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BMR Bulletin
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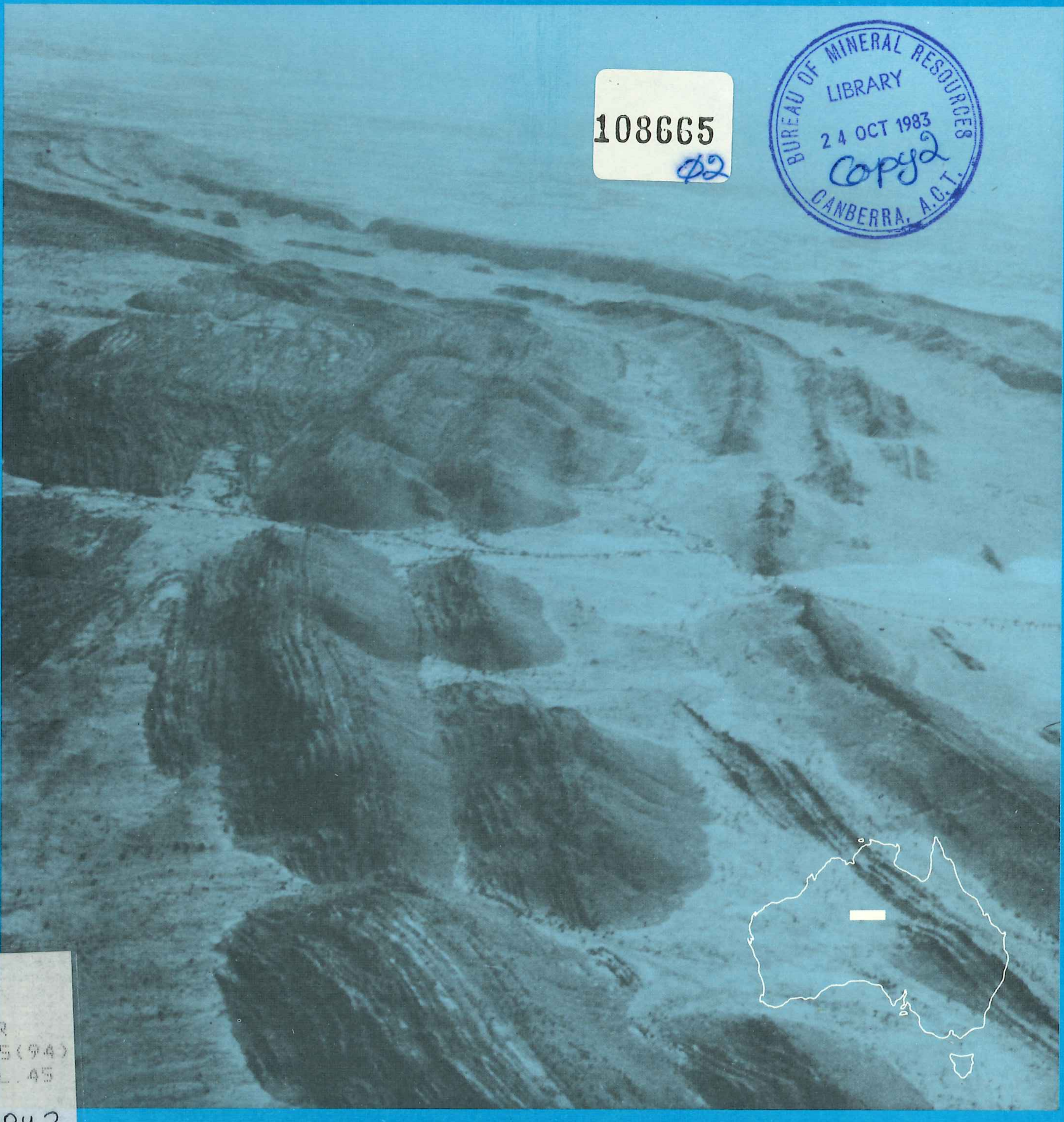

Monolith composed of the Vaughan Springs Quartzite at the entrance to Pulca Currinya Waterhole, in the Stuart Bluff Range. (GA1601)

DEPARTMENT OF NATIONAL DEVELOPMENT & ENERGY
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A. T. WELLS & F. J. MOSS

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Cover: The fold belt constituting part of the Davis Thrust Nappe at the northern margin of the Ngalia Basin. Prominent narrow ridges of the Vaughan Springs Quartzite at the northern margin (near top at left to above centre at right) are separated by a narrow valley from the Mount Eclipse Sandstone in the Patmungala Syncline. Basement rocks underlie the alluvium-covered plains in the distance. The length of the creek traversing the middleground of the photograph is about 2.5 km. (GA1538)

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CONTENTS

TABLES

PLATES

FIGURES

MEASURED SECTIONS

(on microfiche in back pocket)

ABSTRACT

The Ngalia Basin comprises Adelaidean and Palaeozoic, mainly arenaceous sediments, up to about 5 km thick, preserved in an intracratonic downwarp in Lower and Middle Proterozoic igneous and metamorphic basement rocks. The maximum known thicknesses of sediments are Adelaidean, 3200 m; Cambrian, 800 m; probable Ordovician, 300 m; and Devono-Carboniferous 3100 m; but a complete sequence is not present in any one area. The basin sequence is largely concealed by Cainozoic deposits, except for a belt of folded sediments along parts of the northern margin and narrow quartzite ridges along the southern margin.

Unconformities in the Ngalia Basin sequence record nine alternate periods of sedimentation and diastrophism between Adelaidean and late Palaeozoic time. The major unconformities which record these periods of diastrophism divide the succession into four early tectosomes of continental and marine sedimentation and two later tectosomes of continental sedimentation.

Until Devonian time the basin was part of a much larger sedimentary or structural province. Subsequent major latitudinal uplifts to the north and south of the present basin margins formed an ancestral basin outline. These uplifts were the provenance for a thick clastic wedge, comprising the youngest sequence in the basin. A major orogeny in the Carboniferous folded and thrusted the sediments, and thin Tertiary lacustrine and fluvial sediments were deposited on the eroded basin surface.

Seismic data indicate that the basin is essentially a faulted easterly trending asymmetrical syncline in which the thickest sediments are preserved towards the northern margin, where north-to-south thrusting has controlled the structural framework of the basin. Major faults and thrusts outline the main structural divisions of the basin. The northern margin in the west is formed by two thrust nappes, which are partly separated from a gently basinward-inclined platform in the south by a wide fault trough. Farther east, sinusoidal horsts and grabens dominate the structure in the centre of the basin. In the east the thick sedimentary pile at the northern margin is truncated by a thrust.

The large number of unconformities and the absence of demonstrated good source rocks in the sequence reduce the petroleum potential of the basin. However, a probably thick and more complete Palaeozoic sequence in the subsurface may have some potential.

Uranium mineralisation confined to the Devono-Carboniferous continental sandstone is the most important potentially economic mineral deposit. Water supply is principally from bores, but quality varies considerably; Devono-Carboniferous arenaceous sediments have yielded potable water, and Cainozoic rudites have yielded large flows of stock water.

INTRODUCTION

The Ngalia Basin underlies an area of 16 000 km^2 between latitudes 22°00′ to 23°00′ S and longitudes 129°00′ to 133°45′ E in the southern part of the Northern Territory (Fig. 1). The geology of the basin and surrounding parts of the northern Arunta Block is shown in Plate 1; this area is referred to as the 'region' throughout the text.

Settlement and access

Most of the inhabitants in the region are Aboriginals living at the Yuendumu Native Settlement, the largest native settlement in the Northern Territory. Homesteads, which are concentrated in the eastern two-thirds of the region, depend on the cattle industry. They are connected by graded dirt roads to two main access roads: an all-weather dirt road, the Tanami Road, linking the Yuendumu Native Settlement to Alice Springs; and the Stuart Highway, which crosses the Hann Range in the east (Fig. 2). The area west of Mount Doreen homestead is uninhabited, as it consists mainly of sand dunes with spinifex; there are no access roads west of Waite Creek.

Physiography

Outcrops are generally confined to a narrow ribbon of sparse, mostly westerly trending ridges at the perimeter of the Ngalia Basin. These peripheral, more resistant exposures are separated by wide sand plains that for the most part obscure the major portion of the basin sequence. In the north and extreme east, the plains are traversed by a few alluviated valleys which are neither sufficiently large nor deep to expose bedrock.

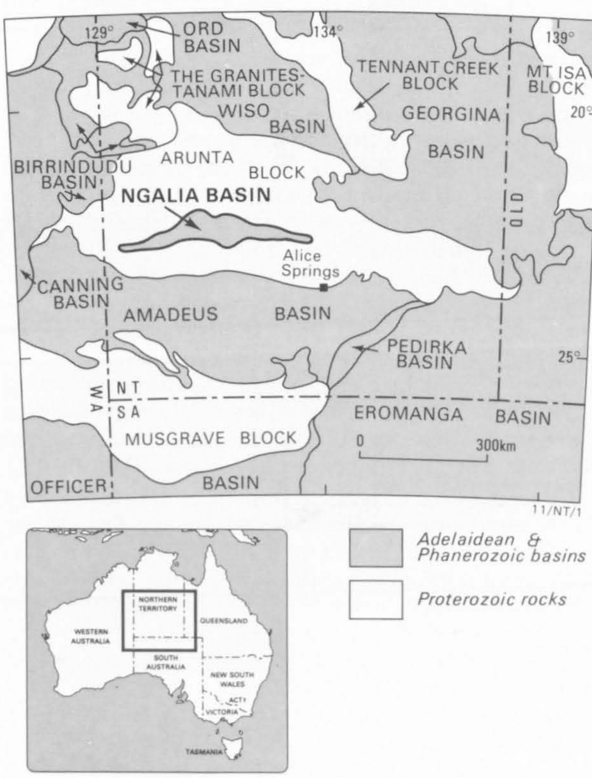


Fig. 1. Location of the Ngalia Basin in relation to the central Australian tectonic domains.

Apart from the mountain ranges in the northeastern part of the region, and the alluvial plains on predominantly granitic rock, which are dotted with monadnocks of variable height, basement rocks are generally obscured by sand plains, salt lakes, and limestone plains.

Seven physiographic divisions have been differentiated in the area covered by the geological map (Fig. 2).

Mountain ranges and quartzite ridges generally trend easterly and some peaks range up to about 500 m above the level of the surrounding plains. Central Mount Wedge, 1090 m above sea level, dominates the southern skyline; Mount Freeling (1000 m) and Mount Thomas (1116 m) are the highest peaks in the north. The mountains and ridges are steeply dissected, and commonly have alluvial fans and erosional tributary slopes with little shallow soil and spinifex cover.

Alluvial fans cover the terrain adjacent to the mountain ranges and quartzite ridges. They commonly grade laterally into the aeolian sand surfaces.

Aeolian sand surfaces are composed of sand plains and dune ridges. The sand plains cover most of the central part of the Ngalia Basin apart from small isolated outcrops of basin sediments. Farther west the plains slope gently towards Lake Mackay. Sand dunes up to 10 m high and several kilometres long, with stable flanks and some active sand on their crests, are common in the western half of the basin. Where drainage channels enter this area, numerous claypans have developed, together with an associated complex network of sand dunes. Vegetation cover is mainly spinifex and sparse shrubs.

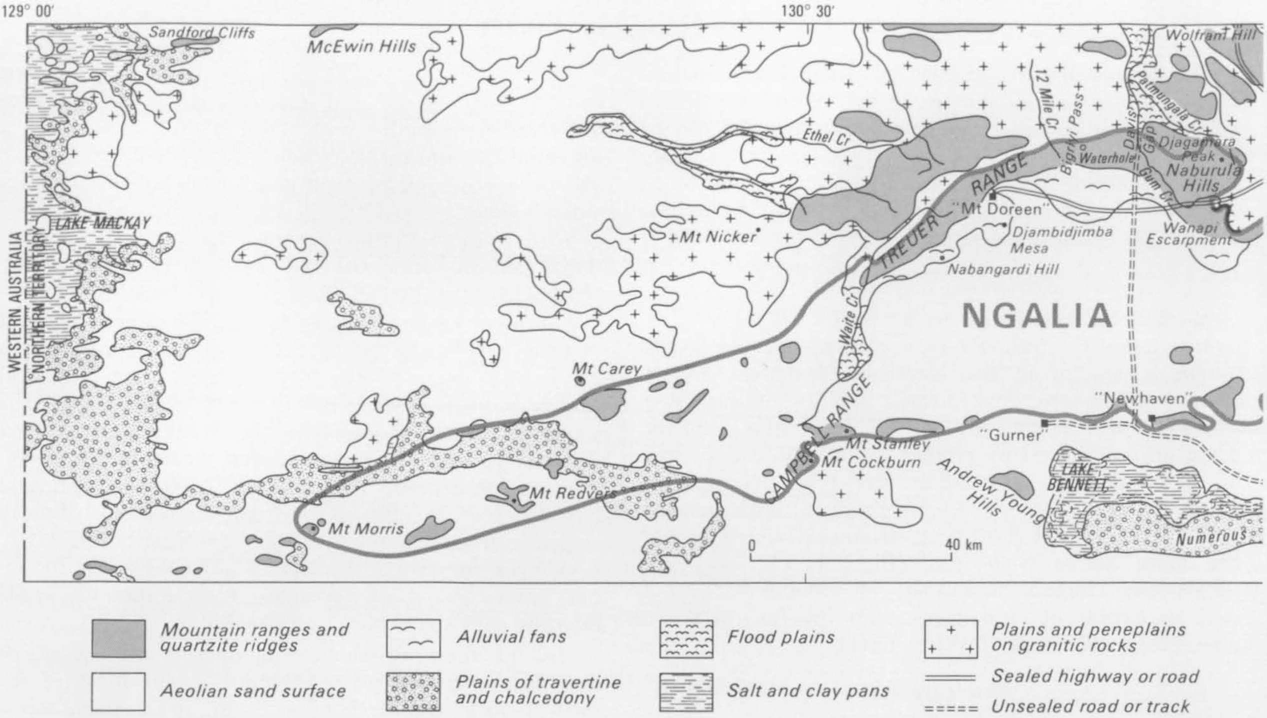
Salt and clay pans, including large salt lakes, bordering the southern margin and western end of the basin (Fig. 33) are remnants of much larger lakes. They occupy depressions in which the water-table is near the surface, and are probably mostly replenished by subsurface drainage; the mean average rainfall is less than 250 mm per annum, evaporation losses are high, and consequently surface water seldom accumulates in them.

