# PART 1 - THE YENEENA GROUP

# CHAPTER 1

# INTRODUCTION AND REGIONAL GEOLOGICAL SETTING

## 1.1 THE TELFER GOLD MINE - A BRIEF HISTORY

The Telfer Gold Mine (Frontispiece) is located in a very remote area of the Great Sandy Desert in Western Australia (Fig. 1.1). Geologically, the Telfer region forms part of the Paterson Province (Fig. 1.2), an area comprising a metamorphic suite and a younger, folded Proterozoic sedimentary sequence (section 1.4), within which the Telfer gold deposits occur. Due to the remoteness from population centres and the aridity, the Telfer region remained very poorly known until only a decade ago, when prospectors and mining companies began tentative explorations in the area.

The history of the discovery and development of the Telfer gold deposits has been described by Tyrwhitt (1976, 1979). Briefly, the sequence of events was as follows. Sparse auriferous gossans, which formed the surface expression of the gold deposits, were first discovered and assayed for gold in 1971. The gossans were brought to the attention of Newmont Pty. Ltd. (now Newmont Holdings Pty. Ltd.) in early 1972, and this company quickly initiated an exploration programme to assess their economic potential. By late 1975 Newmont had established that strata-bound deposits existed, containing economic concentrations of gold. In conjunction with Dampier Mining Co. Ltd. (a wholly owned subsidiary of Broken Hill Pty. Ltd.) Newmont then began the construction of a mill and small township at Telfer, and mining operations began in March 1977. The name "Telfer" was given to the project in December 1973, in honour of Mr. A.H. Telfer, a former Under Secretary for Mines in Western Australia.

When mining began published ore reserves were 3.8 m tonnes at 9.6 g Au/tonne, and at the end of 1979 reserves were 3.9 m tonnes at 8.6 g Au/tonne. The initial output from the mine increased Australia's gold production by about fifty percent, and made Telfer the largest single gold mine in the country (Australian Financial Review, 23 Nov. 1978).

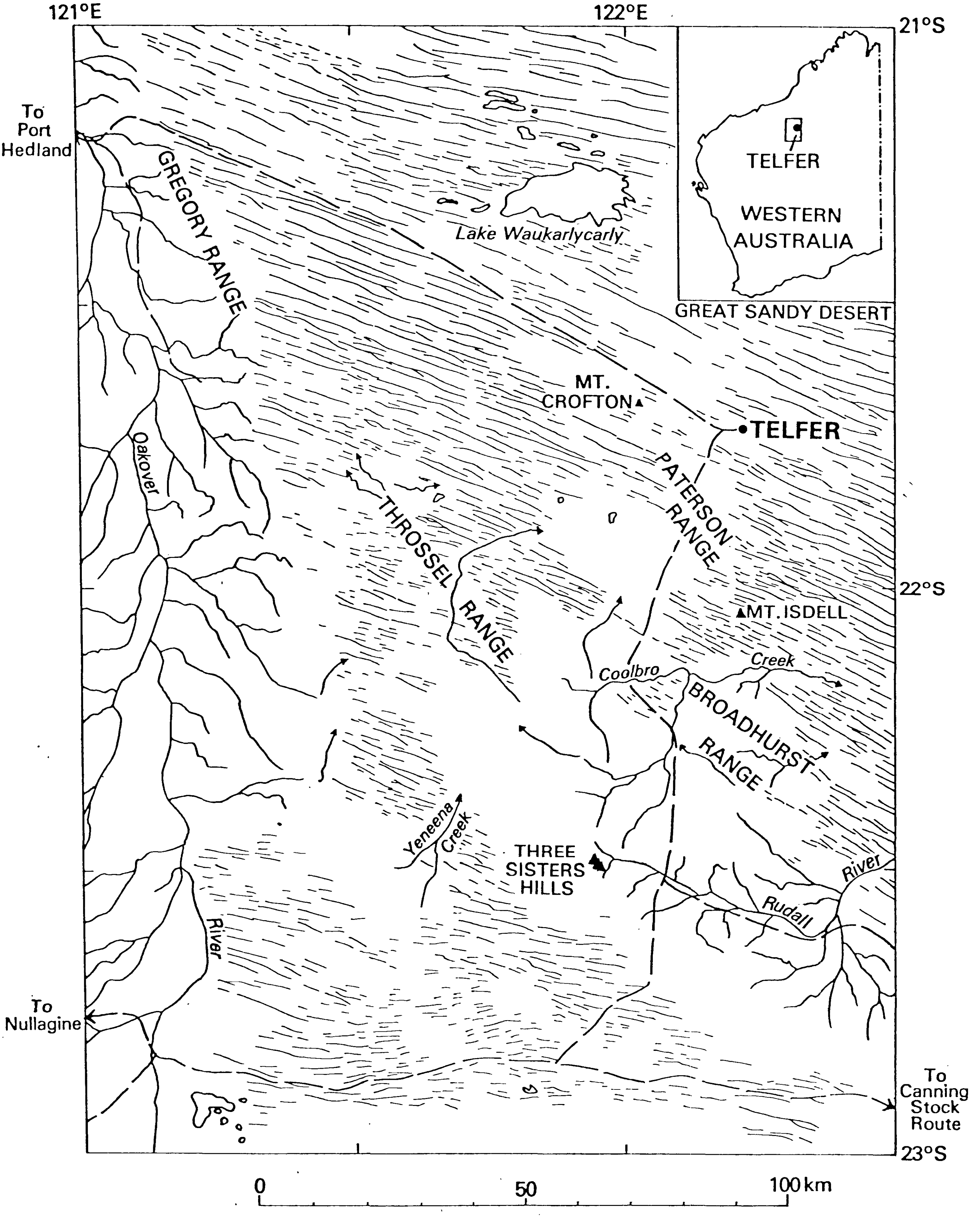


Figure 1.1 - Location of Telfer in the Great Sandy Desert, Western Australia. Drainage courses are ephemeral (arrow heads); enclosed areas - salt lakes; NW-SE features - sand dunes; dashed lines - main vehicle tracks. From 1:1,000,000 Oakover River Sheet (1977).

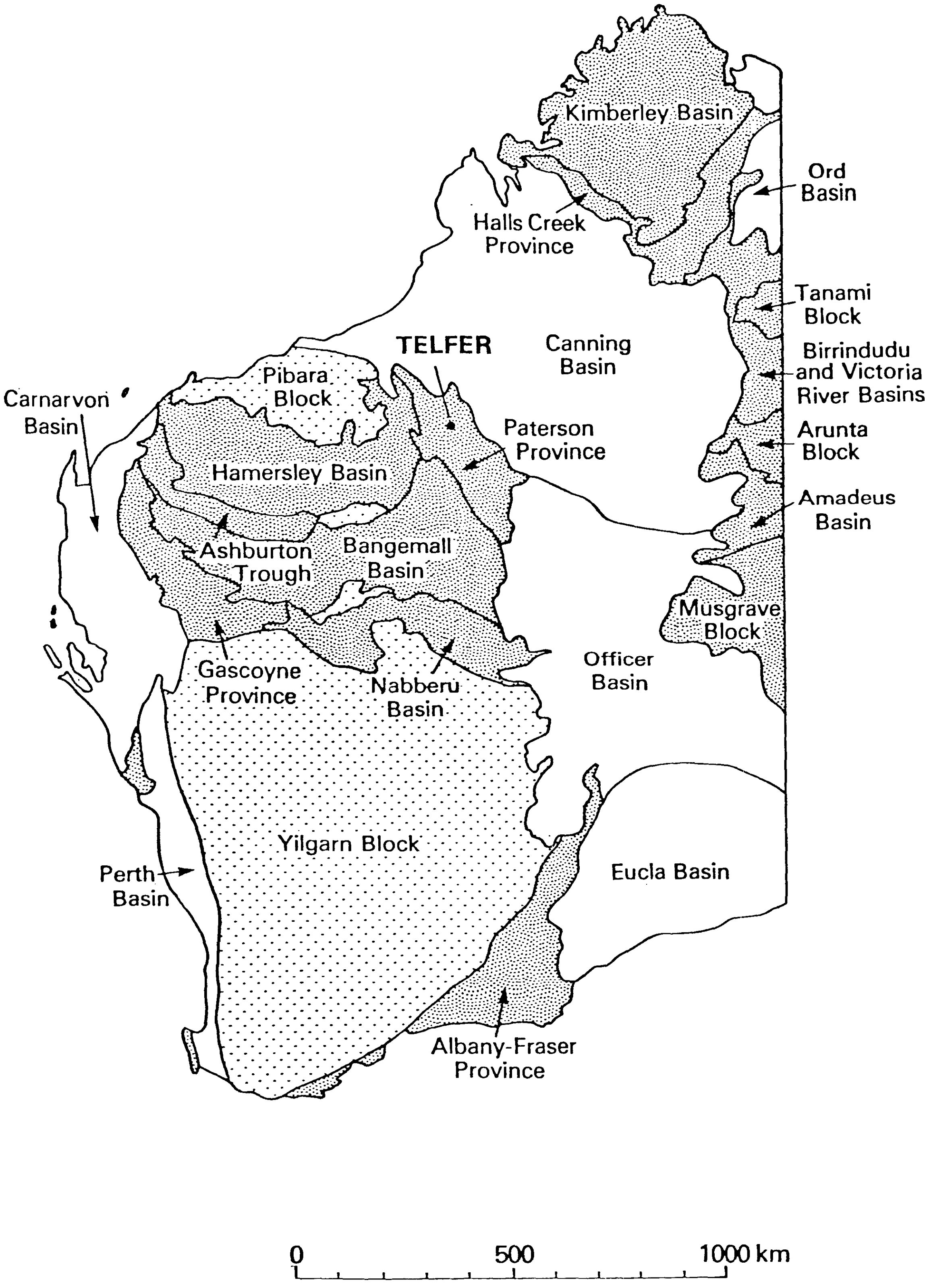


Figure 1.2 - Tectonic units of Western Australia. From 1:2,500,000 Geological Map of Western Australia (G.S.W.A., 1979). Light shading - Archaean; dark shading - Proterozoic; unshaded - Phanerozoic.

