387.65–389.20	Massive carbonate containing thin shale beds with pyrite nodules (Shale NS 3)
389.20–398.05	BIF with carbonate mesobands and two thin beds of black shale near top. Mainly evenly banded to flat podded; some traces of riebeckite
398.05–398.17	Massive stilpnomelane with a thin white carbonate band at top
398.17–398.65	Thick-banded BIF with pyrite near base
398.65–399.38	'Shale' band comprising 7 cm chert 18 cm dark shale with carbonate 37 cm massive carbonate 8 cm silicate iron-formation
399.38–410.65	Mainly even-banded to flat-podded BIF. Some riebeckite bands, one replacing rare bunched pods. A little crocidolite at 405.20 m and some diagenetic pyrite associated with riebeckite at 405.25 m. Podding becomes more pronounced downwards; bunches and ovoid styles between 406 and 408 m
410.65–411.00	Interbedded BIF, chert and stilpnomelane
411.00–415.57	BIF, cherty near top. Some riebeckite bands
415.57–415.80	Shale, bedded near top
415.80–416.10	13 cm carbonate, then chert
416.10–419.65	Thick-banded BIF; cherts greenish, probably due to minnesotaite

Bottom of Mount Newman Member

419.65–420.80	Shale and chert

Appendix 3

Core log of type section of the MacLeod Member: Hole DDH 275

416.10–419.65 (m)	Thickly mesobanded BIF with greenish chert bands, ?minnesotaite

Top of MacLeod Member

419.65–421.05	Dark shale with white, bitter efflorescence and three white chert mesobands. Last 15 cm streaky, laminated chert.
421.05–421.30	Finely microbanded BIF
421.30–421.80	Interbedded stilpnomelane shale and white chert
421.80–423.05	BIF with above-normal content of silicate mesobands
423.05–423.65	Stilpnomelane shale with central 10 cm chert band
423.65–425.10	Silicate-rich BIF with few chert mesobands

425.10–425.85	Interbedded chert and black shale; shale beds have white efflorescence
425.85–427.65	BIF; flat-podded with greenish cherts
427.65–427.90	Magnetite-poor BIF (chert and iron silicates)
427.90–429.10	Interbedded black shale and chert. Pyrite nodules and pods at about 428.3 m
429.10–432.70	BIF; some poor in magnetite
432.70–433.80	Interbedded chert and shale
433.80–434.65	BIF; first 20 cm poor in magnetite
434.65–440.10	Interbedded black shale, chert and carbonate, some silicate-rich BIF; white efflorescence on shales
440.10–440.92	Massive chert–carbonate
440.92–443.70	Interbedded black shale and chert; some brecciation
443.70–444.20	Thickly mesobanded, magnetite-poor BIF
444.20–444.30	Black shale with white efflorescence
444.30–455.92	Greyish BIF with numerous carbonate mesobands. Thickly mesobanded at first, but becomes more thinly banded downwards
455.92–459.17	Interbedded black shale and chert with distinctive ovoid chert pods at about 456.7 and 457.7 m ('potato beds').
459.17–459.80	Very poddy chert
459.80–460.00	Black shale
460.00–460.55	Very poddy chert
460.55–460.70	Black shale
460.70–462.90	Magnetite-poor BIF with minor shale
462.90–463.30	Black shale with white efflorescence
463.30–464.40	Thickly mesobanded chert
464.40–466.00	Black shale with minor chert pods
	Base of MacLeod Member
466.00–480.75	Thickly mesobanded and podded BIF with minor shale macrobands and stilpnomelane mesobands. Riebeckite replaces chert in part.

N.B. Misplaced core blocks from 444 m onwards may have introduced minor discrepancies into the subsequent measurements.

Appendix 4

Measured section of the Nammuldi Member in the Hardey River Gorge

7.0 (m)	Chert and shaly BIF
9.0	Poorly exposed chert and shale
	Top of Nammuldi Member
15.0	BIF with flattened chert pods and stilpnomelane partings at approximately 2 m spacings
2.7	Poddy BIF, transitional to more distinctly podded BIF below
0.5	Shaly band weathering out to a natural stope
16.5	Distinctively podded BIF comprising rhythmic alternations of very podded cherty BIF and thinner shaly BIF. Most pods are almost circular in cross section. Unit is informally referred to as the 'ball-stack beds'.
12.0	Alternations of black and yellow, thickly mesobanded BIF with thinner bands of shaly BIF. Podding becomes more pronounced upwards.
0.25	Shaly bed
1.8	Podded, black and yellow BIF, thickly mesobanded
0.8	Goethite and chert; weathers out as a notch
2.0	BIF with pinch-and-swell cherts
0.5	Yellow shale
16.5	Prominent unit of black, brown and white BIF with poor definition into macrobands. Contains alternations of podded and pinch-and-swell cherts
4.0	Relatively even-banded BIF with white cherts and rare pods
13.5	Shaly BIF with thick (15 to 25 cm) chert bands. Weathers out upslope to form a cave
0.3	Shaly BIF
4.0	Poddy BIF. Pods occur as overlapping bunches and, in some instances, as discrete eyes
1.0	More weathered zone with shaly BIF and yellow chert
8.5	Poddy, thickly mesobanded BIF. Most pods are connected but some horizons have disconnected pods
0.8	Poddy BIF and shale. Pods are elliptical in cross section but elongated down dip
2.0	Thickly mesobanded BIF with flattened chert pods
0.25	Exposure gap; probable shale
2.5	Thickly mesobanded, wavy-bedded BIF with few discrete chert pods
0.25	Yellow shale

5.0	Interbedded poddy, cherty BIF and shaly BIF weathers out
0.6	Shale and cherty BIF; weathers out
1.3	Thickly mesobanded BIF
0.25	Shale and chert
2.2	Thickly mesobanded BIF; green chert at 1.2
0.5	Thinly mesobanded, shaly iron formation
4.2	Thickly mesobanded, Mn-stained BIF with shaly (?stilpnomelane) partings
0.2	Massive yellow shale (?weathered stilpnomelane)
4.0	Thickly mesobanded chert with shaly partings up to 10 cm thick
0.15	White-to-pink, well-bedded shale
1.5	Thickly mesobanded BIF with small cavities, possibly after carbonate
	Base of Nammuldi Member
1.0	White-weathering shale of Jeerinah Formation
20+	Dolerite sill