Waite, Keridi, Gidyea, Napperby, and Day Creeks are the largest drainage channels to cross or partly traverse the basin area and are flanked by generally narrow *flood plains*. With the exception of Napperby Creek they peter out in sand plains, resulting in a considerable admixture of aeolian sand with water-borne sand; however, Napperby Creek drains into Lake Lewis, a large salt lake south of the Stuart Bluff Range (Fig. 33).

Plains and peneplains on granitic rocks with residual rounded domes and tors are present in the north. They have varied vegetation cover, though mulga and spinifex are the most common types.

Plains of travertine and chalcedony with moderate sand cover are most common to the south of the southern margin of the basin, chiefly south of the Siddeley Range between Lakes Bennett and Lewis, and along part of the southern edge of the Stuart Bluff Range. Relief is rarely over 3 m, and the soil is mostly shallow sandy calcareous earth with a cover of sparse shrubs, short grass, and spinifex.

Perry & others (1962) have described the geomorphology of the area.



History of investigations

The geology and geophysics of the basin have been systematically studied only relatively recently; the early explorers made only cursory references to the geology, but contributed the first knowledge of topography and surface drainage.

Stuart (1861) named physiographic features in the eastern part of the basin; W. C. Gosse also named many topographic features and commented on the nature of the rocks in parts of the region, and so did Warburton (1875) and Winnecke (1882). Although Tietkins (1891) did not enter the area he named prominent features whilst making observations from Mount Leisler, which lies to the southwest at latitude 23°20′ S, longitude 129°22′ E.

Outcrops of quartzite and quartzose sandstone (Vaughan Springs Quartzite) in southeast LAKE MACKAY* were recorded by Maurice & Murray (1904). Chewings (1928) regarded the quartzites and slates of the Hann and Stuart Bluff Ranges as probably Cambrian. He correlated them with the 'Heavitree Gap quartzite' (now defined as the Heavitree Quartzite) and other similar quartzites in the northern part of the 'Amadeus sunkland' (Amadeus Basin), and correctly suggested that the Stuart Bluff Range was the 'northern limit of an arch, the southern limb of which may be recognized in the Mount Liebig quartzite ridge.'

Tindale (1933) published geological notes on his journey from the Hann Range to Cockatoo Creek. He divided the rocks into five groups: a metamorphic series of Archaean age; granites intruded into the Archaean rocks; the Giles Range series (which he tentatively considered to be of older Proterozoic age and to represent the northern equivalents of the Pertaknurra series as defined by Mawson & Madigan, 1930, and Madigan, 1932); the Hann Range-Uldirra Hill-Crown Hill series of unmetamorphosed quartzites, arkose, grits, and conglomerate; and consolidated grits and recent deposits of the Mamba Plain, Ngalia Plain, and the Lander valley. Tindale recognised that the Hann Range-Stuart Bluff Range rocks constitute the 'southern marginal beds which form a shallow synclinal fold, the Ngalia Syncline'; this is the first known use of the name which was subsequently revised by Cook & Scott (1966, 1967) to the Ngalia Basin.

Several aerial traverses over parts of the basin were made in 1930 by the Mackay Aerial Survey Expedition and a reconnaissance map was prepared (Mackay, 1934). Terry (1934), who traversed the eastern part of the basin reported potassium nitrate in a sandstone outcrop (possibly the Mount Eclipse Sandstone outcrop at Nabangardi Hill) south of Mount Davenport. Ryan (1958) recorded a unit of 'sandstone' (Vaughan Springs Quartzite) from the Ngalia Basin, and recognised the significance of a major fault at the northern margin of the basin (Napperby Thrust) in a sketch map in his report on the geology and mineral deposits of the Reynolds Range area.

Jones & Quinlan (1962) discussed the water resources of the region. The water resources of the Yuendumu Native Settlement have been the subject of reports by BMR geologists (Jones & Quinlan, 1958; Quinlan, 1958a, b; Cook, 1962). Kingdom, Woolley, & Faulks (1967) compiled a series of maps showing the positions of water-bores in the southern part of the Northern Territory, including the Ngalia Basin.

Quinlan (1962) based a resumé of the geology of the Ngalia Basin on limited field studies and photo-interpretation. The first systematic description of rocks in the Ngalia Basin was made in 1962 by Cook (1963), who mapped the 2200 km² of the Yuendumu Native Reserve; he included in his report three sections measured by D. R. Woolley in 1960. Milligan (1964) examined rocks in the Hann Range.

The first geophysical survey of the basin was a regional airborne magnetometer survey by Aero Services Limited (Hartman, 1963) for Pacific American Oil Company (PAOC). A total of 4100 km of traverses was flown at a line spacing of about 3 km at an altitude

* Names of 1:250 000 Sheet areas are printed in capital letters.

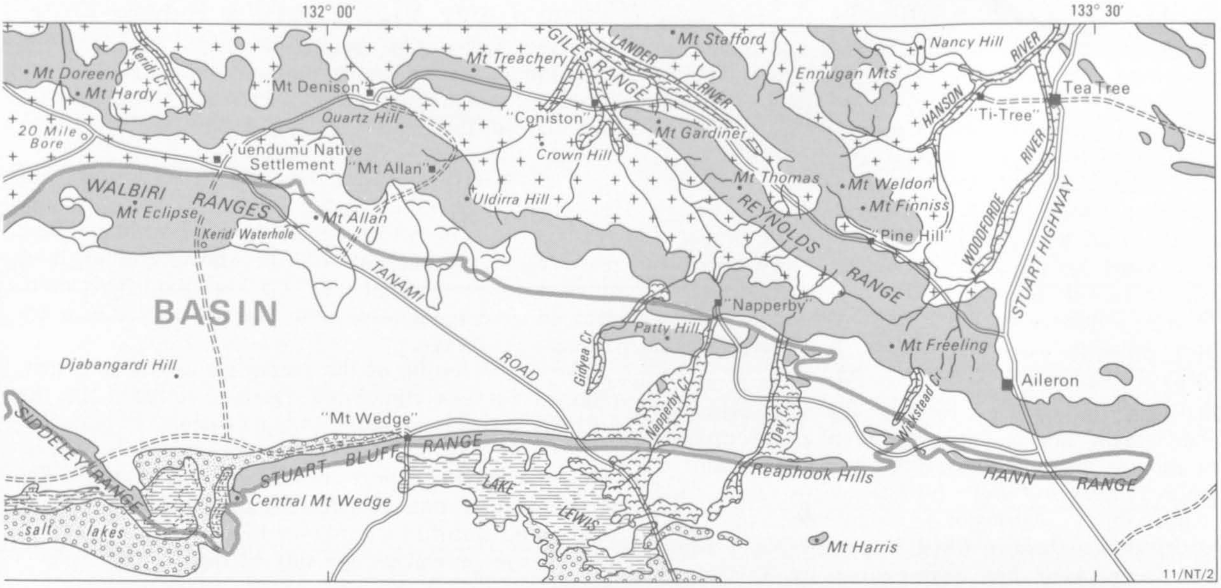


Fig. 2. Physiographic divisions.

of about 1200 m above sea level.The survey provided results to complement those obtained by BMR in 1958 (Carter, 1960) along the northern margin of the basin and over part of the surrounding Precambrian basement block. The magnetic interpretation suggests the presence of sediments up to about 6000 m thick near the northern margin of the basin. PAOC made photointerpretation (Fitzpatrick, 1964) and further geological studies (Fitzpatrick & Webb, 1963), and took out an oil permit (OP81).

PAOC followed the reconnaissance magnetic survey with a seismic reflection and gravity survey by Geophysical Associates Pty Ltd in the Napperby area in 1964 (Hudson & Campbell, 1965). The seismic work yielded about 170 km of continuous reflection coverage in the southern part of the basin. The gravity survey, which was conducted concurrently with the seismic work, used seismic shot-point locations as gravity stations. Hudson & Campbell (1965) compiled a depth contour map on a tentatively identified 'Lower Palaeozoic horizon'. They inferred that the maximum depth to this horizon is 4000 m, and that numerous faults are present in the sections. PAOC's oil permit expired without the company carrying out further work in the area.

Further reconnaissance geological mapping of the basin by BMR in 1964 was reported by Cook & Scott (1966, 1967), and by Rivereau (1965), who prepared photointerpretation maps of the basin at 1:250 000 scale.

Scott (AMDEL, 1966) and Morgan (1962) reported on petrographic studies of rocks from the region. The results of diamond drilling investigations of possible mineralised zones near White Point, and a general account of copper deposits south of Yuendumu, are given by Grainger (1967, 1969).

BMR made a reconnaissance helicopter gravity survey over the eastern part of the Ngalia Basin in 1965 (Flavelle, 1965), and completed the reconnaissance coverage of the basin and its surroundings with a helicopter gravity survey of parts of the Northern Territory and Western Australia in 1967 (Whitworth, 1970). Gravity stations were read at about an 11-km spacing on a square grid, and were barometrically levelled and tied to an Isogal control network (Barlow, 1970) and optically levelled road traverses.

Regional geological mapping of the basin by BMR commenced in 1967 (Wells, Evans, & Nicholas, 1968), continued in 1968 (Evans & Glikson, 1969; Nicholas, 1969), and was completed in 1969. Most of the basin was mapped by means of reconnaissance traverses on which four-wheel drive vehicles were used for transport. However, a fixed-wing aircraft was used for brief aerial reconnaissance of the well-exposed portions of the basin, and a helicopter was used to map LAKE MACKAY and to make spot checks on the basement rocks north and south of the basin in MOUNT DOREEN. AMDEL (1967, 1968a, b, 1969) described rock samples collected during the mapping surveys. Wells & Perry (1971) discussed the results of experimental aerial colour photography of the central northern margin of the basin in 1967; further aerial colour photographs of the northern halves of NAPPERBY and MOUNT DOREEN were taken in 1971.

BMR seismic surveys in 1967 (Jones, 1969), 1968 (discussed by Smith, 1968, and reported on by Tucker 1969), and 1969 consisted of 285 km of continuous reflection profiling, refraction work, and velocity spreads mainly on north-south traverses across the basin in four main, widely separated locations. The BMR work was tied to earlier PAOC traverses. Moss & Jones (1974) discussed the survey operations and results, and briefly mentioned work done later by Magellan Petroleum (Australia) Limited, who followed up leads from the earlier work.

After BMR's initial systematic mapping in the basin, Magellan obtained an oil permit (OP161) over the area, and, in conjunction with Southern Pacific Petroleum, carried out an exploration program of mainly gravity and seismic surveys. The gravity surveys, in which over 4000 stations were read along 1000 km of mainly north-south seismic and other traverses, were reported on and interpreted by Hickey (1969, 1970), Sabitay (1971), Pratt (1971), Gibson (1971), and Pfitzner (1974). Krieg (1972) interpreted the results of the seismic survey, conducted in 1971, which comprised 440 km of continuous reflection profiling—including 110 km of six-fold CDP coverage —mainly in the western part of the basin. He prepared contour maps for the reflection times to two horizons that he tentatively identified with the base of the Carboniferous sequence and the top of the lower Adelaidean sequence. He recognised in his interpretation the role of major faulting in the basin.

Shallow stratigraphic drilling, designed primarily to supplement and extend stratigraphic information from surface mapping, was reported on by Evans & Nicholas (1970) and Wells (1974), and is summarised in Appendix 1. Microfloral assemblages recovered from calcareous clays in BMR Napperby No. 1 stratigraphic hole were first investigated by D. Burger (BMR, personal communication) and later described and dated by Kemp (1976).

Cooper, Wells, & Nicholas (1971) discussed the results of isotopic dating of glauconitic sandstones from the Treuer Member of the Vaughan Springs Quartzite and from the Djagamara Formation. Using data obtained from several measured sections in the Amadeus Basin and one section from Central Mount Wedge, Clarke (1975, 1976, and personal communication) attempted an interpretation of the palaeogeography during deposition of the Heavitree and Vaughan Springs Quartzite.

Wells (1972), Evans (1972), & Nicholas (1972) compiled first-edition geological maps at 1:250 000 scale and explanatory notes that cover the Ngalia Basin. Wells, Moss, & Sabitay (1972) discussed the petroleum potential of the basin, and they and Wells (1976) outlined the geology of the basin.

In 1976 BMR acquired new magnetic coverage of the Ngalia Basin during the Arunta Block aeromagnetic survey, in which continuous recordings were made at an altitude of 150 m above ground level along north-south flight lines 1.5 km apart. This more detailed coverage complements the earlier PAOC aeromagnetic coverage.

The initial results of the recent geological and geophysical surveys stimulated renewed interest in the area by private mining and petroleum exploration companies. The re-interpreted and new information presented in this report indicates potential areas for further exploration for hydrocarbons and minerals, and will be useful as a guide for more extensive surveys and for the general prospecting of the region.

Constraints on geological interpretation

The following discussion of the basin stratigraphy, structure, and petroleum and mineral potential attempts to synthesise all available information. Important constraints on determining a sound knowledge of the structure and stratigraphy of the basin are sparse surface outcrop, the absence of fossils from many of the units, the absence of deep drillholes, the presence of many unconformities and overlapping sequences, and difficulties in correlating key seismic reflections across major faults and identifying them with outcrops near the basin margins.

BASEMENT ROCKS

Precambrian metamorphic and igneous basement rocks of the Arunta Block surround the Adelaidean* and Phanerozoic sedimentary rocks of the Ngalia Basin (Fig. 1, Plate 1). Granitic rocks around the immediate basin margin (Plate 1) may also compose the basin floor; correlation of the dominant Bouguer gravity anomaly features with basement suggests a uniform basement density, and a mainly granitic basement is implied (Anfiloff & Shaw, 1973).

Most of the geology of the basement rocks shown in Plate 1 is based on photointerpretation, supplemented by limited spot field checking, except in the Reynolds Range, Aileron, Denison, and Tea Tree 1:100 000 Sheet areas, where the geology of the Arunta Block is described by Stewart & others (1980). The geology of the four major basement units of the northern part of the Arunta Block in the vicinity of the Ngalia Basin, and the structures and other features of the rocks that are genetically related to the development of the basin, are only summarised here; the regional distribution and relations of the four major groups of rock units throughout the Arunta Block are described by Stewart & Warren (1977). The basement rocks are best exposed to the northeast of the Ngalia Basin, where outcrops have yielded most of the information on rock types and sequences.

Lithologies

Unit 1 (Ꝑr in Plate 1) consists of gneiss; granofels; pelitic, mafic, and subordinate felsic granulite; and minor amphibolite and quartzite. It has been metamorphosed to high amphibolite and low granulite facies. Its age is uncertain; it probably includes the oldest-known group of rocks in the northern part of the Arunta Block, although the possibility that they may be in part highly metamorphosed equivalents of the rocks of the succeeding units 2 and 3 cannot be entirely ruled out. A minimum age of late Early Proterozoic is indicated for the granulites by isotopic dating of some of the intrusive rocks, which include granite, charnockite, and dolerite dykes (Stewart & others, 1980).