## 1.2 GEOGRAPHICAL ASPECTS

In most geological field studies the physiography and climate of the area are important factors, limiting both access and exposure. Therefore, a brief geographical description of the Telfer region is given.

Most of the region is an arid partially vegetated peneplain (Frontispiece) about 300 m above sea level (Telfer Village is at an elevation of 297 m). Low strike ridges and plateaux of Proterozoic rocks, and mesas and buttes of flat-lying Phanerozoic rocks rise above the plain up to elevations of about 100 m. Simple longitudinal sand dunes trend northwest-southeast across the plain at spacings generally between 100m and 2 km, and have heights of up to 30 m (Crowe, 1975). The main topographic features of the area and access routes are shown on Figure 1.1. In the immediate vicinity of Telfer there are no perennial streams, but 50 km to the south a few permanent pools exist in Coolbro Creek and the Rudall River (Fig. 1.1). To the north, east and south of the area shown in Figure 1.1 are the Great Sandy and Gibson Deserts, whilst to the west there is an abrupt change at the Gregory Range to the more dissected topography of the Oakover River drainage basin.

Vegetation in the area is dominated by spinifex, with low shrubs and sparse eucalypts generally less than 5 m in height (Beard, 1969). Ridges are less vegetated than the sand plains, and have rock exposures or extensive mantles of scree. Mean monthly maximum temperatures range from about 27°C in July to 42°C in January, with mean minimum temperatures of about 5°C in July and 21°C in January. Rainfall is very erratic, but probably averages less than 250 mm per year (Beard, op. cit.).

## 1.3 PREVIOUS WORK AND SCOPE OF THESIS RESEARCH

### 1.3.1 PREVIOUS WORK

Apart from the observations of a few explorers who passed through the western margin of the Great Sandy Desert towards the end of the nineteenth century (see Beard, 1969), the first geological reconnaissance in the Paterson Province (Fig. 1.2) was made by H.W.B. Talbot in 1908-09 (Talbot, 1910; cited by Chin and de Laeter, 1981). Talbot recognised two major rock sequences, an older unit of plutonic igneous and metamorphic rocks and a younger sedimentary sequence (now known as the Rudall Metamorphic Complex and the Yeneena Group respectively - see section 1.4). Further geological exploration in this area of Western Australia began in the 1940's (Wells, 1959), when interest was shown by Oil Companies in the Phanerozoic rocks of the Canning Basin, to the east of Telfer (Fig. 1.2). In 1954 a survey of the southwest Canning Basin and a reconnaissance of the adjoining Precambrian areas was carried out by the Bureau of Mineral Resources (Traves et al., 1956). This led to the publication of the first geological map of the Paterson Range area (Wells, 1959), which includes the Telfer region (Fig. 1.3). Additional traverses of parts of the Paterson Province in 1966 and 1969 by the Geological Survey of Western Australia allowed Blockley and de la Hunty (1975) to summarize the geology of the province.

The discovery of the Telfer gold deposits in 1971 stimulated further interest, and several mining companies have since carried out extensive exploration in the region. Much of the published information concerning the geology of the Paterson Province is contained in reports of the 1:250,000 scale geological map sheets shown on Figure 1.3, most of which were mapped during the 1970s. The two map areas most relevant to the present study are Paterson Range (Chin and Hickman, 1977) and Rudall (Chin et al., 1980). Williams et al. (1976) made use of this regional mapping to summarize the geology of the Paterson Province, and defined the terms Rudall Metamorphic Complex and Yeneena Group for the two major Precambrian rock sequences of the province.

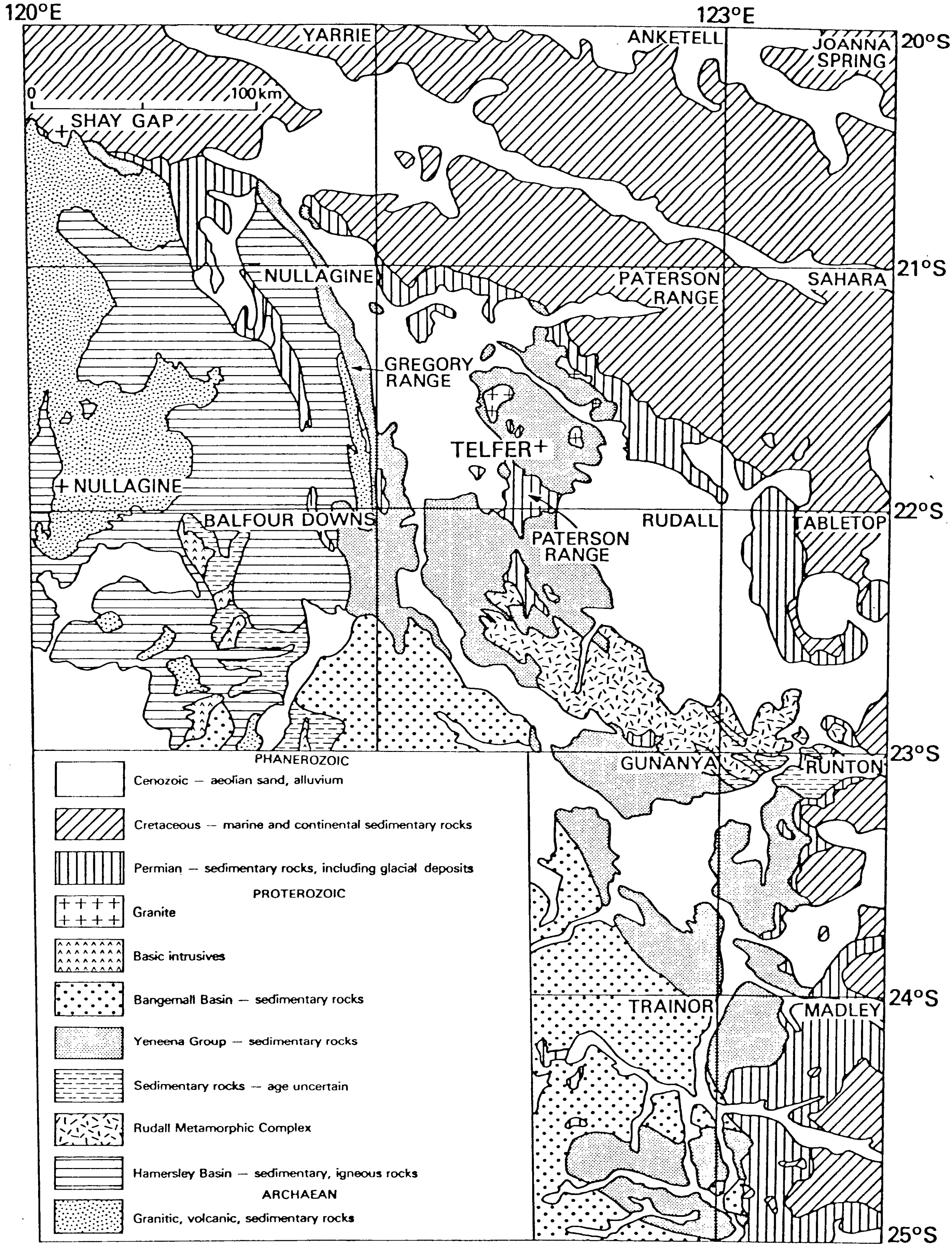


Figure 1.3 - Geology of the Paterson Province (Rudall Metamorphic Complex and Yeneena Group) and adjacent areas. From 1:2,500,000 Geological Map of Western Australia (G.S.W.A., 1979). List of individual map sheets - Table 1.1.

| | |
|---|---|
| YARRIE | - Hickman and Chin, 1977 |
| NULLAGINE | - Hickman, 1978 |
| PATERSON RANGE | - Chin and Hickman, 1977 |
| SAHARA | - Yeates and Towner, 1978 |
| BALFOUR DOWNS | - de la Hunty, 1964 |
| RUDALL | - Chin, et al., 1980 |
| TABLETOP | - Yeates and Chin, 1979 |
| GUNANYA | - Williams and Williams, 1977 |
| RUNTON | - Crowe and Chin, 1979 |
| MADLEY | - Kennewell, 1975 |

Table 1.1 Reference list of Geological Survey of Western Australia 1:250,000 scale map sheets used in the compilation of Figure 1.3.

Radiometric age determinations of about 600 million years have been reported by Trendall (1974) and de Laeter et al. (1977) for a granite which intrudes the Yeneena Group northwest of Telfer (Fig. 1.3, and section 5.3). More recently, the results of age determinations from samples of the Rudall Metamorphic Complex have been used by Chin and de Laeter (1981) to more precisely date the tectonic events of the Paterson Province. These results indicate that deposition of the Yeneena Group occurred between about 1333 and 1132 million years ago (see section 1.4).

Very little has been published on the mineralisation at Telfer. Blockley (1974) briefly examined the gold deposits during the exploration stage, and recorded the basic form of the ores as quartz-limonite reefs containing free gold, which occur conformably in a sequence of sandstone, siltstone and shale near the crests of domes or anticlines. Blockley reported that at this time Company geologists working at Telfer regarded the source of the gold as either syngenetic, being concentrated into the reefs during folding and metamorphism, or as purely epigenetic, being related to the intrusion of granite north-west of Telfer.

Capill (1977) carried out mapping around the main area of mineralisation at Telfer, and discussed the sedimentology and structure of the host rocks, and the nature of the gold deposits. He suggested that the sediments were shallow marine deposits, and that the origin of the ores, although enigmatic, may have been due to remobilisation of detrital gold from siltstone and claystone during folding, and concentration of the gold in anticlinal crests. Numerous short unpublished company reports exist, concerning various aspects of the geology of the Telfer deposits. Listing of these is impractical in the present context, but reference to specific reports is made where appropriate. Two accounts by Tyrwhitt (1976, 1979) are useful sources regarding the general geology of the Telfer deposits. A further brief account of the stratigraphic setting and nature of the gold ores was presented by Turner (1980), and a preliminary discussion of sulphur isotope values from sulphide minerals at Telfer has been given by Sun and Turner (1981). Silcrete in the Telfer region has been described recently by Turner and McKelvey (1981).

### 1.3.2 THESIS RESEARCH

The current Ph.D. research project was set up in mid 1977 (see acknowledgments), to follow on from the initial work of Newmont geologists by further elucidating the stratigraphy, sedimentology and detailed nature of the ores. The major objective was to identify the controls of mineralisation and the genesis of these unusual ores. It was hoped that this would indicate criteria on which to base further exploration for gold in the Telfer area and possibly also elsewhere.

When the research project began, mining by an open cut method had been in operation for about five months. The surface ores are entirely oxidised and consist mainly of auriferous limonite and quartz set in kaolinitic siltstone. The distribution of this ore type and its mineralogy were broadly known at this time. The oxidised ore extends to depths of between 90 m and 100 m, with pyritic mineralisation at deeper levels. Little work had been done on the textural and stratigraphical relationships between ore and host sediments. The project therefore began with the study of drill core intersections of the main Telfer ore body and the logging of sedimentary characteristics of the adjacent lithologies. Research then expanded to laboratory studies of the few unoxidised ore intersections which were available, and to stratigraphical and sedimentological field studies of the Yeneena Group over an area of some 1,200 sq km (Map 1).

The research has been as wide-ranging as practicable, it being reasoned that too restricted a line of research in an area which was relatively poorly known geologically, would be unlikely to result in reliable conclusions concerning the genesis of the mineralisation. However, two major aspects of the geology have been studied, the sedimentary rocks of the Yeneena Group and the ore deposits themselves. The first part of the thesis is essentially a sedimentological and palaeogeographical investigation of the Yeneena Group, with the main emphasis being placed on the formations which host the ores. Details of the structural geology and metamorphism are also given to provide a more complete picture of the geological history. This is followed by a description of the occurrence, mineralogy and chemistry of the gold ores, and finally, the ore genesis is discussed in relation to the geological evolution of the region.

## 1.4 TECTONIC UNITS OF NORTH CENTRAL WESTERN AUSTRALIA

The regional geological setting of the Telfer gold deposits and the Yeneena Group can be described by reference to the various tectonic units of north central Western Australia (Fig. 1.2) which have been established by the State Geological Survey (Trendall, 1975; Gee, 1979). A brief geological review of the Paterson Province and its bordering structural units is given below, but first some of the nomenclature used is explained.

The tectonic units are known by a number of terms which have been defined by Trendall (1975, p.30). A block is an area of crust, generally of complex geology, which has remained essentially stable over a very long period of time while adjacent regions have been more mobile; a province is an area in which the rocks have a geological character, or characters, in common (usually either age, metamorphic grade, structural style or type of mineralisation); and a basin is an area underlain by a thick sequence of dominantly sedimentary rocks, which possess unifying features of stratigraphy and structure.

The nomenclature of Precambrian time-stratigraphic subdivisions used in the following discussion is that adopted by the Geological Survey of Western Australia in 1965 (Trendall, 1975, p.26). It is unnecessary here to review the numerous papers dealing with the complexity of Precambrian time-stratigraphic terminology (e.g. James, 1978), as the nomenclature used below merely facilitates the distinction of the broad age relationships between the major stratigraphic units of north central Western Australia. Archaean refers to rocks with age dates greater than about 2,500 m.y. (James, 1978; G.S.W.A., 1979). Lower Proterozoic refers to the approximate time span 2,500-1,750 m.y., Middle Proterozoic to the time span of about 1,750-1,000 m.y. and Upper Proterozoic to the interval from about 1,000 m.y. to the base of the Cambrian (about 600 m.y. - G.S.W.A., 1979). The ages 1,750 m.y. and 1,000 m.y. are those used by

Goode (1981) in a recent review of the Proterozoic geology of Western Australia.

### 1.4.1 HAMERSLEY BASIN

This is the oldest tectonic unit adjacent to the Paterson Province, and comprises Lower Proterozoic volcanic and sedimentary rocks which rest unconformably on the southern and eastern borders of the Archaean Pilbara Block (Fig. 1.2). Parts of the basin have been studied in detail, due to the presence of vast iron ore reserves in the central part of the sequence. A review of the geology and of previous studies was given by Trendall (1975), and the nature of the basin has been further defined by Gee (1979) and by Goode (1981).

The Fortescue Group is the oldest unit of the Hamersley Basin, and comprises a very extensive sequence of basaltic lavas, with subordinate shale, siltstone and dolomite. Conformably overlying the Fortescue Group is the Hamersley Group. This is dominated by sedimentary rocks, but thick dolerite sills and acidic lava flows and tuffs also occur in places. Iron formation is the dominant sedimentary rock in the central and western parts of the basin (Trendall, 1973), followed in abundance by shale and dolomite. Together, the Hamersley and Fortescue Groups form a stable shelf assemblage about 6 km thick, which covers the southward and eastward extensions of the Pilbara Block (Gee, 1979).

Much of the eastern part of the Hamersley Basin, bordering the Paterson Province, has been mapped and described by Hickman (1978). The Fortescue Group dominates the sequence in this area, with flood basalts forming much of the group. However, felsic lavas, pyroclastics and an associated granophyre body occur at the base of the group along the eastern flank of the Gregory Range (Fig. 1.3), where the lavas overlie a granitic complex of probable Archaean age (Hickman, 1978; de Laeter et al., 1977). The Hamersley Group in this eastern area consists of a single formation, the Carawine Dolomite. This formation is up to 200 m thick, and comprises well bedded grey dolomite, which commonly contains thin interbeds of chert (de la Hunty, 1964; Hickman, 1978).

### 1.4.2 PATERSON PROVINCE

The geology of this remote arid area (Fig. 1.2) was first synthesized by Blockley and de la Hunty (1975), but at that time no detailed geological mapping had been carried out in the area. However, much of the area has subsequently been mapped on a regional basis (e.g. Williams et al., 1976; Chin and Hickman, 1977; Chin et al., 1980), and the geology can now be summarised as follows.

The province has a dominant northwesterly structural trend, and comprises two major geological divisions, the Rudall Metamorphic Complex and the overlying Yeneena Group (Williams et al., 1976). The Rudall Metamorphic Complex (Fig. 1.3), named after the Rudall River (Fig. 1.1) has not been examined in detail by the writer, and the following summary is based on the reports of Chin et al. 1980, Crowe and Chin (1979), Yeates and Chin (1979) and Chin and de Laeter (1981).

Two metamorphic sequences form the complex, an older sequence of strongly deformed gneissic and granitic rocks, and a younger metasedimentary sequence of quartzite and quartz-mica schist. The older sequence includes metasedimentary rocks which were probably originally greywacke and arkose, hornblende-plagioclase gneiss derived from basalt or dolerite, ultramafic gneiss, and banded quartzite representing metamorphosed chert. All of these lithologies occur in small isolated belts "enclosed in a sea of quartz-feldspar-biotite (-muscovite) gneiss" (Chin et al., 1980, p.7). This granitic gneiss probably represents intrusions into a previously metamorphosed sequence.

The younger metasedimentary sequence of the Rudall Metamorphic Complex is dominated by massive and laminated medium grained metaquartzite, in which rare cross bedding is preserved. Strongly deformed conglomerate and sandstone were the original sedimentary rocks. There is a gradational sequence from quartzite through quartz-muscovite schist to muscovite (-quartz) schist, derived from more pelitic sediment. Graphitic schist, banded quartz-magnetite rocks derived from iron formation, banded marble, metabasalt and metadacite are minor constituents of the younger sequence.

The age of the older gneissic and granitic sequence of the Rudall Metamorphic Complex has not been firmly established, due to the later metamorphic effects, but Chin et al. (1980) pointed out that this sequence closely resembles Archaean gneissic terrains elsewhere in Western Australia. They suggested that the granitic gneiss of the older sequence was the metamorphic equivalent of the granitic rocks in the Gregory Range (Fig. 1.3), dated by de Laeter et al. (1977) as 2,651 ± 60 m.y. The metasediments and metavolcanics of the older suite therefore pre-date this age (Chin and de Laeter, 1981). The younger metasedimentary sequence was deposited during the Early or Middle Proterozoic, and was deformed and metamorphosed at about 1,333 ± 44 m.y. (Chin and de Laeter, op. cit.).

The Yeneena Group, named after Yeneena Creek (Fig. 1.1), is a folded slightly metamorphosed sedimentary sequence totalling about 9,000 m in thickness. It unconformably overlies the Rudall Metamorphic Complex and the Gregory Range igneous complex at the eastern margin of the Hamersley Basin (Fig. 1.3). The group is best known in the Rudall and Paterson Range map areas, where eight formations have been established (Chin and Hickman, 1977; Chin et al., 1980). The three oldest formations are here informally termed the lower Yeneena Group (described in Chapter 2), and the five younger formations are called the upper Yeneena Group (Chapter 3). To the south of the Rudall Metamorphic Complex, formations within the Yeneena Group have not been recognised, due to the relatively sparse isolated nature of the outcrops (Williams and Williams, 1977; Crowe and Chin, 1979).

The Yeneena Group post-dates the second metamorphic event of the Rudall Metamorphic Complex, and is therefore younger than 1333 ± 44 m.y. (Chin and de Laeter, 1981). An upper age limit of the group is given by the fact that it is overlain by the Bangemall Group, which is dated as about 1100 m.y. (Gee, 1979). The Yeneena Group is therefore of Middle Proterozoic age. The age of the deformation and metamorphism of the Yeneena Group is possibly about 1132 ± 21 m.y. (Chin and de Laeter, op.cit.), which is the date obtained from pegmatite cutting the Rudall Metamorphic Complex, that Chin and de Laeter suggest may have been generated during this metamorphic event.

To the northwest of Telfer (Fig. 1.3) the Yeneena Group has been intruded by granite (see Chapter 5) which has been dated as close to 600 m.y. (Trendall, 1974; de Laeter et al., 1977).

A few small dolerite bodies intrude the Yeneena Group throughout its outcrop area. Field relationships are generally obscure, and none of these intrusions has been studied in detail. The closest intrusion to Telfer was reported by Chin and Hickman (1977) as 30 km east-northeast of the mine.