Unit 2 (Ꝑm in Plate 1) consists of large enclaves of metamorphosed sedimentary rocks which occur in the mainly granitic terrain. The rock types include slightly metamorphosed sandstone and shale, and minor quartzite, chert, and amphibolite. The degree of metamorphism of the mainly pelitic and psammopelitic rocks ranges from lowermost greenchist facies to pyroxene hornfels facies and high amphibolite facies. The time of deposition of the original sediments is uncertain, but is tentatively considered to be Early Proterozoic. The rocks are intruded by late Early Proterozoic porphyritic microgranite and diorite and subsequently by major granite batholiths of late Early

* The arbitrary divisions of the Proterozoic time scale used in this report to assign relative ages to the basement units are Early Proterozoic (1800–2500 m.y.), Middle Proterozoic (900–1800 m.y.), and Late Proterozoic or Adelaidean (570–900 m.y.).

and early Middle Proterozoic age. There is no known exposed basement to the rocks of unit 2.

Unit 3 (Ꞓq in Plate 1) rocks are the youngest-known sedimentary rocks of the basement, and comprise quartzite, shale, and dolomite which unconformably overlie the rocks of unit 2. The Patmungala beds (Ꞓp), defined in Appendix 2, are tentatively included in unit 3, although they are differentiated on the geological map (Plate 1). The metamorphic grade of unit 3 rocks ranges from low greenschist facies in the west to amphibolite and granulite facies in the east. Acid igneous bodies and sills, including porphyritic microgranite and microadamellite are included in unit 3. These porphyritic intrusives are Early Proterozoic in age and antedate the major episodes of granite intrusion. The rocks of unit 3 are therefore older than the late Early or early Middle Proterozoic ages assigned to the large intrusive granite bodies (Stewart & others, 1980).

Unit 4 (Ꞓg in Plate 1), the most widespread unit, includes the youngest-known basement. It comprises major batholithic intrusive granitic rocks which have been dated isotopically at 1800-1550 m.y. (Stewart & others, 1980). Many of the granitic rocks are syntectonic and were intruded at various crustal levels concurrently with the main phase of deformation and metamorphism in the Middle Proterozoic. Many of them show various degrees of retrogressive metamorphism.

Structure and geochronology

The metasedimentary rocks of both basement units 2 and 3 are tightly folded, but the structural trends and style of folding are more apparent in the rocks of unit 3. Isoclinal folds cut by major strike faults and transcurrent faults are the two major types of structure. Fold axes trend from northwest to west.

Many structural trends and metamorphic zones in the rocks of the Arunta Block can be directly related to, and so presumably influenced, the tectonic development of the Ngalia Basin. The shape of the northern margin of the basin is controlled by overthrust tectonics, which account for both the prominent fold pattern impressed on the basin sediments and for the close parallelism of structural lineaments between the basin and basement. The trends of many of the fold axes, faults, mylonites, schist zones, major shears, flaser granite, quartz veins, and other dyke rocks in the basement are largely parallel or subparallel to the northern thrusted margin of the Ngalia Basin. The mainly northward dip of the strata in parts of the basement may also be attributed to the overthrusting.

Retrograde metamorphism, which reset the isotopic chronometry causing anomalously young ages for some areas of basement rocks, has been attributed to the effects of the Mount Eclipse Orogeny, the last major period of diastrophism that folded and overthrusted the Ngalia Basin. For instance, retrogressively metamorphosed basement rocks in the Napperby area, near the northern margin of the Ngalia Basin, yield K-Ar mineral dates as young as about 400 m.y. (L. P. Black *in* Stewart & others, 1980). However, because there are several other K-Ar dates which lie in the range 400-900 m.y. (Stewart & others, 1980), it seems likely that all are probably only partly reset. Therefore, the orogeny could be much younger than 400 m.y., and may be about the same age as the Alice Springs Orogeny in the Amadeus Basin.

Magnetic features

The main structural trends in these rocks are also evident in the magnetic contour directions and the trend directions of groups of elongate magnetic anomalies over parts of the basement (Plate 2). Structural trends and information on metamorphic zones in areas of poor exposure fringing the Ngalia Basin may also be interpreted from the magnetic results.

The contact between the basement rocks in the north and the basin sedimentary rocks is characterised generally by a change in magnetic pattern from short-wavelength anomalies associated with near-surface magnetic sources in basement rocks to broad magnetic anomalies associated with the deeper magnetic basement of the basin. In places—for example, over the Waite Creek and Yuendumu Thrust Zones—the magnetic pattern suggests that the contact may be placed considerably farther to the northwest and north of the respective surface expressions of the thrusts, implying extensions of the deeper magnetic basement in these directions. Short-wavelength low-amplitude magnetic anomalies associated with granites which are exposed in most areas around the northern margin also interfere with the broad contour pattern in these areas.

In contrast, the different types of magnetic anomalies associated with the near-surface basement rocks along the southern margin of the basin suggest that the rock types differ significantly from place to place along that margin. Stewart (*in* Shaw & others, 1979) has made a qualitative interpretation of the magnetic anomalies and their associated rock types in the Napperby 1:250 000 Sheet area. The very short-wavelength magnetic highs in the southeast are mainly associated with felsic and mafic granulites of unit 1, and on the southern flank of the Stuart Bluff Range with quartz-hematite veins. A clear boundary between the mafic granulites and granites to the west can be seen by the change from the very short-wavelength anomalies associated with the granulites to longer-wavelength anomalies similar to those associated with the granites

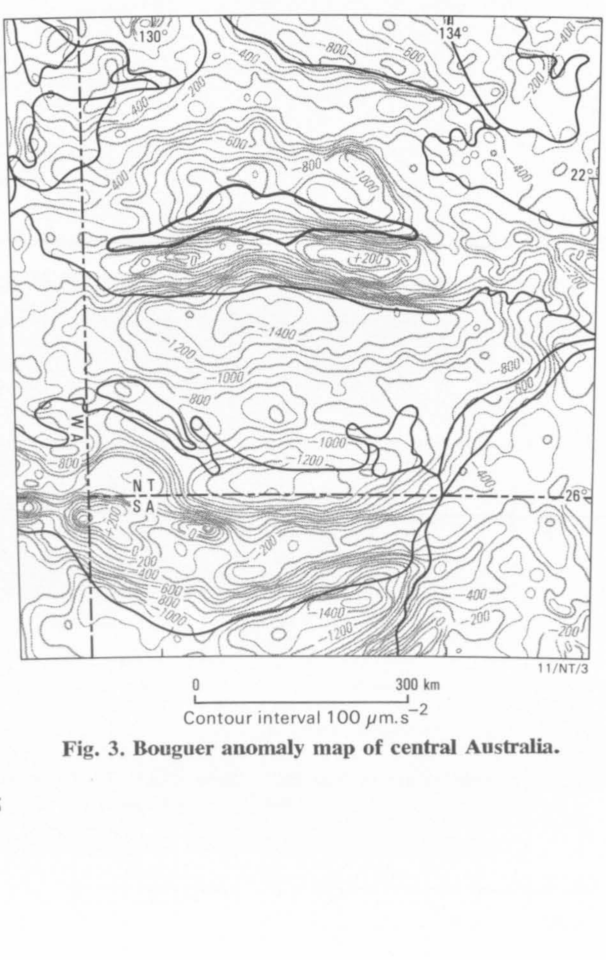
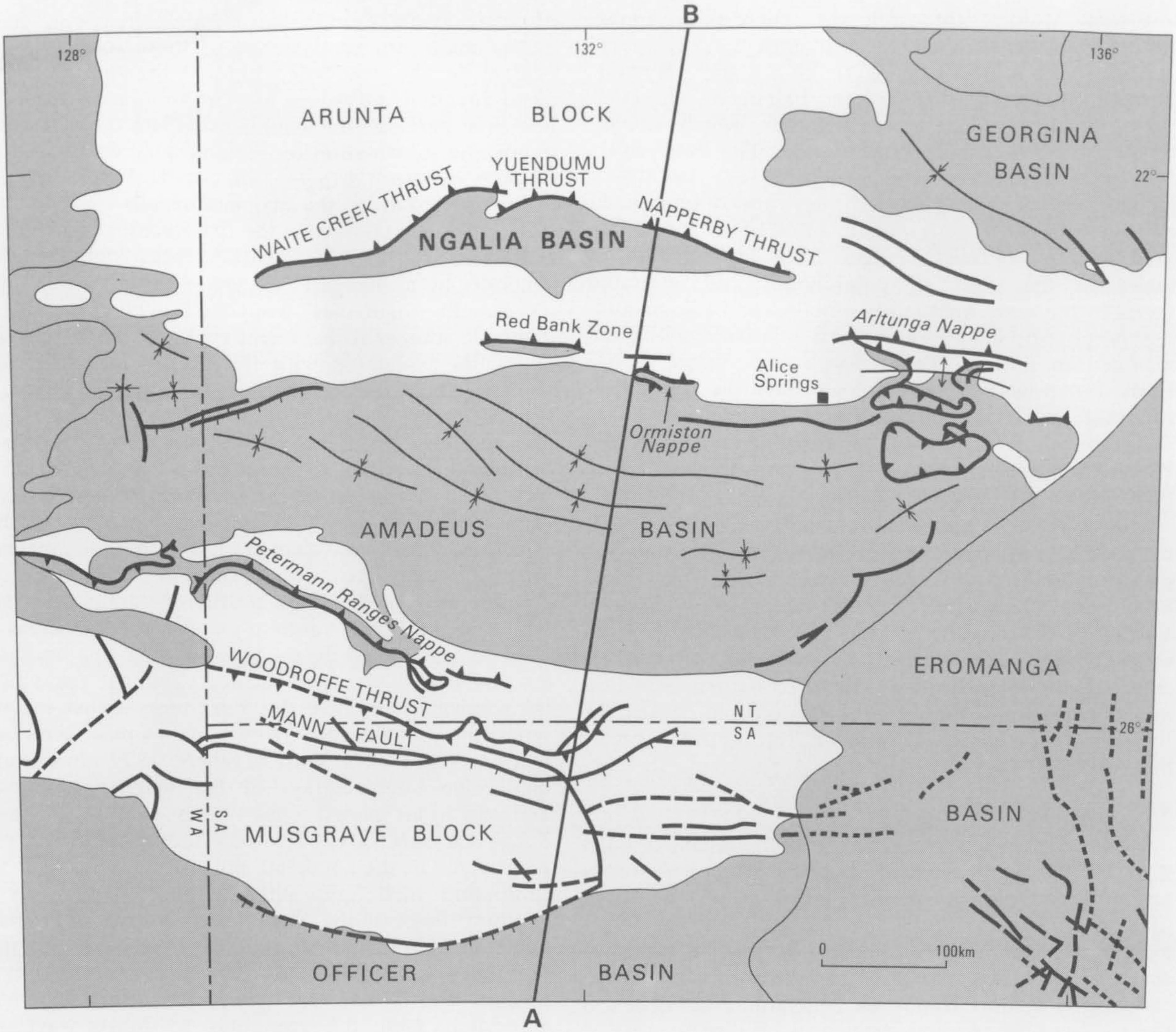


Fig. 3. Bouguer anomaly map of central Australia.



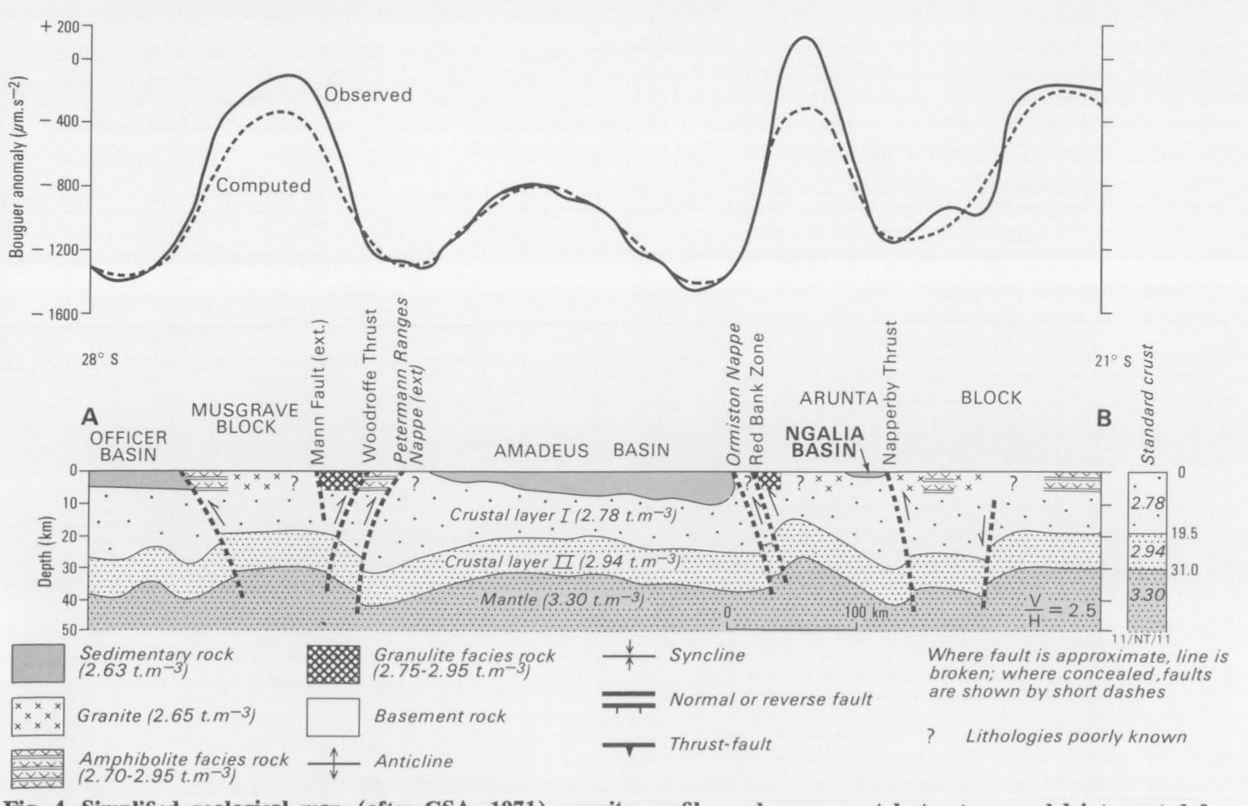


Fig. 4. Simplified geological map (after GSA, 1971), gravity profile, and gross crustal structure model interpreted from the Bouguer anomalies (after Mathur, 1976), central Australia.

elsewhere. Longer-wavelength high-amplitude anomalies farther west are associated with granulites probably of unit 3. The variable trend directions of magnetic anomalies suggest that complex faulting at the margin of the Ngalia Basin probably also extended into the surrounding basement rocks. The magnetic pattern over the southwestern margin of the basin suggests that the basement rocks there are mainly granites.