A further Precambrian sedimentary unit occurs in the Paterson Province to the southeast of the Rudall Metamorphic Complex (Fig. 1.3). This is termed the Karara Beds by Williams et al. (1976) and Karara Formation by Crowe and Chin (1979). The unit is approximately 2000 m thick, and comprises conglomerate, sandstone, siltstone, shale and dolomite. The formation is of uncertain age, but it unconformably overlies both the Rudall Metamorphic Complex and the Yeneena Group, and may correlate with the Bangemall Group (Crowe and Chin, 1979).

### 1.4.3 BANGEMALL BASIN

The Bangemall Basin is the youngest Proterozoic basin in the Western Australian Shield (Gee et al., 1976), being dated as between 1000 and 1100 m.y. (GSWA, 1979). The basin is an arcuate east-west trending structural unit to the southeast of the Paterson Province (Fig. 1.2). It consists of a single sedimentary sequence, the Bangemall Group. The geology was reviewed by Daniels (1975a) and Gee (1979), and more detailed descriptions have been given by Brakel and Muhling (1976), Williams et al. (1976) and Goode and Hall (1981).

The Bangemall Group consists of dolomite, sandstone, shale, chert, tuffaceous sandstone, acidic volcanic rocks, conglomerate and breccia, which form a sequence up to 6700 m thick (Daniels, 1975a). In the west of the basin some of the lower sedimentary units have been interpreted as terrestrial deposits, and the remainder of the sediments in the central and western areas were deposited in various shallow marine and shelf environments (Brakel and Muhling, 1976). Williams et al. (1976) also invoked shelf deposition for the formations in the eastern Bangemall Basin, and in the same region Goode and Hall (1981) recognised basal sandstones of shallow marine or coastal aeolian origin and an upper sequence of probable deltaic origin.

The Bangemall Group overlies most adjacent Precambrian units of the shield with marked unconformity. However, the nature of the contact with the Yeneena Group of the Paterson Province is not entirely clear. Chin et al. (1980, p.14) suggested that the Bangemall Group unconformably overlies the Yeneena Group, but Goode and Hall (1981) postulated that the two groups are of equivalent age. The Balfour Downs area to the west of the Rudall area (Fig. 1.3) is currently being remapped by the Geological Survey of Western Australia, which may assist in resolving this uncertainty.

### 1.4.4 PHANEROZOIC BASINS

To the east and north of the Paterson Province thick sequences of flat-lying sedimentary and minor volcanic rocks of Phanerozoic age occur in the Officer and Canning Basins (Fig. 1.2). The Officer Basin contains about 1000 m of such rocks, comprising Ordovician volcanics, younger Palaeozoic sediments and Cretaceous sediments (Playford et al., 1975). From borehole data and aeromagnetic and gravity surveys these authors estimated that about 4500 m of Precambrian (probably Upper Proterozoic) sedimentary rocks unconformably underlie the Phanerozoic sequence in this basin.

The Canning Basin is the largest sedimentary basin in Western Australia, and contains Ordovician to Cretaceous sedimentary rocks, dominantly of marine origin, which may exceed 13,000 m in aggregate thickness (Playford et al., 1975). Permian glacigene sediments extend westwards from the Canning Basin to cover patches of the Paterson Province (Fig. 1.3). The geology of the onshore part of the Canning Basin has been described by Horstman et al. (1976) and by Playford et al. (1975), and details of the sedimentary sequence immediately east of the Paterson Province have been given by Yeates and Towner (1978) and Yeates and Chin (1979). In all of these publications, the Phanerozoic - Precambrian basement contact, immediately east of the

Paterson Province, is shown as a planar surface which dips gently to the northeast. However, in the northeast and the northwest of the Canning Basin the basement contact is faulted, and deep Phanerozoic sub-basins occur.

## 1.5 GRAVITY DATA

The Telfer region lies on a major north-northwest trending gravity high (Fig. 1.4), termed the Anketell Regional Gravity Ridge by Fraser (1976). The ridge is about 120 km wide, and near Telfer the maximum Bouguer Anomaly value is about +25 mGals. To the northwest the gravity values increase and the ridge trends offshore across the continental shelf. Southeastwards the gravity values are lower, but the ridge can be traced as far as the Blackstones Regional Gravity Ridge in central Australia (Fraser, 1976). To the east of the ridge in the Telfer region is a regional gravity low corresponding to the Canning Basin, and to the west is a complex gravity low extending across the eastern Hamersley Basin and the Pilbara Block (Fig. 1.4). The gravity ridge does not reflect the surface geology as it corresponds to the Yeneena Group fold belt in the Telfer area. Such a thick sequence of sediments would be expected to result in a gravity low. The gravity ridge must therefore reflect the deeper crustal structure beneath the Yeneena Group.

The western edge of the ridge passes along the eastern side of the Gregory Range and crosses the Rudall Metamorphic Complex to the southeast (Fig. 1.4). The contrast between the ridge and the complex gravity low to the west is very pronounced. This indicates that the basement beneath the Yeneena Group is unlikely to be similar to the eastern Hamersley Basin (Lower Proterozoic volcanics and sediments overlying Archaean rocks).

The most likely explanation for the gravity high is that the Yeneena Group is underlain by a metamorphic mobile belt, of which the Rudall Metamorphic Complex forms a small part. However, the exposed area of the Rudall Metamorphic Complex lies on the flank of the gravity ridge, where gravity values are not particularly high. The postulated extension of this metamorphic complex beneath the Yeneena

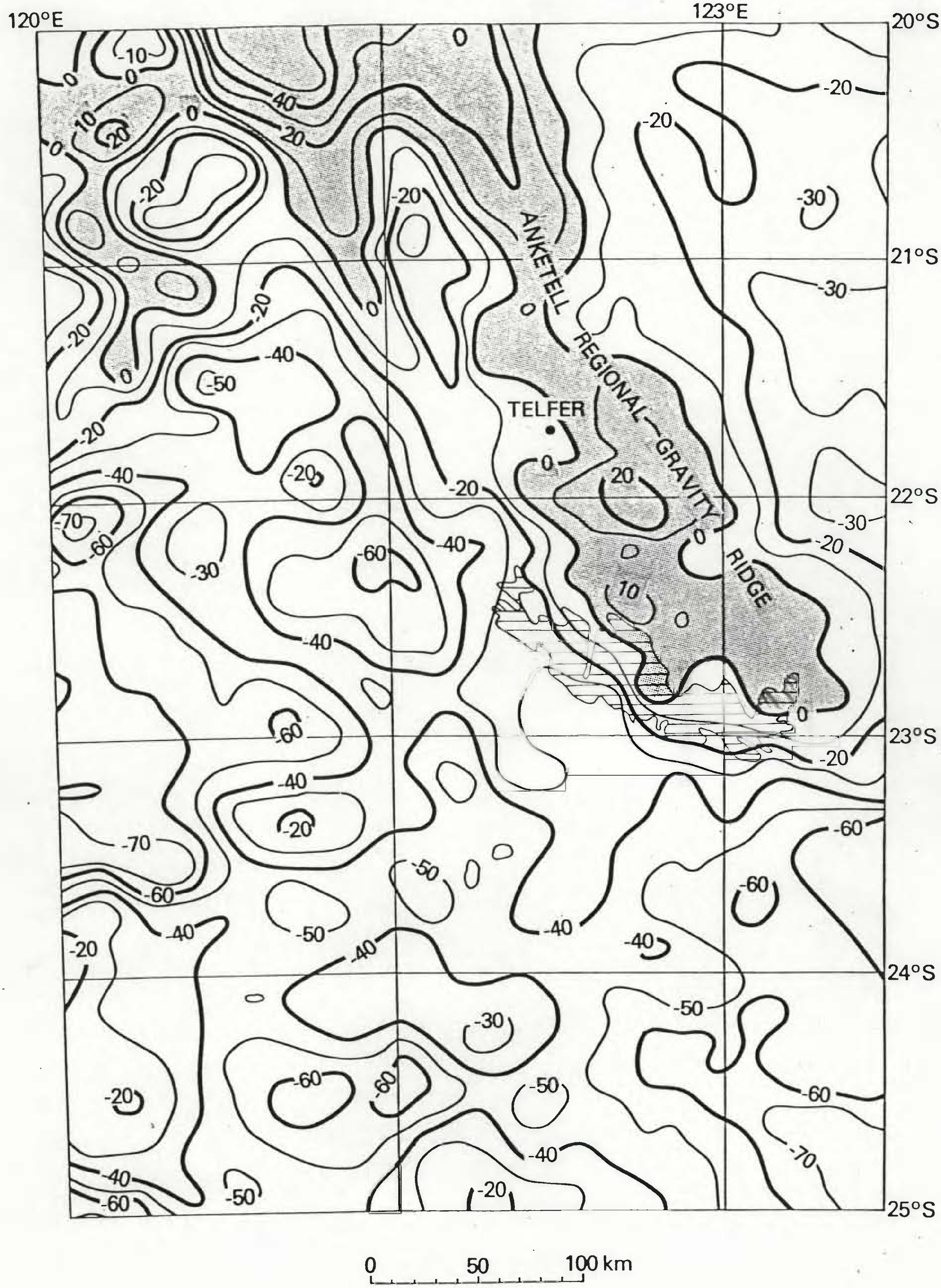


Figure 1.4 - Bouguer Anomaly map of area shown in Figure 1.3. Contour interval 10 mGals; dark shading, greater than 0 mGals; lined area, Rudall Metamorphic Complex. From BMR 1:5,000,000 Gravity Map of Australia (1976).

Group must therefore either include denser rocks than in the exposed area, or represent a thinner crustal sequence than on either side of the ridge. Chin et al. (1980) indicated that thrust faults which dip northeastwards occur along the southwest margin of the Rudall Metamorphic Complex, and invoked crustal upthrusting to account for the gravity high.