Gravity features

The structural setting of the Ngalia Basin in the basement complex is indicated in an analysis of the gravity features in central Australia (Fig. 3). The dominant gravity features are a series of slightly arcuate, easterly elongated gravity highs and lows, of which one—the Yuendumu Regional Gravity Low—is principally associated with the Ngalia Basin and immediate northern marginal areas. This feature has a similar shape to the basin, but it extends well to the north of the basin, and its axis lies along or to the north of the northern margin.

Several authors have proposed different interpretations to explain the gravity features. Mathur (1976) and some earlier authors suggested that the anomalies are due to deep crustal folds and faults extending into the upper mantle, and uplift along large thrust faults. Anfiloff & Shaw (1973) considered that most of the anomalies are caused by density variations within the the upper 20 km of the crust, and that most of the gravity lows are due to granite. They also implied that there is little or no density variation or structural deformation in the lower part of the crust. Wellman (1978) proposed a simple model in which he considered that the gravity anomalies are elongate dipoles caused by abrupt changes in mean crustal density at the junction of major crustal blocks.

The model proposed by Mathur (reproduced here in Fig. 4) is supported by the results from two isolated deep crustal reflection probes in the Ngalia and Amadeus Basins (Brown, 1970). Short-wavelength differences between the computed and observed anomalies are probably caused by generalising the near-surface geology in the modelling process; in particular, a better fit may have been obtained if allowance had been made for near-surface granites and basic granulites as proposed by Anfiloff & Shaw (1973). This interpretation of the gravity anomalies strongly supports the hypothesis that the structural fabric of the basin is mainly the result of north-south compression which produced east-west fold axes in the separate structural elements, and major north-south overthrusting which generated thrusts extending to great depths through the crust.

NGALIA BASIN SEQUENCE

The Ngalia Basin is a present-day structural feature in which mainly arenaceous sedimentary rocks of Adelaidean and early and late Palaeozoic ages are preserved. During the Adelaidean and early Palaeozoic, sedimentation in the basin was at various times part of more extensive intracratonic basin sedimentation, but during the Late Devonian and Carboniferous it was probably restricted to an area roughly bounded by the present margins of the Ngalia Basin.

For the purposes of discussion and easy reference, the basin may be divided into three arbitrary zones which will be referred to throughout the text. They are a western zone, a central zone between longitudes 131°25′ and 132°00′E, and an eastern zone.

The base of the Ngalia Basin is marked by either a heterolithic or angular contact of the basal quartzite with the Early and Middle Proterozoic basement rocks. The sedimentary rocks are best exposed in strips up to about 15 km wide along the northern margin. Ridges of the basal quartzite delineate the southern margin. The rest of the basin is largely covered by superficial Cainozoic sediments.

The sedimentary rocks — of Adelaidean, Cambrian, probably Ordovician, Devonian, and Carboniferous ages — are divided into eleven formations and four members, and have a maximum aggregate thickness of about 7500 m. Most of the formations are bounded by unconformities, and a complete sequence is not present in any one area. The thickest accumulation (about 5000 m) and the deepest part of the basin occur in the northern half of the central zone. The maximum thicknesses of the sediments are: Adelaidean 3200 m; Cambrian, 800 m; probable Ordovician, 300 m; and Devono-Carboniferous, 3100 m.

The stratigraphy of the Ngalia Basin sequence and overlying superficial sediments is summarised in Table 1; measured thicknesses of formations are listed in Table 2; and the locations of measured sections are illustrated in Figure 5. The relations between formations in outcrop are shown diagrammatically (in Plate 1), and stratigraphic columns at localities along the relatively well-exposed northern margin of the basin are illustrated in Figure 6. Stratigraphic correlations of formations in the Ngalia, Amadeus, Wiso, and Georgina Basins and Adelaide Geosyncline are shown in Figures 7 and 8.

The formations have previously been described briefly in the explanatory notes for MOUNT DOREEN (Wells, 1972), LAKE MACKAY (Nicholas, 1972), and NAPPERBY (Evans, 1972), and in papers by Cooper & others (1971), Wells, & others (1972), and Wells (1976). Outcrops of the formations have been described in detail in unpublished reports by Wells & others (1968), Nicholas (1969), and Evans & Glikson (1969). Graphic logs of all measured sections (MS-1 to MS-7) are reproduced in microform and enclosed (in a pocket inside the back cover) as a supplement to this Bulletin.

ADELAIDEAN

Vaughan Springs Quartzite

Definition

The Vaughan Springs Quartzite is here defined as a formation of tough pink, grey, and white massive to thickly bedded orthoquartzite, and in places, white friable sandstone* that weathers pink to red-brown and is interbedded with minor green and blue shale. Pebble to boulder conglomerate and pebbly hematitic

* The sandstones of the formation mostly correspond in composition to quartz arenites as defined by Pettijohn, Potter, & Siever (1972)—that is, sandstones consisting essentially of quartz with no appreciable matrix (under 10%) and containing no more than 10 percent of feldspar and rock particles.

TABLE 1. STRATIGRAPHY OF THE NGALIA BASIN AND GENERALISED BASEMENT LITHOLOGIES

Age	*Formation*	*Map symbol*	*Maximum thickness (m)*	*Topographic expression*	*Lithology*	*Remarks*
CAINOZOIC — QUATERNARY		Qa		River bed, flood plain, and flood-out	Alluvium	
		Qs		Plains and dunes	Sand	
		Qr		Plains	Red soil and alluvium	
		Qe		Plains around salt lakes	Sand, evaporites, and calcrete	
		Qt		Salt lakes and salt pans	Evaporites	
		Ql		Low mounds	Calcrete	
		Qc		Talus and detrital slopes	Colluvium	
CAINOZOIC		Cz		Mesas and buttes of low relief and low rounded hills	Silcrete and ferricrete	
DEVONIAN TO CARBONIFEROUS	MOUNT ECLIPSE SANDSTONE	Pzt	2400±	Hogbacks, cuestas, and prominent rounded hills	*Sandstone* and *subgreywacke,* pale brown and red-brown, coarse-grained, poorly sorted, thin-bedded to massive, cross-bedded, arkosic, in part micaceous and calcareous. *Cobble* and *boulder* beds common and a few micaceous *siltstone* and *shale* interbeds	Poorly preserved plant fossils of Late Carboniferous age in upper part of formation. Late Famennian spores from lower part of formation; Visean spores from middle part. Sandstone lithologically similar to the Mount Eclipse Sandstone at McEwin Hills is mapped as undivided Palaeozoic (Pz)
ORDOVICIAN OR DEVONIAN	KERRIDY SANDSTONE	Pzy	703	Low irregular hills with small sharp hogbacks	*Sandstone* and *subgreywacke,* red-brown, medium and coarse-grained, moderately sorted, silty, in part arkosic and calcareous, thin to thick-bedded, and cross-bedding is common; interbedded *siltstone*	
?ORDOVICIAN	DJAGAMARA FORMATION	Od	320+	Prominent hills, cuestas, and strike ridges	*Sandstone,* laminated to thick-bedded, siliceous, grey and white, in part glauconitic and with abundant clay pellets. Interbedded green and dark grey *siltstone* is a major component of the formation in some areas, principally in the west	Minimum age of 450 m.y. by K-Ar isotopic measurements
CAMBRIAN	BLOODWOOD FORMATION	Єb	270	Well-rounded hills	*Siltstone,* red-brown to purple-brown and pale green, thin-bedded, and red *sandstone.* Both the siltstone and sandstone are in part richly micaceous	Abundant trace fossils and rare macrofossils occur in beds near the middle of the formation. They suggest an Early Cambrian age
	WALBIRI DOLOMITE	Єw	250+	Dolomite forms rounded hills and low cuestas; other units in the formation occur in low mounds, beneath scree slopes, and in valleys	*Dolomite,* light and dark grey, pink, and red, thick-bedded and massive, in part glauconitic. *Siltstone* and *shale,* in part micaceous and fossiliferous, and thin interbeds of pink stromatolitic and oolitic *dolomite* and grey *sandstone.* Minor glauconitic *dolomite* near the base	Abundant fragmentary marine macrofossils near the base of the formation. They indicate an Early Cambrian or possibly early Middle Cambrian age

ADELAIDEAN TO EARLY CAMBRIAN	Yuendumu Sandstone	Ꝑ Єy	700+	Mostly rounded hills and small cuestas	*Sandstone,* fine to coarse-grained, moderately well sorted, medium and thin-bedded, flaggy, in part arkosic and micaceous, cross-bedded and slumped, red-brown and some pale brown. Minor coarse-grained *arkose,* and *quartzwacke*	Trace fossils in upper part
ADELAIDEAN	Mount Doreen Formation	Ꝑ aq	97+	Generally forms scree slopes with Wanapi Dolomite Mbr at top in low scarp. Otherwise in valleys or at base of scarps		
	Newhaven Shale Member	Ꝑ an	17+	Weathers recessively and underlies valley floors	*Shale,* uniform red, leached yellow-brown and fawn at unconformity	
	Wanapi Dolomite Member	Ꝑ aw	4	Low scarps and ridges	*Dolomite,* fine-grained, pink, laminated, weathers yellow-brown, manganese grains and dendrites, limonite pseudomorphs after pyrite, in part silicified, and stromatolitic	
	Mount Davenport Diamictite Member	Ꝑ ad	77	Poor outcrops generally beneath scree slopes	*Diamictite,* polymictic, subrounded boulder, pebble, and cobble erratics to 4 m across, striated and faceted, mostly quartzite and granite, in blue-green poorly sorted *siltstone* matrix	
	Rinkabeena Shale	Ꝑ ar	100	Weathers recessively, exposed only in creek banks, underlies low rounded rises, and forms floors of valleys	*Shale,* green, uniform; subordinate *siltstone,* dark grey, finely micaceous (biotite), well sorted, laminated, graded, in part calcareous and pyritic, thin quartz and calcite veins in places	
	Central Mount Stuart Formation	Ꝑ as	150	Mostly prominent hills and ridges	Mostly red-bed arenite sequence; includes silicified *sandstone* with limonite pseudomorphs, silty *sandstone,* coarse arkosic *conglomerate, siltstone, shale,* and commonly a basal *diamictite* with purple-brown poorly sorted *siltstone* matrix and polymictic erratics to 2.5 m, faceted and indistinctly striated	
	Naburula Formation	Ꝑ aa	8	Poor outcrops in banks and beds of creeks, and beneath scree slopes	*Shale,* dark grey to black, well bedded. *Diamictite,* polymictic erratics to 30 cm (largest of granite, quartzite most abundant), in poorly sorted, green-brown *siltstone* matrix. *Dolomite,* thin-bedded, dark green-grey, weathers yellow-grey and dark brown, fine-grained, septarian nodules	

	ALBINIA FORMATION	Ᵽab	150+	Dolomite poorly exposed in low rounded, mostly calcrete encrusted mounds and low knobbly outcrops. Siltstone exposed only in banks of larger creeks	*Siltstone* and *shale*, white, leached and deeply weathered, dolomitic in part. *Dolomite* pale grey to black, foetid, stromatolitic, with either white, grey, or black *chert*	Microfossils in black chert
	VAUGHAN SPRINGS QUARTZITE	Ᵽav	2500+	Mostly prominent resistant ridges	*Orthoquartzite*, white and pink, tough, closely jointed, thick-bedded and massive. Basal coarse-grained and pebbly hematitic granule *conglomerate*, *sandstone*, and pebble to boulder *conglomerate*. Small cross-beds common. Minor *shale*, *siltstone*, and *arkose*	
	TREUER MEMBER	Ᵽat	700±	Mostly rubble-covered flats with a few sharp low discontinuous ridges	*Siltstone*, thin to poorly bedded, white to grey, chert nodules and evaporite efflorescence in places. *Sandstone*, laminated to thin-bedded, siliceous, white to grey, cross-bedded, micaceous and glauconitic in part, interbeds rich in clay pellets	Occurs in lower half of the Vaughan Springs Quartzite. May contain interbedded evaporites
PROTEROZOIC		Ᵽg		Rounded hills and ranges; few isolated high tors	*Granite, granodiorite, orthogneiss*	
	PATMUNGALA BEDS	Ᵽp	1100±	Groups of irregular-shaped hills and low discontinuous strike ridges with high relief	*Sandstone, quartzite, siltstone*, recrystallised *tuff, chert-pebble conglomerate*	Slightly metamorphosed. Intruded by granite. May be correlative of Ᵽq
		Ᵽq		Long high ranges with prominent quartzite ridges	*Orthoquartzite, shale, siltstone, dolomite, limestone;* minor *arkose* and *conglomerate; schist, pelitic granofels, metaquartzite, calc-silicate, acid volcanics*	Metamorphic grade ranges from lower greenschist facies in the west to amphibolite and granulite facies in the east
		Ᵽm		Subdued hills and low ranges	*Metasandstone, shale, slate*, and *schist*. Minor *quartzite, chert, calc-silicate*, and *basic rocks*	High-grade metamorphism in east
		Ᵽr		Isolated low hills and minor range country	*Gneiss, granofels, pelitic granulite, mafic* and subordinate *felsic granulite*, and minor *amphibolite, charnockite, quartzite*, and *calc-silicate*	

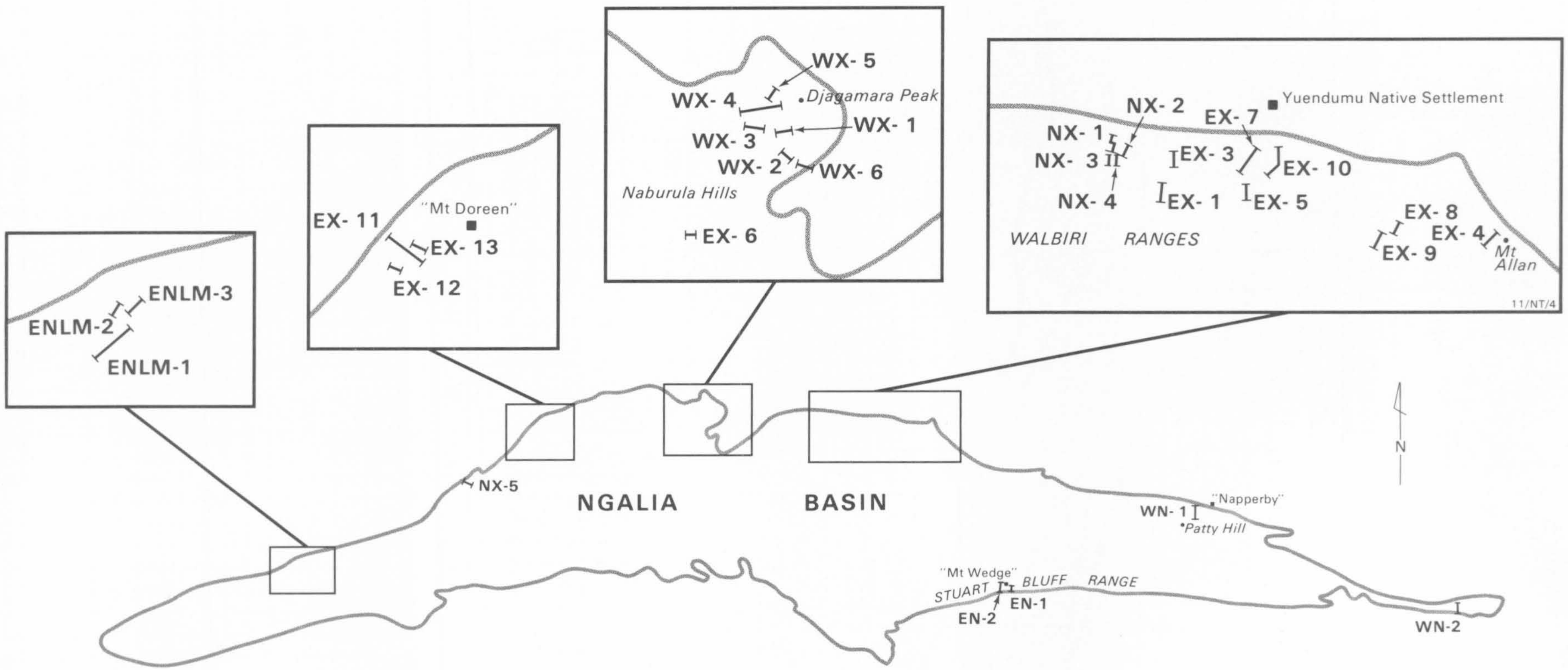


Fig. 5. Locations of measured sections.

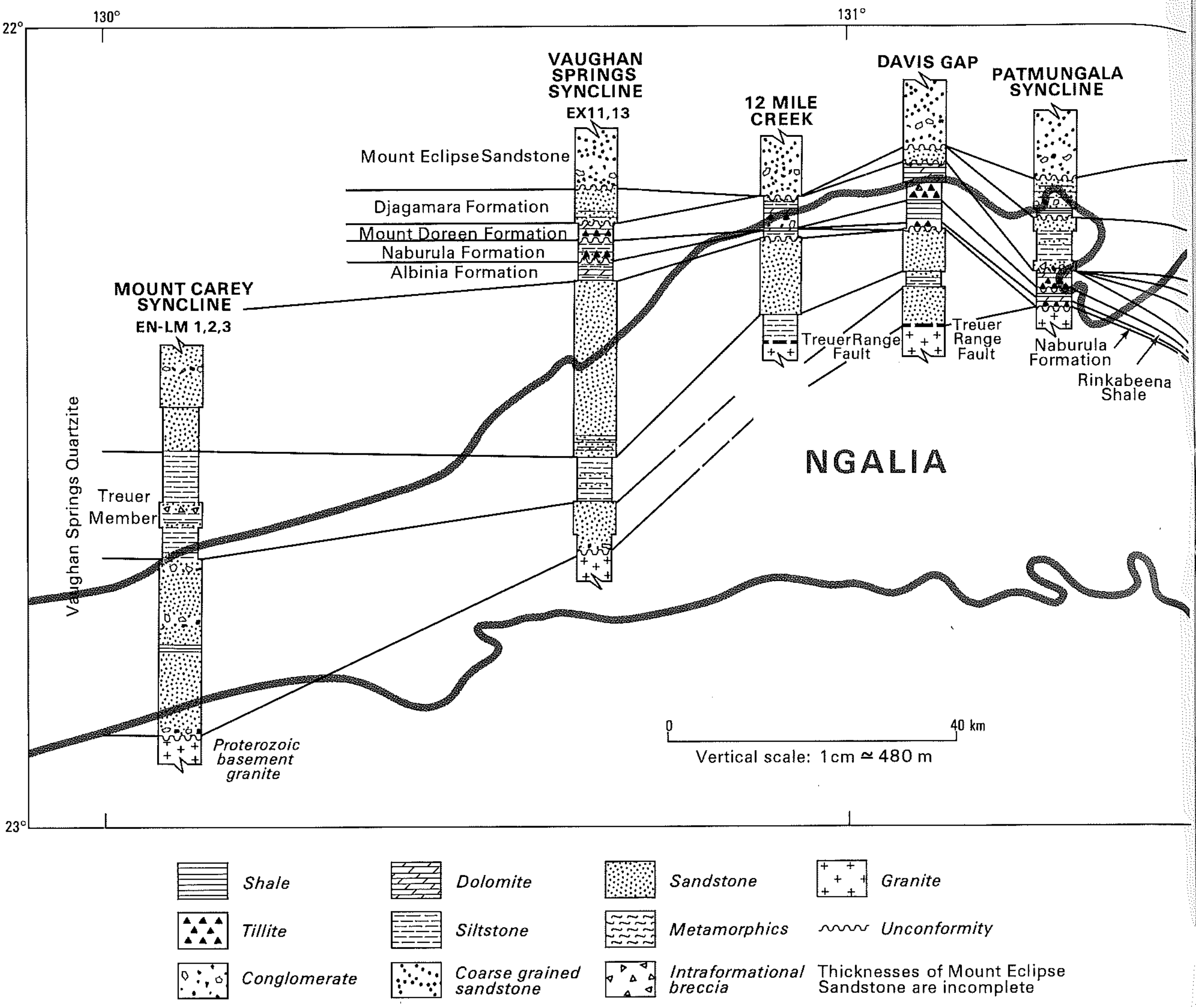


TABLE 2. MEASURED THICKNESSES OF

Formation	*WX-1 WX-3*	*WX-2*	*WX-4*	*WX-5*	*WX-6*	*NX-1*	*NX-2*	*NX-3/ DDH1*	*NX-4*	*NX-5*	*EX-1*
Mount Eclipse Sandstone	50+		127+								48+
Kerridy Sandstone	200		163								703
Djagamara Formation	290	12+	239+	235+							320+
Bloodwood Formation								271	158+		
Walbiri Dolomite						164+	148+				
Yuendumu Sandstone						280+					
Mount Doreen Formation	81+	97+									
Newhaven Shale Member	16+	17+									
Wanapi Dolomite Member	4	3									
Mount Davenport Diamictite Member	61	77									
Rinkabeena Shale		15+									
Naburula Formation					8						
Albinia Formation											
Vaughan Springs Quartzite											
Treuer Member										540	

All thicknesses are in metres. Thicknesses measured at type sections are underlined.
*(True thickness about 250 m)

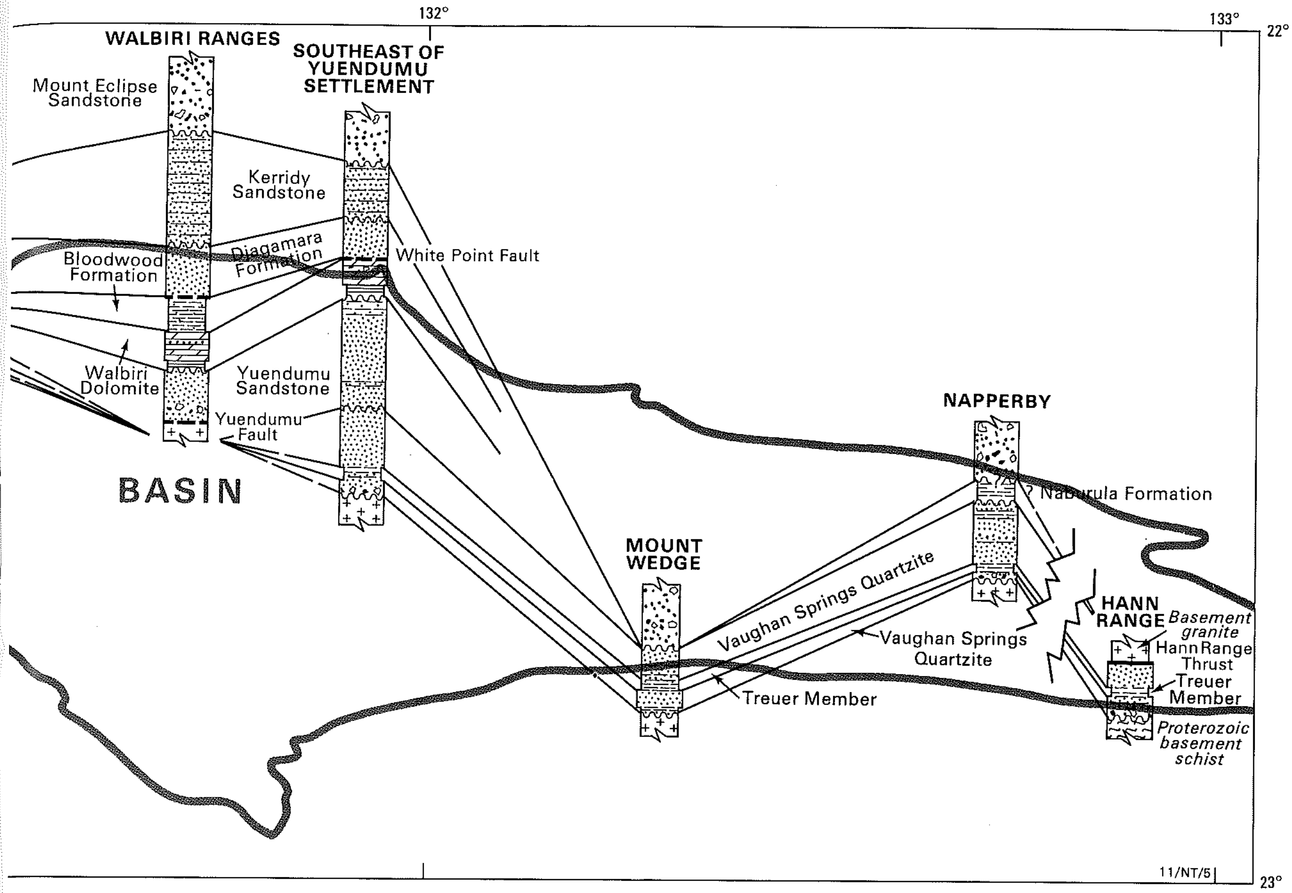


Fig. 6. Stratigraphic columns at selected localities. The midpoints of the columns coincide with the localities of the measured sections on the map.

FORMATIONS IN THE NGALIA BASIN

EX-3	*EX-4*	*EX-5*	*EX-6*	*EX-7*	*EX-8*	*EX-9*	*EX-10*	*EX-11*	*EX-12*	*EX-13*	*EN-1*	*EN-2*	*WN-1*	*WN-2*	*EN-LM-1,2,3*
			122+		15+	512+				115+					
		232			332										
		238+	52+		73+			122+	82+	227					
433+*															
				703+			555+								
									150+						
	180+						361+	1750			127+	107+	402+	320+	2500+
								623					30	50	700