Upfaulting of the entire crust, and consequent crustal thinning, has also been deduced for the southeastwards extension of the gravity high (the Blackstone Regional Gravity Ridge) in central Australia (Mathur, 1976). Here, the gravity ridge occurs over the Proterozoic Musgrave Block, which includes high grade metamorphic rocks, metamorphosed sedimentary and igneous rocks, and a major basic and ultrabasic intrusive igneous complex (Daniels, 1975b). Gee (1979) has referred to this continuous ridge of high gravity as the Paterson-Musgrave belt.

# CHAPTER 2

# STRATIGRAPHY AND SEDIMENTOLOGY OF THE LOWER YENEENA GROUP

## 2.1 INTRODUCTION

In the Rudall and Paterson Range map areas (Fig. 1.3) the Yeneena Group has been subdivided into eight formations by the Geological Survey of Western Australia (Fig. 2.1 and section 1.4.2). The lower three formations are geographically and geologically distinct from the higher units (which are considered in the following chapter), and are here termed the lower Yeneena Group. These three formations are the Coolbro Sandstone (dominantly sandstone, with minor conglomerate), the Broadhurst Formation (mainly shale and siltstone) and the Choorun Formation (conglomerate, sandstone, siltstone and shale) (Fig. 2.1).

The lower Yeneena Group differs significantly from the upper Yeneena Group (in which the Telfer gold deposits occur), as will become apparent in the following chapters. The inclusion of the lower Yeneena Group in this study is to provide a comprehensive view of the sedimentary basin development. Also, since the Telfer gold deposits were discovered, several mining companies have carried out explorations for metalliferous deposits in the area of the lower Yeneena Group. Thus, any new data on this area may have potential economic importance.

The descriptions and brief interpretations below are based on the examination by the writer of specific localities, and on the regional mapping of the Geological Survey. More extensive discussions of the palaeocurrents, depositional processes and sedimentary environments are given in Chapter 4.

The three formations were defined and mapped by Chin et al. (1980) in the Rudall map area (Fig. 2.2), and the terminology of these authors is retained here. However, their threefold subdivision may be rather misleading, as the writer considers it possible that the area mapped as the Choorun Formation is in fact part of the Coolbro Sandstone (see section 2.2). As mapped by the Geological Survey, the

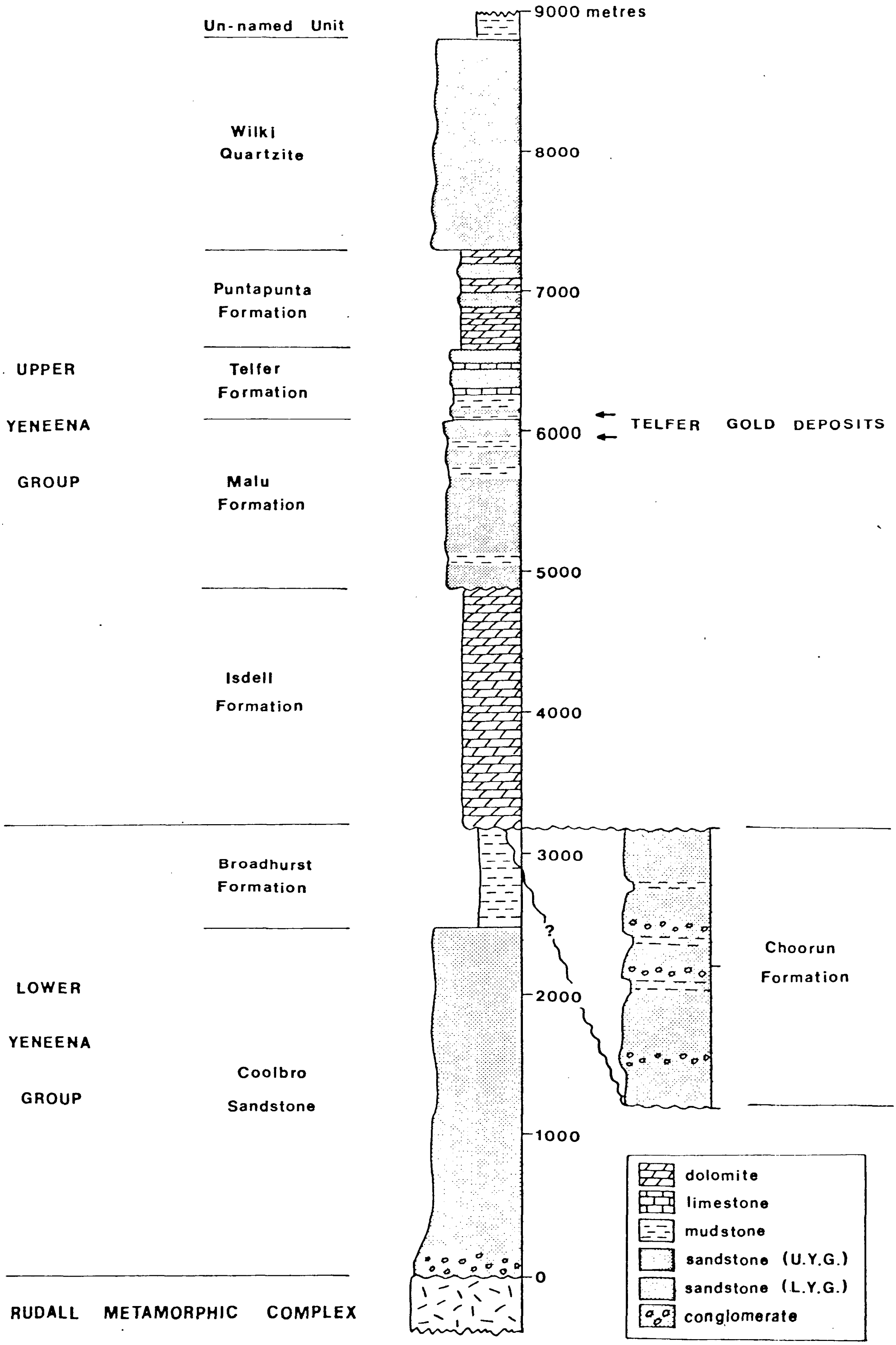


Figure 2.1 - Stratigraphy of the Yeneena Group in the Rudall and Paterson Range map areas.

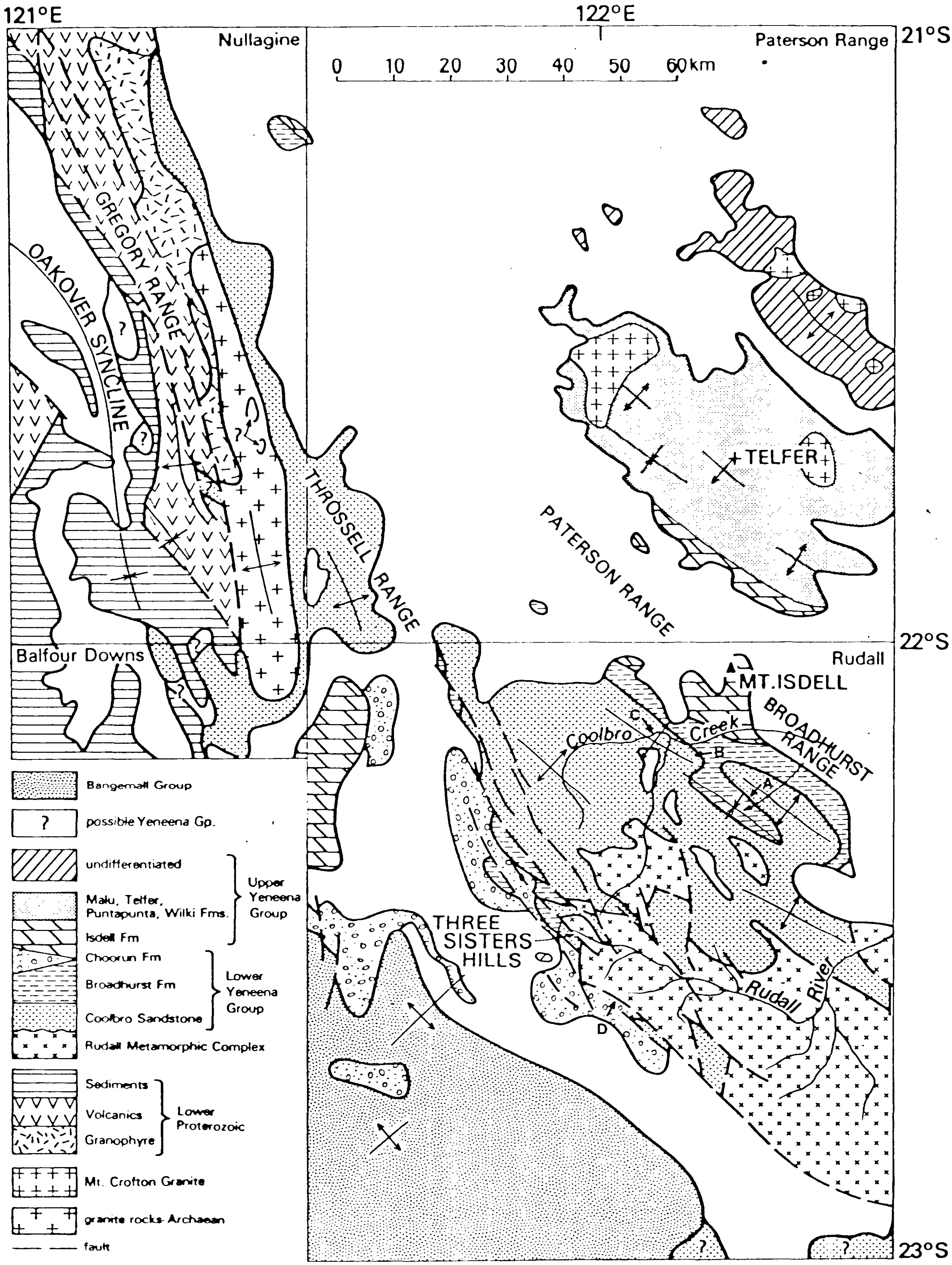


Figure 2.2 - Precambrian rocks of the Telfer - Rudall River - Gregory Range area. Same area as Figure 1.1. Modified from de la Hunty (1964), Chin and Hickman (1977), Chin et al., (1980) and Hickman (1978).

formations are restricted to the area adjacent to the Rudall Metamorphic Complex, and to the west and northwest of these older rocks (Fig. 2.2).