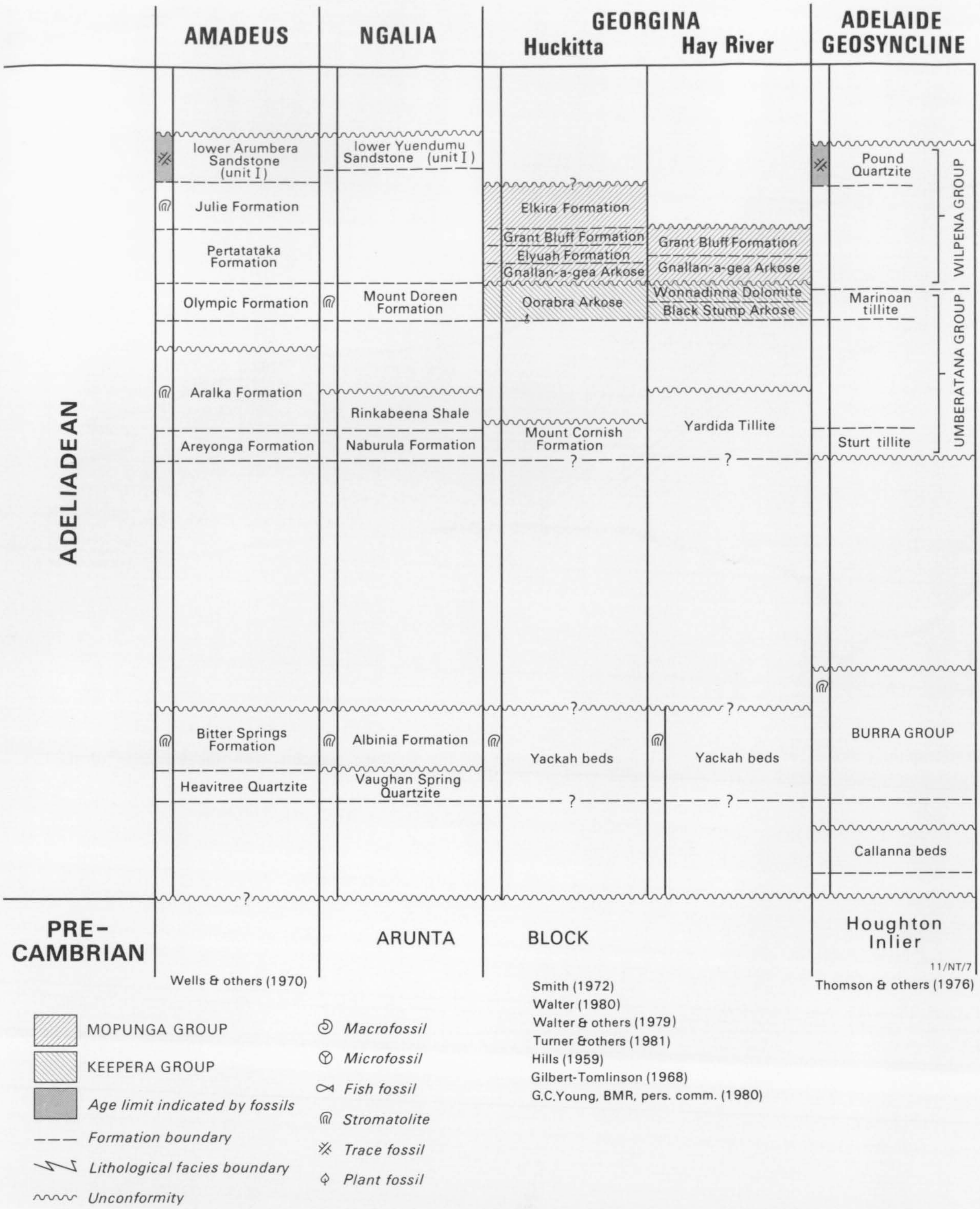
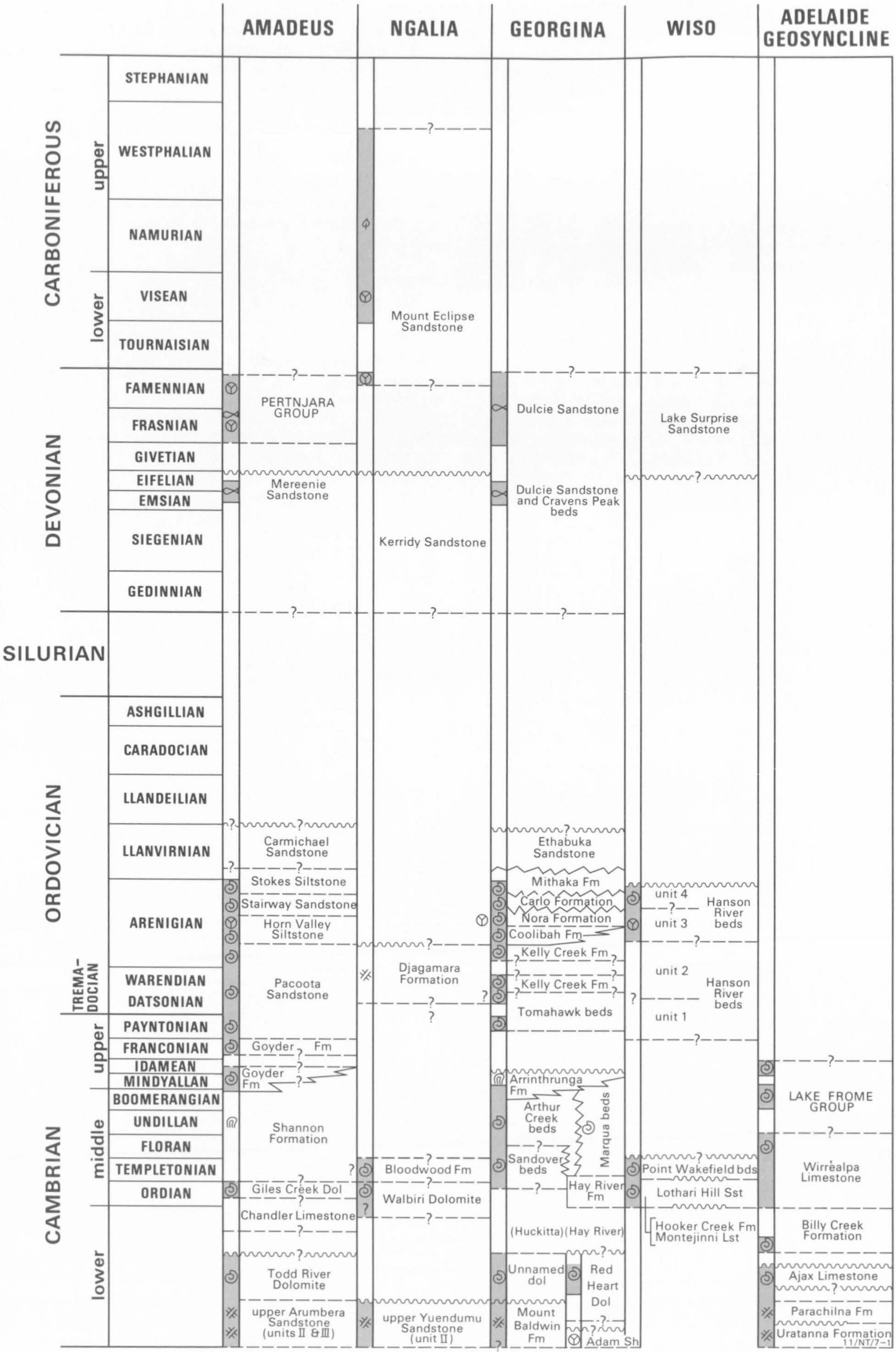


Fig. 7. Regional stratigraphic correlations of Adelaidean units in the Ngalia, Amadeus, and Georgina Basins and the Adelaide Geosyncline.

Fig. 8. Regional stratigraphic correlations of Palaeozoic units in the Ngalia, Amadeus, Georgina, and Wiso Basins and the Adelaide Geosyncline. Stratigraphic terminology and ages for the Wiso Basin units are from Gilbert-Tomlinson *in* Kennewell & Huleatt (1980); literature references to the other sequences, and a key to the symbols, are included in Fig. 7.


AMADEUS
NGALIA
GEORGINA
WISO
ADELAIDE GEOSYNCLINE
CARBONIFEROUS
upper
lower
STEPHANIAN
WESTPHALIAN
NAMURIAN
VISEAN
TOURNAISIAN
DEVONIAN
FAMENNIAN
FRASNIAN
GIVETIAN
EIFELIAN
EMSIAN
SIEGENIAN
GEDINNIAN
SILURIAN
ORDOVICIAN
ASHGILLIAN
CARADOCIAN
LLANDEILIAN
LLANVIRNIAN
ARENIGIAN
TREMA-DOCIAN
WARENDIAN
DATSONIAN
CAMBRIAN
upper
middle
lower
PAYNTONIAN
FRANCONIAN
IDAMEAN
MINDYALLAN
BOOMERANGIAN
UNDILLAN
FLORAN
TEMPLETONIAN
ORDIAN
Mount Eclipse Sandstone
PERTNJARA GROUP
Dulcie Sandstone
Lake Surprise Sandstone
Mereenie Sandstone
Dulcie Sandstone and Cravens Peak beds
Kerridy Sandstone
Carmichael Sandstone
Ethabuka Sandstone
Stokes Siltstone
Mithaka Fm
Stairway Sandstone
Carlo Formation
Horn Valley Siltstone
Nora Formation
Coolibah Fm
unit 4
unit 3
Hanson River beds
Kelly Creek Fm
Djagamara Formation
Pacoota Sandstone
Kelly Creek Fm
unit 2
Hanson River beds
Tomahawk beds
unit 1
Goyder Fm
Goyder Fm
Arrinthrunga Fm
LAKE FROME GROUP
Arthur Creek beds
Marqua beds
Shannon Formation
Sandover beds
Bloodwood Fm
Point Wakefield bds
Wirrealpa Limestone
Giles Creek Dol
Walbiri Dolomite
Hay River Fm
Lothari Hill Sst
Chandler Limestone
(Huckitta) (Hay River)
Hooker Creek Fm
Montejinni Lst
Billy Creek Formation
Todd River Dolomite
Unnamed dol
Red Heart Dol
Ajax Limestone
upper Arumbera Sandstone (units II & III)
upper Yuendumu Sandstone (unit II)
Mount Baldwin Fm
Adam Sh
Parachilna Fm
Uratanna Formation
11/NT/7-1

granule conglomerate and sandstone commonly form the base locally. High-angle cross-bedding is common in the orthoquartzite and sandstone, and ripple marks, flow casts, mud-pellet casts, and mud-cracks are prevalent in places. Thinly bedded platy sandstone and siltstone in the lower part of the formation are mapped as the Treuer Member (see p. 20).

The formation name is derived from Vaughan Springs, in the basin's western zone.

Contacts

The Vaughan Springs Quartzite lies unconformably or is faulted against basement granite and, less commonly, metamorphic rocks. This contact is exposed in innumerable places around the margins of the basin (Fig. 9).

The quartzite is possibly disconformably overlain by the Albinia Formation in the southwest Vaughan Springs Syncline. It is unconformably overlain by diamictite of the ?Naburula Formation in the central northwest flank of the Vaughan Springs Syncline; by the Mount Doreen Formation in the Treuer Range and southern and western dip slopes of the Wanapi Escarpment; by the Yuendumu Sandstone in the central northern part of the basin southeast of Yuendumu; by the Mount Eclipse Sandstone in the Treuer Range at an isolated outcrop 40 km southwest of Yuendumu, and probably along parts of the basin's southern margin. The Mount Eclipse Sandstone occurs in a stratigraphic drill-hole close to outcrops of the Vaughan Springs Quartzite at the northern edge of the Stuart Bluff Range.

Type section

The type section, EX-11 (Fig. 11; see also MS-1), is on the northwest flank of the Vaughan Springs Syncline, about 6 km west of Mount Doreen homestead.

History

The earliest recorded observations of the Vaughan Springs Quartzite were made by Maurice & Murray (1904) and Chewings (1928). Tindale (1933) included the formation in his Hann Range-Uldirra Hill-Crown Hill series of unmetamorphosed quartzite and conglomerate.

Rivereau (1965) informally referred to the quartzite along the northern margin of the basin as unit a, but the quartzite along the southern margin, which he considered to be different from any other units of the

Fig. 9. Proterozoic granite capped by a thin layer of the Vaughan Springs Quartzite in the Wanapi Escarpment. (GA714)

northern margin, he referred to as 'undifferentiated Upper Proterozoic'.

Cook (1963) and Cook & Scott (1967) split the formation into two informal units: unit A^1—a poorly sorted conglomerate and conglomeratic siltstone with minor sandstone at the base of the succession; and unit A—the overlying intensely silicified sandstone. Cook & Scott (1967) reported the basal siltstone to be tillitic in aspect, but observed no striae on the boulders forming the conglomerate. There is no evidence that their unit A^1 has a glacial origin, and it is included in the Vaughan Springs Quartzite as a basal conglomerate. They did not recognise the Treuer Member lithologies.

Distribution and outcrop

The Vaughan Springs Quartzite underlies and is exposed mainly in two long belts at the northern and southern margins of the Ngalia Basin. Outliers of the formation occur near Nancy Hill in the east, and undifferentiated sandstone of Adelaidean age at Sandford Cliffs in the west is lithologically similar to the Vaughan Springs Quartzite.

The orthoquartzite beneath the Treuer Member comprises the bulk of the prominent outcrops throughout the basin, except in the Treuer Range, where the orthoquartzite above the Treuer Member is more prominently exposed.

The formation is intensely silicified and thus highly resistant to weathering, forming mountain ranges, cuestas, mesas, and prominent escarpments.

Thickness

The Vaughan Springs Quartzite thickens gradually from about 300 m in the east to over 2500 m in the west. The thickness in the type section (EX-11, Fig. 11) is about 1750 m and is the only measured section that shows upper and lower contacts. The thickest exposure of the Vaughan Springs Quartzite known in the Ngalia Basin is in an unnamed group of hills in the western zone about 6 km southeast of Mount Carey; over 2500 m of the formation was measured here in three composite sections—EN-LM-1, 2 and 3(MS-1). Along the southern margin of the basin, the thickest-known exposure of the formation is estimated to be at least 450 m in the area of Central Mount Wedge.

Lithofacies

With few exceptions the Vaughan Springs Quartzite is of uniform lithology throughout the basin. The main differences are minor variations in grainsize, and beds that lens out over short distances.

The characteristic rock type is a pink, white, or grey, massive to thickly bedded and cross-bedded orthoquartzite that commonly shows a pitted weathered surface caused by weathering and removal of ?pyrite crystals. In contrast, some of the interbedded quartz sandstones are very friable and have only a thin silicified crust.

About 70 percent of the formation in the type section is arenaceous; the Treuer Member forms the bulk of the predominantly lutite sequence. The basal part of the type section below the Treuer Member comprises about 200 m of white, thinly cross-bedded medium-grained orthoquartzite which is highly silicified over the basal 20 m. Orthoquartzite about 1000 m thick above the Treuer Member is mostly medium but includes some fine and coarse-grained, thick-bedded to massive, pink, white, and some grey, tough, mostly silicified, friable in part, well rounded, and well sorted, and contains pellet casts.

Although no basal conglomerate is exposed at the type section, most other sequences in the formation contain beds of conglomerate of various thicknesses at the contact with the basement. Exceptions are outcrops from the Siddeley Range to Mount Cockburn, where orthoquartzite commonly rests on basement, and in the western Stuart Bluff Range, where the lowermost beds in the formation are in places shale and siltstone. At the base of the formation in the eastern part of the basin, arkose is more common than conglomerate.

The most common basal conglomerate consists of granules and pebbles of quartzite and vein quartz in a hematitic groundmass of angular quartz grains and silt; the hematite is commonly confined to grain boundaries. Granitic phenoclasts are rare. The largest-known phenoclasts are of quartzite up to 1 m across in the Wanapi Escarpment. At Central Mount Wedge, 30 m of poorly sorted conglomerate with phenoclasts chiefly of quartzite up to 25 cm is the thickest-known basal conglomerate; near its base the matrix contains concentrations of corroded crystals of magnetite. In places the basal granule conglomerate contains abundant fragments of green illite similar to that which occurs in the underlying deeply weathered granite; this suggests that some of the conglomerates originated either from a residual lag gravel or as a fossil regolith.

Conglomerate interbedded in the formation is rare; a well-rounded pebble conglomerate in a lens up to 3.5 m thick occurs 15 m above the base of the formation near Patty Well at the eastern end of the Stuart Bluff Range.

The orthoquartzites in the formation above and below the Treuer Member are essentially monomineralic and mostly evenly medium-grained, though in places minor coarse-grained feldspathic sandstone occurs in the orthoquartzite. Minor mineral constituents include detrital tourmaline and zircon, and sericite. Weathering and diagenesis have produced stylolites, intense ferruginisation along joints, chalcedonic silica in a basal purple fine-grained sandstone, and pitted surfaces due to the weathering out of either pellets or possibly euhedral pyrite.

Sedimentary structures common in the orthoquartzites are medium-scale and high-angle cross-stratification, oscillation and translation ripple marks (including oscillation ripple marks with a ripple index of 6-9), flow casts, and desiccation cracks.

Apart from the Treuer Member, lutite is not common in the formation. Siltstone is present in the lower orthoquartzite in the Stuart Bluff Range and is thickest 19 km east-northeast of Central Mount Wedge (sections EN-1 and EN-2, see MS-1). Near Mount Wedge homestead, green, blue, and in places red shale beds up to about 30 m thick lie above a few metres of thin basal conglomerate, coarse-grained sandstone, and purple fine-grained sandstone. The shale is finely micaceous, thin-bedded to laminated and contains desiccation cracks and ripple marks. Some red and red-brown pebbly siltstone and mudstone occur in the upper part of the basal conglomerate on the south side of the Naburula Hills.