## 2.2 STRATIGRAPHY

The Coolbro Sandstone forms the lowest unit of the Yeneena Group, and unconformably overlies a variety of older rocks, as outlined below. However, the actual contacts are rarely exposed. The Rudall Metamorphic Complex is overlain by basal conglomerate of the Coolbro Sandstone (see section 2.3.1) at a few localities in the Rudall and Gunanya map areas (Chin et al., 1980; Williams and Williams, 1977); and farther east, in the Runton and Tabletop map areas (Fig. 1.3), these metamorphic rocks are overlain by sandstone, which is correlated with the Coolbro Sandstone (Crowe and Chin, 1979; Yeates and Chin, 1979). To the west, in the Balfour Downs map area (Fig. 1.3), Archaean granite and Lower Proterozoic sedimentary and volcanic rocks are unconformably overlain by conglomerate. This was termed the Googhenama Conglomerate by de la Hunty (1964), but has been correlated with the basal unit of the Coolbro Sandstone by Chin et al. (1980). Finally, in the Nullagine map area (Fig. 1.3), the Archaean and Lower Proterozoic rocks of the Gregory Range are in places unconformably overlain by sandstone, termed the Bocrabee Sandstone by Hickman (1978), but correlated with the Coolbro Sandstone by Chin and Hickman (1977).

The thickness of the Coolbro Sandstone is difficult to estimate due to extensive deformation of the formation (Chapter 5), but Chin et al. (op. cit.) indicated a maximum thickness of 4,000 m along a north-westerly trending axis passing through the Broadhurst Range (Fig. 2.2). However, this figure may well be an overestimation; 2,500 m is a more realistic thickness for the formation immediately south of the Broadhurst Range, based on the map of Chin et al. (op. cit). These authors also reported that the formation thins rapidly to the northeast and southwest, but the cause of this was not discussed. Thinning to the northeast is difficult to demonstrate, as the base of the formation is not exposed, and along the southwest side of the Rudall Metamorphic Complex extensive faulting (Fig. 2.2) hampers thickness estimations.

The Coolbro Sandstone is conformably overlain by the Broadhust Formation in the Broadhurst Range. At locality A on Figure 2.2 this relationship can be observed in vertically dipping beds (Plate 2.1A), where coarse grained quartzose sandstone of the Coolbro Sandstone passes upwards through a poorly exposed 7 m thick unit of fine grained sandstone and siltstone, to shale of the Broadhurst Formation.

Elsewhere, the Broadhurst Formation has been mapped on the southwest side of the Rudall Metamorphic Complex (Chin et al., 1980), and as a small area in the northeast of the Nullagine map area (Fig. 2.2). Hickman (1978) included this latter outcrop as part of the Wandy Wandy Shale, but Chin and Hickman (1977) correlated it with the Broadhurst Formation.

The thickness of the Broadhurst Formation in the Broadhurst Range is probably between 500 m and 1000 m (Chin et al., 1980), but in the Three Sisters Hills area (Fig. 2.2) on the southwest side of the Rudall Metamorphic Complex, a thickness of only 40 m was estimated by these authors. The reasons for this disparity are unclear, but the writer suspects that the thin shale unit in the latter area is either not part of the Broadhurst Formation, and instead is a fine grained member of the Coolbro Sandstone, or that it is a fault slice of the Broadhurst Formation.

The Choorun Formation is restricted to the southwest side of the Rudall Metamorphic Complex, where it reaches a thickness of 2000 m (Chin et al., op. cit.). It is in fault contact with the Rudall Metamorphic Complex and the Coolbro Sandstone, but it apparently overlies the 40 m thick shale unit of the (?) Broadhurst Formation discussed above (Chin et al., op. cit.). The geographic location of the Choorun Formation (Fig. 2.2), the lithological similarities with the Coolbro Sandstone, and the uncertain (faulted) stratigraphic relationship between these two formations, suggests to the writer that the Choorun Formation may actually be part of the Coolbro Sandstone. However, this uncertainty cannot be resolved without further extensive field work, which is beyond the scope of the present study.

## 2.3 SEDIMENTOLOGY

### 2.3.1 COOLBRO SANDSTONE

Lithology. The Coolbro Sandstone can be divided lithologically into two units, a basal conglomerate, and an overlying very thick monotonous sequence of sandstone, the type locality of which is in the headwaters of Coolbro Creek (Chin et al., 1980). The basal conglomerate has not been studied by the writer, and the following descriptions are based on scant published data. However, several exposures of the sandstones have been examined in some detail by the writer.

In the Rudall map area Chin et al. (op. cit.) stated that lenses up to 20 m thick of unstratified conglomerate with a maximum clast size of 50cm, occur at the base of the unit. These lenses are overlain by an unspecified thickness of interbedded conglomerate (with a maximum clast size of 15 cm) and feldspathic and micaceous sandstone. Clast lithologies are dominated by quartzite and vein quartz, with fewer clasts of other lithologies from the underlying Rudall Metamorphic Complex. Both clast size and conglomerate bed thickness decrease upward from the unconformity.

In the Gunanya map area, south of the Rudall area (Fig. 1.3), Williams and Williams (1977) describe a basal conglomerate and sandstone unit up to 250 m thick. The conglomerate here is poorly sorted. It has a matrix of micaceous sand, and contains clasts that range in size from pebbles to large cobbles, which were locally derived from the underlying metamorphic rocks. Basal conglomerate in the Balfour Downs area, to the west of the Rudall area (Fig. 1.3), has a maximum thickness of 100 m (de la Hunty, 1964). Clasts of unspecified lithology grade in size upwards from as much as 1 m at the base to fine pebble grade at the top. In the adjoining Nullagine map area (Fig. 1.3) a thin conglomerate, containing chert and quartzite clasts, occurs at the base of the Coolbro Sandstone (Hickman, 1978).

The bulk of the Coolbro Sandstone, which gradationally overlies the basal conglomerate, comprises moderately well sorted fine to coarse grained quartzose and micaceous sandstone. In many areas the bedding is poorly defined due to recrystallisation or to a pervasive schistosity (Chapter 5), but some outcrops, particularly in the upper part of the formation, have well developed bedding and sedimentary structures. At exposures examined by the writer and described below, the sandstone is medium to very thick bedded and sedimentary structures include cross bedding, parallel stratification with parting lineation, convolute bedding and apparently massive bedding.

At localities A, B and C on Figure 2.2 cross bedding most commonly occurs in fine to medium grained sandstone as solitary tabular sets (Alpha cross bedding of Allen, 1963). The bases of sets are non-erosional and planar, and set thicknesses vary from about 25 cm to 80 cm (Plates 2.1B and 2.1C). Most foresets are planar and dip at angles of 25°-30°, but some are slightly concave upward. Beds overlying and underlying the solitary cross sets are either parallel laminated or apparently massive. Less commonly, stacked sets of unidirectional planar tabular cross bedding occur (Allen's (1963) Omikron cross bedding) with individual sets varying from 5 cm to 15 cm thick. At locality A (Fig. 2.2) stacked sets of trough cross bedding (Allen's (1963) Pi cross bedding) occur in a 5 m thick medium to coarse grained sandstone unit. The trough sets are unidirectional, up to 1 m across in plan view, and are mostly 15 cm to 20 cm thick. At a few isolated localities faint low angle cross stratification also occurs.

Parallel lamination is probably more abundant in the Coolbro Sandstone than cross bedding, but the two structures commonly occur in close association. Parallel lamination occurs in beds up to 1 m thick, which have a flaggy appearance in outcrop. Parting lineation is commonly well developed on bedding surfaces within these beds, and is orientated sub-parallel to the dip of any associated cross bedding.

At locality B (Fig. 2.2) convolute bedding occurs at several positions in a 100 m thick section of fine to medium grained sandstone, associated with flaggy parallel laminated beds and solitary tabular cross sets. The convolutions occur as bulbous convex-downwards folds in beds about 30 cm thick (Plate 2.1D).

In other areas, cross bedding has been noted in the Coolbro Sandstone at the Throssell Range (Fig. 1.1) (Chin and Hickman (1977), in the Balfour Downs areas (de la Hunty, 1964), in the Runton area (Crowe and Chin, 1979) and in the Tabletop area (Yeates and Chin, 1979). However, none of these authors describe the nature of the cross bedding.

Other, minor lithologies within the Coolbro Sandstone include units of dark grey massive and fissile silty mudstone and shale, up to 40 m thick, to the south of the Broadhurst Range, and thin dolomite, interbedded with siltstone and clayey sandstone, in the southeast of the Rudall map area (Chin et al., 1980). In the Throssell Range (Fig. 1.1) thin shales also occur (Chin and Hickman, 1977, p.6). An extensive sill of gabbro and dolerite intrudes the formation on the eastern side of the Gregory Range (Hickman, 1978).

Mineralogy and micropetrography. A few sandstone specimens from this formation have been examined in detail by the writer. Mineralogically all of these specimens are arenites, containing less than 15% matrix material with a grain size less than 0.03 mm (e.g. Pettijohn et al., 1973, p.158). Medium to coarse grained quartz arenite (e.g. TEL 638 - Table 2.1) and fine grained sericitic subarkose (e.g. TEL 767 - Table 2.1) are the typical sandstone lithologies of the formation. Trace constituents include detrital grains of tourmaline, iron oxides and zircon. Sericite, representing recrystallised clay minerals, is ubiquitous, but is more voluminous in the finer grained rocks than in the medium to coarse grained quartz arenites.

The sandstones have been metamorphically recrystallised to varying degrees in different locations. For example, specimen TEL 638, (Table 2.1) is slightly schistose, and comprises quartz grains with serrated intergrown boundaries, and interstitial sericite and haematite. Much of the detrital texture has been destroyed, but an originally unimodal sandstone, with sand grains having a fair degree of roundness, is suggested by the patches of least recrystallisation. Isolated aggregates up to 0.5 mm across of fine grained sericite may represent original shale chips, but no other rock fragments occur. In

| Formation | Sample | Lithology | Quartz | Sericite | Kaolinite | Chlorite | Plagioclase | K-feldspar | Haematite |
|---|---|---|---|---|---|---|---|---|---|
| Coolbro Sandstone | TEL 638 | Quartz arenite | 90 | 6 | 2 | - | 1 | - | 1 |
| Coolbro Sandstone | TEL 767 | Subarkose | 78 | 12 | 5 | - | 4 | 1 | - |
| Broadhurst | TEL 772 | Siltstone/Claystone | 46 | 43 | - | 8 | 1 | 2 | - |
| Choorun | TEL 760 | Subarkose | 72 | 6 | 1 | - | 2 | 18 | 1 |
| Choorun | TEL 761 | Quartz-rich arenite | 87 | 6 | 4 | - | 2 | 1 | - |
| Choorun | TEL 762 | Quartz-rich arenite | 91 | 2 | 5 | - | 2 | - | - |

Table 2.1 Approximate mineral compositions of samples from the lower Yeneena Group, estimated from X-ray diffraction scans.

contrast, specimen TEL 767 (Table 2.1) is well sorted fine grained sericitic subarkose, in which grain boundaries are better preserved, indicating originally rounded or subrounded grains.

Interpretation. A rigorous interpretation of the Coolbro Sandstone is precluded by the limited amount of sedimentological work carried out on the formation. However, the sedimentary structures described above can be interpreted in terms of depositional processes, and a depositional environment can then be suggested for the units containing these structures.

The tabular cross beds can be interpreted as the deposits of migrating straight crested sand waves, and the trough cross bedding as the result of migrating dunes (e.g. Harms et al., 1975, pp.46-49). The parallel lamination indicates deposition from flows with higher velocities than those required for the formation of sand waves or dunes, the deposition occurring from upper flow regime conditions (e.g. Simons et al., 1965). The convolute bedding can be interpreted as the result of incipient slumping or de-watering of a sandstone bed.

These depositional processes could all have occurred in a sandy braided fluvial system. A limited range of palaeocurrent directions exists (see Chapter 4) which would be consistent with such an interpretation. However, it is uncertain whether the entire Coolbro Sandstone was deposited in a fluvial environment, or whether some of the sediments could be of shallow marine origin (see Chapter 4).

2.3.2 BROADHURST FORMATION

Lithology. The Broadhurst Formation is essentially a shale unit, some of which is highly carbonaceous, and some of which has a high iron content. In the type locality of the Broadhurst Range Chin et al. (1980, p.12) described the formation as follows. "The main lithology is well bedded and laminated, fissile micaceous siltstone and shale. Some of the shale is carbonaceous. Thin interbeds of fine micaceous sandstone occur throughout the formation and thicker units of quartz sandstone up to 5 m thick are found in the basal part of the formation". These authors also reported thin dolomite lenses throughout the formation.

From the writer's observations in the area the following can be added. Most of the shale and other fine grained terrigenous sedimentary rocks are grey in colour, while the highly carbonaceous shales are bluish black, and iron-rich shales are reddish brown. The iron content of some of the beds is probably high enough for the rocks to be termed iron formation (using the 15% iron limit of James, 1954).

Such iron formation occurs as a 1 m thick bed about 100 m above the base of the Broadhurst Formation near locality B (Fig. 2.2), where it is underlain by dolomite and overlain by very fine grained micaceous sandstone. A tentative correlation can be made between this outcrop and a similar iron-rich bed near locality A (Plate 2.1A), which is in the same approximate stratigraphic position, although within a shale sequence. The distance between these two localities is about 12 km, suggesting that thin beds of iron formation may be very extensive laterally throughout the formation.

Sedimentary structures are uncommon in outcrops of the Broadhurst Formation, but graded bedding was noted in a cut specimen of siltstone, and may be more abundant than has been recorded to date. The grading occurs in thick laminae and very thin beds (averaging about 1 cm thick) which have sharp bases, and which grade upwards from siltstone to claystone. Crude parallel lamination also occurs in the siltstone. Chin et al. (1980) recorded small scale ripple marks and slumping in shale and siltstone, and rare small scale ripples in interbedded sandstone, siltstone and shale.

Mineralogy and micropetrography. Examples of the three basic lithologies of the Broadhurst Formation, that is, siltstone-shale, carbonaceous mudstone and iron formation, are described below. The mineralogy of the siltstone and shale is dominated by quartz and sericite (e.g. specimen TEL 772 - Table 2.1), together with minor chlorite, feldspar and haematite, the latter occurring interstitially. Siltstone layers are much more quartz-rich than claystone, and a few detrital tourmaline and opaque grains also occur. In some specimens (e.g. TEL 765) discontinuous thin wavy chert laminae occur within specific beds of the mudstone. A faint cleavage parallel to the bedding, formed by the alignment of sericite, is a feature common to most specimens.

Carbonaceous mudstone (e.g. TEL 640) is basically similar to the non-carbonaceous siltstone, being dominated by quartz and sericite, but it contains abundant (about 10% by volume) diffuse opaque patches of carbonaceous material. This occurs in two forms, as minute interstitial particles (e.g. TEL 771), and as much larger wisps which lie parallel to the bedding or cleavage, and which are associated with thin chert laminae (e.g. TEL 640).

The iron formation varies from being a haematitic siltstone (TEL 641) to a more dense, banded iron oxide-chert-quartz rock (TEL 770B). In the siltstone, detrital quartz, and sericite formed from clay minerals, occur in a matrix of haematite, which also forms thin laminae. In places the interstitial matrix material is granular, some grains having a roughly square outline, which possibly represent oxidised pyrite cubes. In the second type of iron formation, thick laminae of dark brown amorphous iron oxide are interbedded with thin laminae of grey chert and very fine grained quartz. Irregular patches of coarse grained quartz also occur. The content of iron oxides ranges from about 30% to 70%.

Interpretation. The entire Broadhurst Formation was probably deposited in a quiet marine environment. The fine grain size and scarcity of sedimentary structures imply very weak currents, but grading in some siltstone beds suggest that at times deposition took place from small turbidity currents. The presence of carbonaceous shale and iron formation indicates periods of stagnation of the water column (Chapter 4).

### 2.3.3 CHOORUN FORMATION

Lithology. In the Rudall map area Chin et al. (1980) recognised two major lithofacies of the Choorun Formation, one immediately west of the Rudall Metamorphic Complex, and the other still farther west, bordering the Balfour Downs map area (Fig. 2.2). According to these authors the Choorun Formation in the former area includes cyclic units, comprising pebble and cobble conglomerates overlain by reddish-brown coarse to medium grained quartz arenite, purple micaceous siltstone and minor chocolate brown shale. Silty dolomite and calcareous shale were reported as minor lithologies of some sequences. In the area further west these authors describe the formation as non-cyclic sandstone and minor micaceous siltstone, which contain symmetrical and asymmetrical ripple marks, cross bedding, and possible mudcracks.

The writer has not visited the more westerly facies of the Choorun Formation, but exposures of the cyclic facies have been examined. At locality D on Figure 2.2 a northeasterly dipping cuesta exposes upward fining cycles of pebble conglomerate, pebbly sandstone, feldspathic sandstone and shale (Plate 2.1E, Fig. 2.3). The conglomerate at the base of this section comprises angular to subrounded white quartz clasts up to 7 cm long, and less common pink potash feldspar fragments up to 1 cm across. The conglomerate is matrix supported, this matrix being coarse to very coarse grained arkosic sandstone (see below). No cross bedding occurs in the conglomerate, but a directional pebble fabric occurs, with the long axes of clasts orientated down dip. A similar fabric occurs in the conglomerate in the middle of the measured section (Plate 2.1F, Fig. 2.3). The alignment of pebble axes is roughly perpendicular to the dip of cross bedding in nearby sandstone beds.

The sandstone beds are generally poorly sorted and coarse to very coarse grained, but some are fine grained and well sorted. Cross bedding is present, but is generally poorly preserved, although a well defined solitary planar set 20 cm thick occurs near the top of the section (Fig. 2.3). Pronounced channelling also occurs in sandstone at the top of the section, with a typical channel having the dimensions of 4 m wide and 1 m deep. Purplish red shale, which overlies granule conglomerate, forms two units up to 2 m thick near the top of the section (Fig. 2.3).