At Sandford Cliffs, about 250 m of sandstone correlated with the Vaughan Springs Quartzite is preserved in an isolated westerly plunging syncline, but no contacts with older rocks are visible. The sandstone is medium and fine-grained, white (rarely red-brown), cross-bedded, well sorted, and has a small amount of silt in the matrix, which is commonly opalised; it is mostly thin-bedded and commonly traversed by numerous small quartz stringers.

Age

The Adelaidean age of the Vaughan Springs Quartzite is supported by isotopic dating of contained glauconite, by superposition, and by a comparison with better dated sequences in nearby areas. The only fossils that it contains are possible tracks and trails.

If the Vaughan Springs Quartzite is contemporaneous with the Heavitree Quartzite of the Amadeus Basin, then a Riphean or older age is indicated. Walter (1972) has correlated stromatolites in the Loves Creek Member of the Bitter Springs Formation, which conformably overlies the Heavitree Quartzite, with the late Riphean of the USSR (950 ± 50 m.y. to 680 ± 20 m.y.). Dating of basement rocks by Black, Shaw, & Offe (1980) has shown that the Heavitree Quartzite is younger than about 900 m.y., the isotopic age of dolerite dykes from the Stuart Dyke Swarm in the southern part of the Arunta Block, south of the Ngalia Basin.

Cooper & others (1971) calculated a minimum age of 1280 m.y. from Rb-Sr and K-Ar measurements on five glauconite samples from the Treuer Member, and suggested that sedimentation in the Ngalia Basin began shortly before this time.

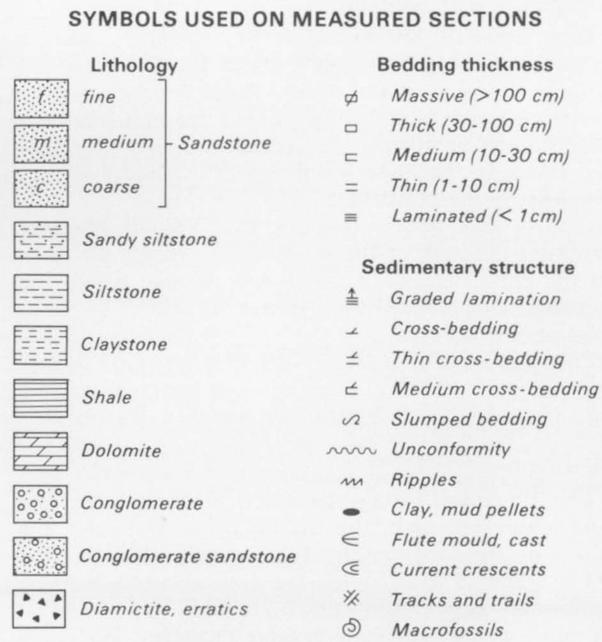
Migmatites unconformably overlain by the Heavitree Quartzite near Ormiston Pound at the northern margin of the Amadeus Basin were dated by Marjoribanks & Black (1974) as 1076 ± 50 m.y., which they regarded as a maximum age for the start of sedimentation along the northern margin of the Amadeus Basin. They observed that—if the Heavitree and Vaughan Springs Quartzites are equivalents—this age conflicts with both the 1280 m.y. date that Cooper & others (1971) derived for the Vaughan Springs Quartzite and an Rb-Sr estimated age of 1170 m.y. that V. M. Bofinger (written communication in Wells & others, 1967) derived for a single specimen of shale from the Bitter Springs Formation. They concluded that—if the late migmatisation and granite intrusion in the Arunta Block are correctly dated—then either the Vaughan Springs Quartzite is at least 200 m.y. older than the Heavitree Quartzite, or the 1280 m.y. date quoted by Cooper & others (1971) for the Vaughan Springs Quartzite is too old, which it would be if the analysed glauconite was of detrital or partly detrital origin.

There seems little reason to doubt the correlation of the Vaughan Springs and Heavitree Quartzites (see below), and hence the glauconite dated for the Vaughan Springs Quartzite and the Rb-Sr age of the shale in the Bitter Springs Formation must be considered unreliable.

Correlation

The Vaughan Springs Quartzite is correlated with the Heavitree Quartzite of the Amadeus Basin (Fig. 7) on the basis of lithological similarity and their similar unconformable relations with rocks of the Arunta Block; also, they both antedate late Precambrian tillites and thicken westwards; and, in addition, outcrops of quartzite tightly infolded with the basement rocks are almost continuous between the Ngalia and Amadeus Basins, and outcrops of the two quartzites are only 20 km apart in the eastern parts of the two basins. Clarke (1975, 1976) considered that the uppermost few beds of clean quartz sandstone at Central Mount Wedge can be correlated with the lower part of the youngest member of the Heavitree Quartzite.

The Munyu Sandstone of the Birrindudu Basin (Blake, 1978) can be correlated with the Vaughan Springs Quartzite on lithological and superpositional grounds, and for similar reasons with the Heavitree Quartzite of the Amadeus Basin (Blake, 1977). The Townsend Quartzite in the Officer Basin is probably also a correlative. The sandstone at Sandford Cliffs



ABBREVIATIONS USED ON MEASURED SECTIONS

Mineralogy and Lithology

Cgl	Conglomerate
Do (do)	Dolomite (ic)
Fs (fs)	Feldspar (thic)
Gl (gl)	Glauconite (ic)
Hem (hem)	Hematite (ic)
Fe (fer)	Iron oxide (ferruginous)
Kao (kao)	Kaolin (itic)
Lim	Limonite
Mn	Manganese
Mi (mi)	Mica (ceous)
Oqt	Orthoquartzite
Q (qc)	Quartz (itic)
Qt	Quartzite
Sst	Sandstone
Sh	Shale
Si (si)	Silica (eous)
Sltst	Siltstone

Qualifier

dk	Dark
lt	Light
sli	Slight

Colour

bk	Black
bl	Blue
br	Brown
cr	Cream
gn	Green
gy	Grey
og	Orange
pk	Pink
pu	Purple
r	Red
wh	White
y	Yellow

Grainsize

vf	Very fine
f	Fine
m	Medium
c	Coarse
vc	Very coarse

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Fig. 10. Key to symbols and abbreviations used in graphically illustrated type sections in Figs. 11, 13, 16, 18, 19, 20, 21, and 23.

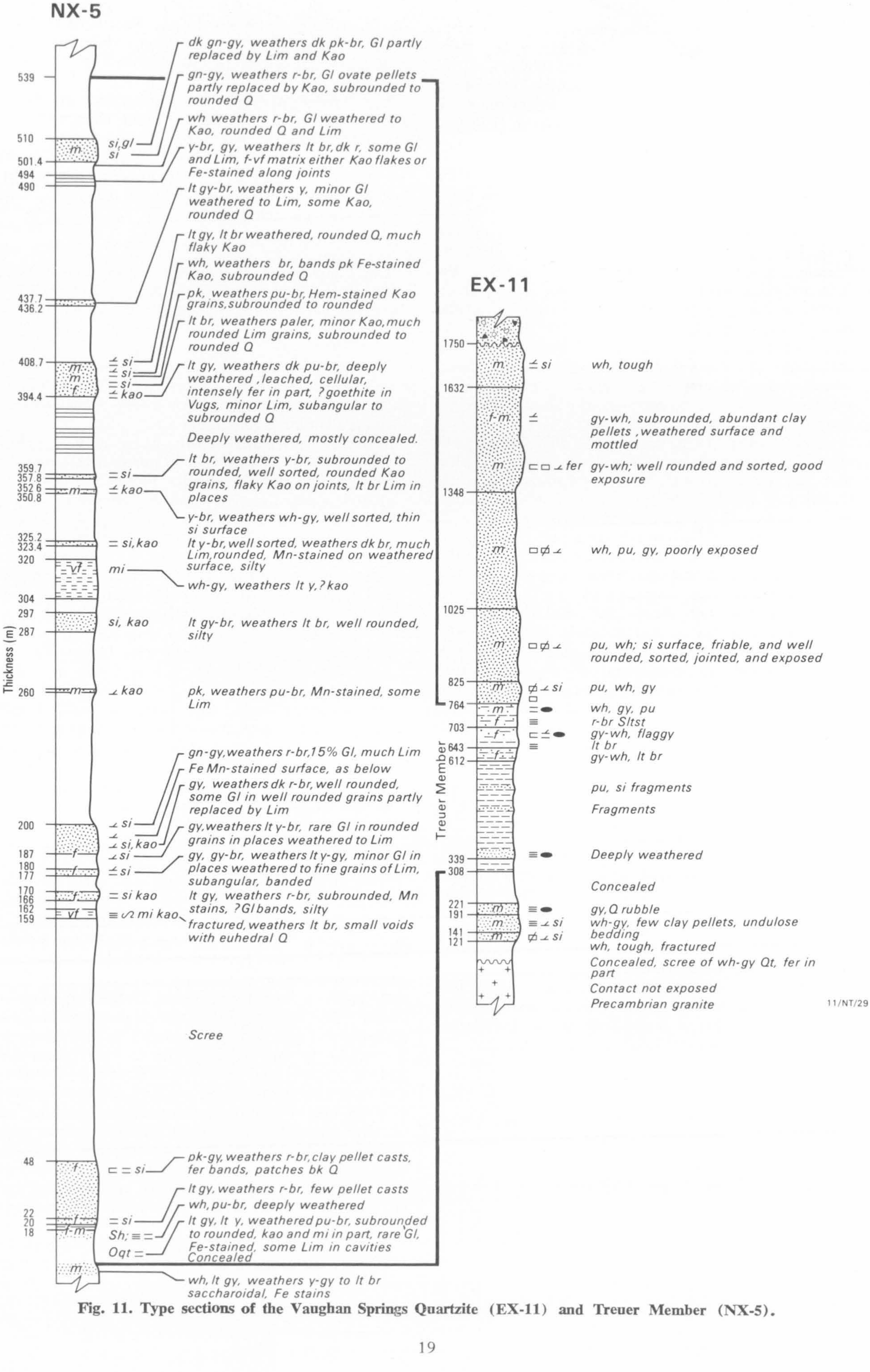


Fig. 11. Type sections of the Vaughan Springs Quartzite (EX-11) and Treuer Member (NX-5).

may be equivalent to the Adelaidean Vaughan Springs Quartzite, though it is better sorted, more thinly bedded, and generally not as intensely silicified.

In the southern part of the Georgina Basin the lower part of the Yackah beds (Walter, 1980) may be equivalent to the Vaughan Springs Quartzite (Fig. 7).

Palaeogeography and history of deposition

The Vaughan Springs Quartzite was deposited after prolonged erosion had reduced the Precambrian basement to a peneplain.

The occurrence of a predominantly orthoquartzite formation in a sheet-like body which has a minimum thickness of about 460 m, extends laterally for a distance of about 500 km, and underlies an area of about 16 000 km^2 indicates a widespread and uniform interval of sedimentation. (The figure of 16 000 km^2 is only an estimate of the area at present underlain by the formation; the depositional area was without doubt several orders of magnitude greater if the formation was contiguous with the correlative quartzites of neighbouring basins.)

Clarke (1975, 1976) considered that initial sedimentation consisted of alluvial fan deposits. Later, both the Heavitree and Vaughan Springs Quartzites record two or possibly three marine transgressions, which were followed by regressions—probably the result of minor uplifts interrupting a period of general and gentle subsidence. Palaeocurrent directions, grain-size isograds, and isopach trends suggest that the provenance lay to the northeast and north-northeast.

At Central Mount Wedge the basal conglomerate is considered to be of fluvial origin (Clarke, 1975, 1976). It is followed by silty and conglomeratic beds of mixed lacustrine and fluvial origin, and in turn by fluvial feldspathic sandstone, tidal-flat fine-grained sandstone, fluvial and partly littoral medium-grained sandstone, tidal-flat argillaceous sandstone, shallow-marine clean very fine-grained sandstone, and fluvial conglomerate and conglomeratic sandstone.

Treuer Member

Definition

The Treuer Member of the Vaughan Springs Quartzite is here defined as thinly and poorly bedded white and grey siltstone with interbedded, laminated to thin-bedded white and grey sandstone. Subordinate rock types are orthoquartzite, shale, claystone, arkose, chert, and possibly evaporites. The Treuer Member is distinguished from the remainder of the Vaughan Springs Quartzite by the abundance of siltstone, clay-pellet sandstone, thinner bedding, and the presence of glauconite. The member is named from the Treuer Range, which lies in the western zone.

Type locality and section

The type section (NX-5) is about 20 km from Mount Davenport on a bearing of 238° (Fig. 11; see also MS-1).

Distribution and outcrop

Outcrops of the Treuer Member occur at widely separated localities at the margins of the basin as far west as the group of hills 8 km southeast of Mount Carey and as far east as the Hann Range. The largest continuous exposures occur in the Treuer Range.

Outcrops in the southern part of the basin are sparse. Apart from good exposures in the Hann Range, there are small poor exposures in the Stuart Bluff Range about 12 km east of Mount Wedge homestead, and in isolated hills about 16 km northeast of Newhaven homestead.

The Treuer Member was penetrated in shallow stratigraphic drillholes—BMR Mount Doreen No. 15 and BMR Napperby No. 3.

The siltstone and shale of the member weather recessively and they commonly underlie low, rubble-covered areas with resistant beds of platy grey sandstone a few centimetres high.

Thickness

The thickness of the member increases westwards from about 50 m in the Hann Range, in the east, to about 700 m near Mount Carey, in the west.

Lithofacies

Siltstone and sandstone comprise the bulk of the member. Subordinate rock types include orthoquartzite, shale, claystone, and rare arkose. The main attributes of the predominant rock types are:

Siltstone—variegated, mostly white to pale yellow, yellow-brown, creamy yellow, purplish red, and red-brown; fine-grained; finely micaceous; evaporite efflorescence; commonly deeply weathered and in places ironstained.

Sandstone—pale green, pale grey, white, and pale yellow; medium and fine-grained; mostly rounded quartz grains; well sorted; compact and tough; thin and graded-bedded; cross-stratification and flute casts; highly siliceous; well-rounded and some elongate grains of glauconite abundant in restricted beds; partly micaceous, hematitic, feldspathic, and silty; abundant small clay pellets; authigenic quartz overgrowths.

Orthoquartzite—pale grey, grey to light brown, and yellow to white; fine-grained; subangular to sub-rounded; tightly packed; thin-bedded, laminated, and flaggy; cross-stratification, small-scale oscillation ripples, and clay pellet casts; kaolinitic; authigenic quartz overgrowths; numerous small-scale ?worm tracks.