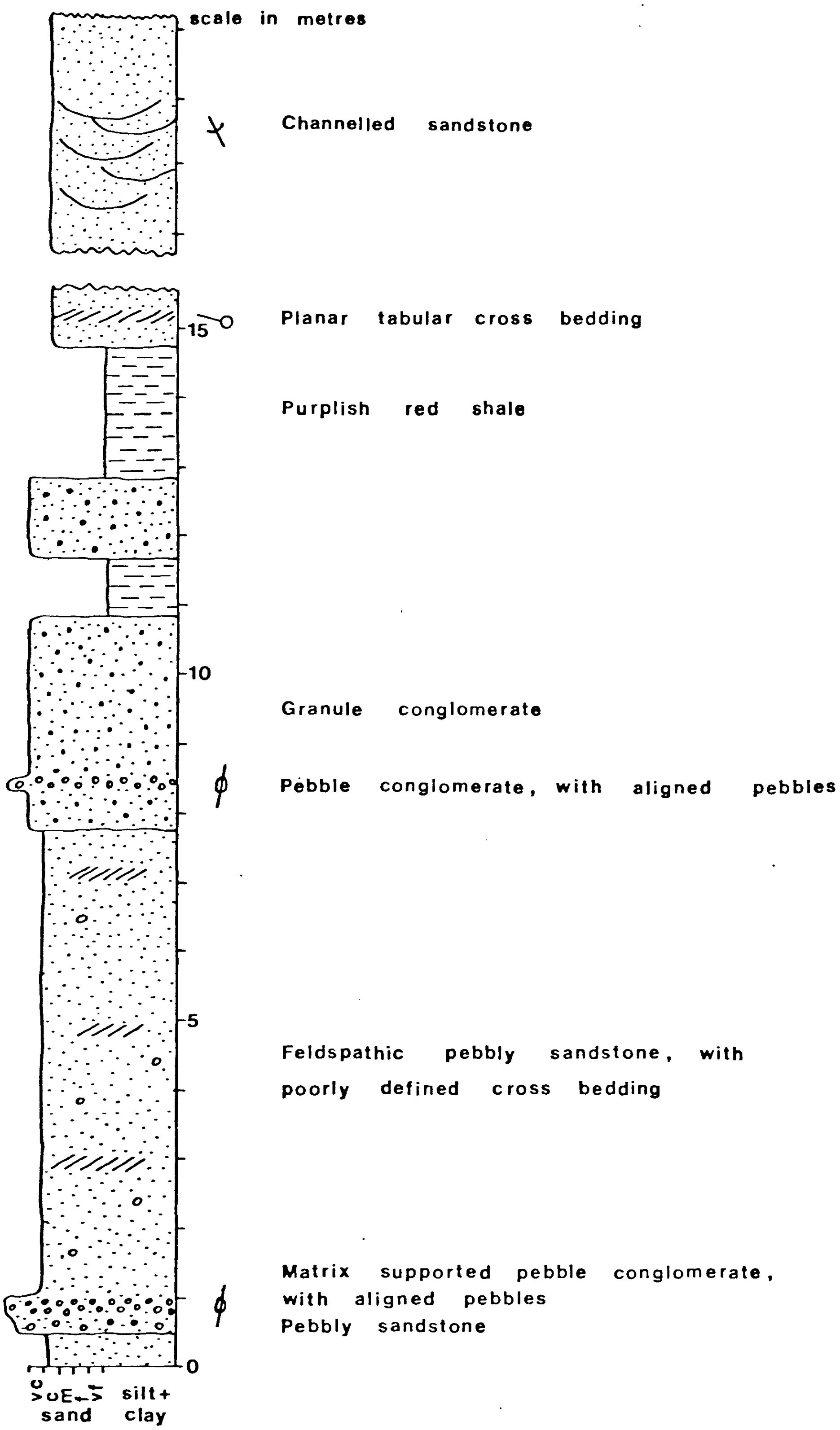


Figure 2.3 - Stratigraphic sequence of the Choorun Formation at locality D (Fig. 2.2). Symbols at right indicate orientation of channels, cross bedding and pebble long axes - north to top of diagram.

At a locality 9 km northwest of locality D (Fig. 2.2) non-conglomeratic cyclic units occur. Here, thick bedded sandstone forms units up to about 20 m thick, which outcrop as cuestas. Poorly exposed finer shaly sediments occur in intervening valleys. The sandstone is medium to coarse grained and commonly massive, although some cross bedding also occurs. Parting lineation occurs on a few bedding planes.

Crowe and Chin (1979) have suggested a correlation of the Choorun Formation with a thick sequence in the Runton map area (Fig. 1.3). This sequence has laminated dolomite at its base and passes upward into cyclic units, each apparently over 100 m thick. These cyclic units fine upwards from granule conglomerate and coarse grained sandstone, through well bedded fine to medium grained sandstone with abundant ripples, to interbedded flaggy siltstone and shale.

Mineralogy and micropetrography. Three specimens of sandstone from this formation have been examined in detail. Specimens TEL 762 and 761 (Table 2.1) are quartz-rich sandstone, bordering on subarkose if the kaolinite indicated in Table 2.1 is assumed to be derived from the weathering of feldspar. The former specimen is medium grained with subrounded to subangular grains, whereas the latter specimen is fine grained with subrounded to angular grains. In both specimens detrital chert and argillite grains constitute about 1% of the rock, and accessory minerals include detrital muscovite, tourmaline, zircon and iron oxide. Haematite occurs in extremely fine grained form within the matrix of TEL 761, giving the rock a purplish grey hue similar to shale with which it is interbedded.

Specimen TEL 760 (Table 2.1) is much more feldspathic however, being subarkose bordering on arkose. This specimen is from the matrix of the lower conglomerate bed shown in Figure 2.3. In thin section it comprises medium to coarse grains of quartz (72%) and microcline (18%) set in a sericitic matrix. A few detrital grains of muscovite occur, and tourmaline plus opaque grains (magnetite and minor limonite) constitute about 1% of the rock. Microcline grains are generally rounded, whereas quartz grains are mostly subrounded. Pink potash feldspar also occurs as granules and small pebbles up to 1 cm in diameter. Such feldspathic sandstone has not been reported previously elsewhere in the region.

Interpretation. The sediments of the Choorun Formation are immature, both mineralogically and texturally, and it is therefore probable that the detritus was transported for only relatively short distances. The occurrences of fining upwards sequences, channelling and cross bedding, and the red colouration of some of the deposits, suggest that both the conglomerate-sandstone-shale sequences, and the sandstone-shale sequences are probably of alluvial origin.

## PLATE 2.1 - LOWER YENEENA GROUP

A. Vertically dipping shale of the Broadhurst Formation (foreground ridge), which encloses a bed of iron formation (more resistant unit where hammer rests), conformably overlying sandstone of the Coolbro Sandstone (ridge in left background). The poorly exposed contact is in the valley between the ridges. Locality A on Figure 2.2.

B. Solitary tabular set of cross bedding in the Coolbro Sandstone at locality B (Fig. 2.2). Bedding is parallel to pencil. The cross bedding is overlain by parallel laminated sandstone, and underlain by apparently massive sandstone.

C. Large scale solitary tabular set of cross bedding (bedding planes indicated by dashed lines) in the Coolbro Sandstone near locality A (Fig. 2.2). Bedding is steeply dipping, with stratigraphic top to the left. Photo by B.C. McKelvey.

D. Down-dip view of convolute bedding in a 30 cm thick bed of fine to medium grained sandstone of the Coolbro Sandstone, at locality B (Fig. 2.2). Note hammer handle in lower left for scale.

E. Outcrop of the Choorun Formation at locality D (Fig. 2.2). Quartz pebble conglomerate and pebbly sandstone in the foreground pass upward through very coarse grained sandstone with minor purplish red shale interbeds (Fig. 2.3) to channelled coarse grained sandstone at ridge crest (figure for scale).

F. Bedding plane exposure of quartz pebble conglomerate in the Choorun Formation at locality D (Fig. 2.2). Note the crude alignment of pebble long axes roughly parallel to the hammer handle.

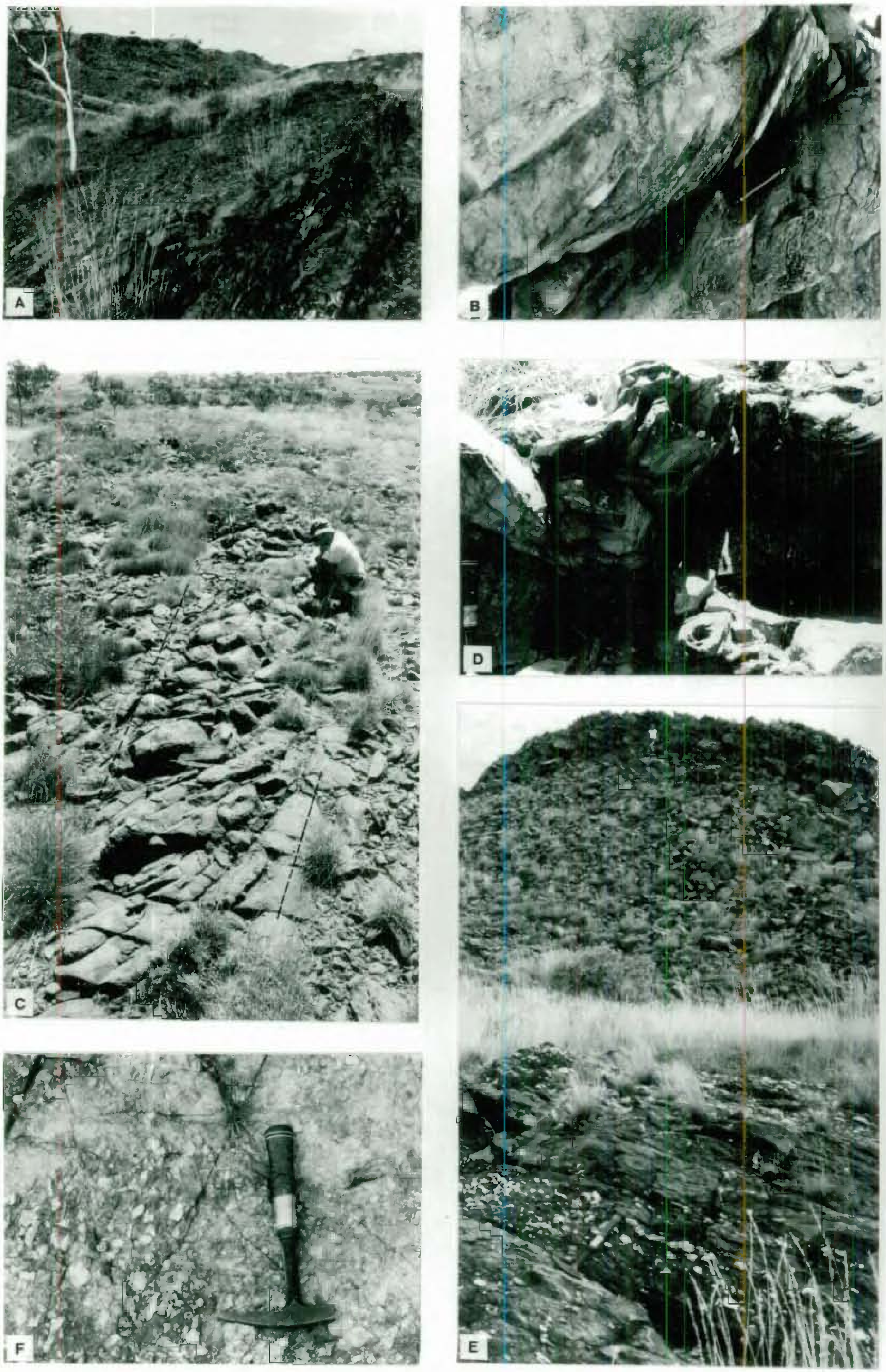


PLATE 2.1