Shale—white, buff, purple, and red; friable; laminated and thin-bedded; slump structures and small-scale cross-stratification; finely micaceous; silicified in part.

The dominant lithologies in the Treuer Member in the northwestern part of the Ngalia Basin can be summarised as follows. The lower part consists of a fine-grained subangular to well-rounded pale grey flaggy orthoquartzite containing considerable amounts of kaolin. The quartz grains are tightly packed and cemented by quartz overgrowths. This orthoquartzite is overlain by thin-bedded white to pale yellow fine-grained siltstone and claystone. Above the siltstone is a compact medium-grained glauconitic sandstone with rounded quartz grains, well-rounded glauconite, and scattered hematite grains of silt size; the quartz grains are cemented by quartz overgrowths. The glauconitic sandstone is overlain by an alternating sequence of white, yellow, buff, purple, and red siltstone and shale interbedded with grey to light brown orthoquartzite up to 3 m thick.

The rock types in the Treuer Member penetrated in BMR Mount Doreen No. 15 stratigraphic drillhole consist of interbedded orthoquartzite, quartz sandstone, siltstone, and claystone. Cubic moulds, probably after pyrite, are common in orthoquartzite. In common with outcrops of the member the bedding is poorly defined and incompetent.

Nodules of specular hematite are present in siltstone of the Treuer Member 16 km west-southwest of Napperby homestead, and staining of siltstone and sandstone in the member by iron and manganese oxides is probably a weathering phenomenon.

The siltstone of the member is commonly replaced by chert. Grey siltstone in outcrops near Native Gap in the Hann Range is partly replaced by nodules and irregular patches of white and grey chert. Similar chert in siltstone was cored in BMR Napperby No. 3, and occurs in outcrops southeast of Mount Carey.

Evaporite efflorescences mainly on the siltstone are present in many exposures, chiefly at Native Gap in the Hann Range, southwest of Napperby homestead, and near Eva Spring in the western Treuer Range; the water soluble portion contains minor amounts of sodium, calcium, magnesium, potassium, chloride, and sulphate ions (Table 10).

Feldspar commonly occurs as an accessory in the sandstone, but an arkose 13 km west of Waite Creek contains 40-45 percent of well-rounded fine-grained potash feldspar, together with subrounded to rounded quartz showing authigenic overgrowths, and minor zircon and iron oxides.

Intraformational breccia occurs in the thickest-known sequence of the member southeast of Mount Carey (Fig. 12). The partly detached and broken clasts in the breccia are composed of tabular bodies of thin-bedded fine-grained sandstone incorporated in a siltstone matrix; they probably formed partly by desiccation and partly by disruption during the influx of the siltstone matrix. Disruption was sufficient in places to completely overturn the tabular clasts.

Environment of deposition

The Treuer Member was probably deposited in a shallow-marine environment; the presence of glauconite and possible interbedded evaporites indicates a partly restricted marine, possibly lagoonal origin for these sediments.

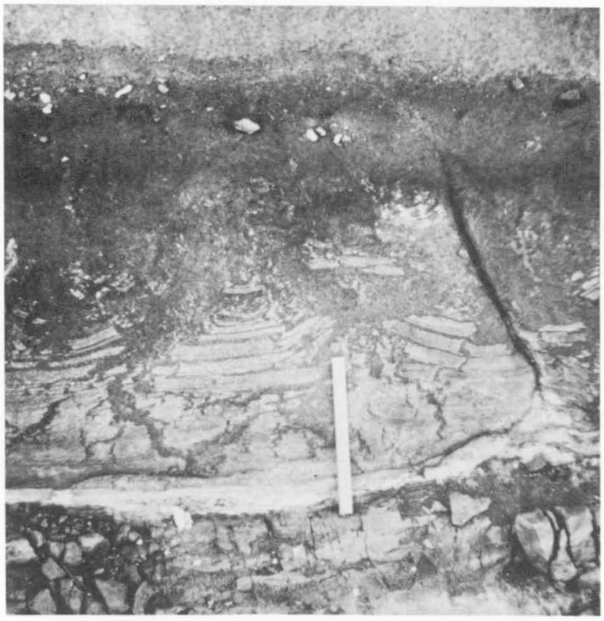


Fig. 12. Intraformational breccia of siltstone beds in the Treuer Member of the Vaughan Springs Quartzite 6.5 km southeast of Mount Carey. (GA1588)

Correlation

The Treuer Member of the Vaughan Springs Quartzite does not appear to have a lithological equivalent in the Heavitree Quartzite of the Amadeus Basin or in similar chronostratigraphic intervals in other basins.

Albinia Formation (new name)

Definition

The Albinia Formation is here defined as a sequence of siltstone, shale, and dolomite. The siltstone is mostly white in outcrop, dolomitic in part, and in places contains tough dolomitic nodules. The dolomite is black to dark grey, weathering light grey, foetid, thin-bedded, and contains stromatolites and thin beds of black, grey, or white chert.

The name is derived from Albinia Spring (lat. 22°25′20″S, long. 130°37′55″E), on Waite Creek, in the western zone.

History

Wells & others (1968) originally mapped the Albinia Formation as the basal part of the Mount Doreen Formation. The beds are now considered to be a separate stratigraphic unit genetically unrelated to the Mount Doreen Formation.

Type section

The type section lies in the southwest part of the Vaughan Springs Syncline (between lat. 22°20′45″S, long. 130°46′15″E and lat. 22°20′30″S, long. 130°47′05″E), and is exposed mostly in the headwaters of Waite Creek, which drains the core of the syncline.

Contacts

The Albania Formation overlies the Vaughan Springs Quartzite possibly disconformably, and is unconformably overlain by the Mount Doreen Formation. Regional relations suggest that there may also be unconformable contacts with the Naburula Formation and Rinkabeena Shale.

In the Treuer Range, dolomite of the formation occurs adjacent to outcrops of thin-bedded platy siliceous sandstone of the Vaughan Springs Quartzite, but contacts are obscured; the formation is overlain here by poorly sorted and bedded pink dolomitic chert-conglomerate of the Mount Doreen Formation.

A thin ferruginous and siliceous nodular zone separates thin-bedded quartzite of the Vaughan Springs Quartzite from white and ferruginised siltstone of the Albinia Formation in several places in the Vaughan Springs Syncline. This is probably the preserved weathered surface of the Vaughan Springs Quartzite, and may indicate a disconformable contact between these formations.

Distribution and outcrop

The Albinia Formation crops out sporadically at the southwestern end of the Vaughan Springs Syncline and in a few places on the northern flank of the basin in the Treuer Range, mainly between Bigrlyi Pass and 12 Mile Creek.

The formation crops out as low, rounded, mostly calcrete-encrusted mounds in a wide arcuate valley in the Vaughan Springs Syncline. The dolomite forms trains of rubble on the surface, and the siltstone and shale are exposed only in the larger creek beds. In the Treuer Range, only the dolomite is exposed on steep rubble-covered slopes of quartzite-cored ridges.

Thickness

The formation, although incompetently folded, is at least 150 m thick (section EX-12) and from photo-interpretation may be as much as 500 m thick in the Vaughan Springs Syncline.

Lithofacies

The most characteristic rock type in the formation is a pale grey to black foetid stromatolitic dolomite which in places contains white, grey or black chert. Although outcrop is extremely poor, the major part of the formation appears to be siltstone, dolomitic siltstone with tough dolomitic nodules in places, and shale, which are in most places deeply weathered and bleached.

The outcrops in the Treuer Range consist of dark grey stromatolitic dolomite; stromatolite columns in the dolomite vary from 2-5 cm across.

Age

The stratigraphic position of the Albinia Formation —below the Mount Doreen Formation, the younger of two Adelaidean tillites, and above a basal quartzite which by inference is younger than 900 m.y.—indicates an Adelaidean age.

The carbonaceous chert beds in the Albinia Formation contain poorly preserved spheroidal plant microfossils which are interpreted as algal remains (Appendix 4). Although similar micro-organisms have been described from the Bitter Springs Formation (Schopf, 1968; Schopf & Blacic 1971), they are not sufficiently diagnostic to be able to draw any inference on the age of the two formations.

Correlation

The Albinia Formation is lithologically similar to, and is correlated with, the Bitter Springs Formation of the Amadeus Basin (Wells & others, 1970; Walter, 1972), which in turn is correlated with the upper part of the Red Cliff Pound Group by Blake (1978) and is probably equivalent to the upper part of the Yackah beds (Walter, 1980) in the southern Georgina Basin (Fig. 7). In the northern part of the Officer Basin the Lefroy, Browne, and Madley beds are correlated on lithological, superpositional, and regional evidence with the Bitter Springs Formation of the Amadeus Basin (Jackson & van de Graaff, 1981), and hence by inference with the Albinia Formation.

Palaeogeography

The Albinia Formation was deposited in a relatively stable environment in a shallow epicontinental sea; the microfossil assemblage in black cherts of the formation suggest that the environment was intertidal to supratidal (Appendix 4). The formation and its equivalents were deposited over a large part of central Australia in a shallow Adelaidean sea, which may have extended at least as far west as the Officer Basin and as far north as the Birrindudu Basin.

NABURULA FORMATION

Definition

The Naburula Formation consists predominantly of dark grey to black shale and minor siltstone, with interbeds of green-grey and dark brown dolomite and a basal diamictite (Wells *in* Preiss & others, 1978).

History of investigation

The Mount Doreen Formation as originally defined (Wells & others, 1968) included a thin sequence of interbedded dark grey and black shale and dolomite overlain successively by green shale, diamictite, pink dolomite, and red shale. The discovery by R. P. Coats and W. V. Preiss, in 1977, of a thin diamictite underlying this section prompted Wells (*in* Preiss & others, 1978) to separate the interbedded dark grey and black shale and dolomite from the Mount Doreen Formation, and include them, together with the basal thin diamictite, in a separate unit which he defined as the Naburula Formation.

The name of the formation is derived from the Naburula Hills (lats. 22°14′ to 22°20′S, longs. 131°12′ to 131°19′E), in the western zone.

Type locality and section

The type section, WX-6 (Fig. 13; see also MS-2), is in the headwaters of Patmungala Creek at latitude 22°17′35″S, longitude 131°18′55″E, and comprises predominantly shale and subordinate diamictite and minor dolomite. A thin sequence of laminated fine-grained green-grey and dark brown ironstained, deeply weathered dolomite forms a characteristic marker at the top of the formation. This dolomite is underlain by an interbedded sequence of dark grey to black well-bedded shale and dolomite similar to the dolomite marker. The basal part of the type section comprises diamictite which has a poorly sorted green-brown

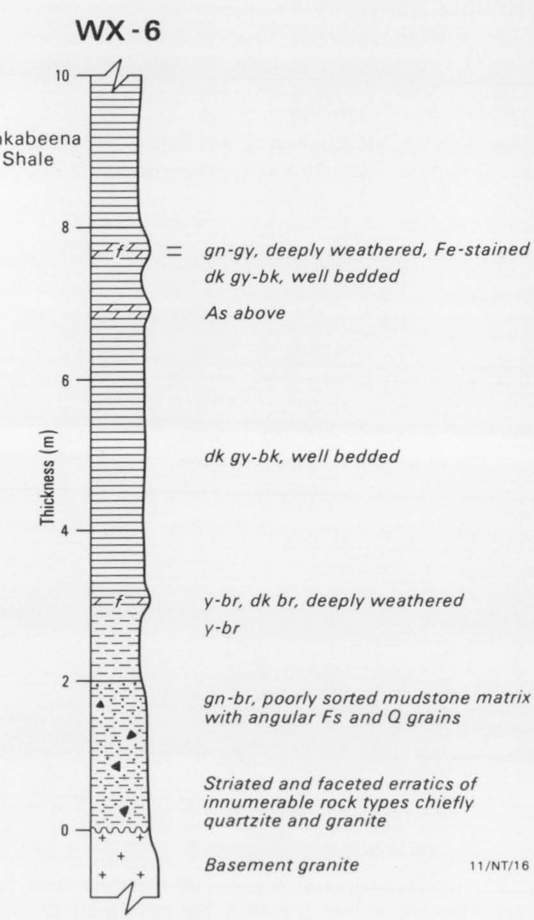


Fig. 13. Type section of the Naburula Formation.

mudstone matrix with striated and faceted polymictic clasts. The diamictite is similar to the Mount Davenport Diamictite Member of the Mount Doreen Formation, except that its phenoclasts are generally smaller though of similar composition.

Contacts

The Naburula Formation unconformably overlies Precambrian basement granite and is conformably overlain by the Rinkabeena Shale in the type section in the eastern Naburula Hills. Diamictite, probably of the Naburula Formation, unconformably overlies the Vaughan Springs Quartzite and by inference the Albinia Formation in the Vaughan Springs Syncline, and unconformably overlies the Patmungala beds north of the Naburula Hills, but the upper contacts at these localities are concealed. Regional stratigraphic relations suggest that an unconformable contact is present with the Mount Doreen Formation.

Distribution and outcrop

Outcrops of the Naburula Formation extend intermittently around the eastern closure of the Patmungala Syncline and in a few places in the low steep banks and narrow bed of the headwaters of Patmungala Creek.

Diamictite overlying the Vaughan Springs Quartzite on the northwest flank of the Vaughan Springs Syncline is tentatively referred to the Naburula Formation. Here the formation is exposed in only a few small creek gullies draining the steep, scree-covered slopes of ridges composed of Vaughan Springs Quartzite.

Black siltstone penetrated in BMR Napperby No. 5 is correlated with the Naburula Formation.

Thickness

The Naburula Formation is 8 m thick in the type section, but elsewhere its thickness is unknown.

Lithofacies

In the eastern Naburula Hills the erratics in the basal diamictite comprise several varieties of quartzite, granite, quartz, quartz-mica schist, silicified yellow-grey siltstone, vein quartz with tourmaline, feldspar porphyry, spotted blue-grey hornfels, quartz granule grit, black slate, and grey dolomite. Quartzite, the most common rock type, includes dark grey, pink, and dense fine-grained milky grey to blue-grey varieties; another variety, which contains abundant golden brown mica, may be a hornfels. The largest erratics are of granite about 30 cm across.

The clasts are lithologically similar to those in the Mount Davenport Diamictite Member of the Mount Doreen Formation. The only differences are the presence in the Naburula Formation of striated clasts of silicified yellow-grey siltstone, and the absence of pink dolomite with jasper. The green-brown siltstone matrix is poorly sorted and commonly contains angular grains of feldspar and quartz. The erratics are commonly closely fractured and the diamictite shows incipient cleavage.

Septarian nodules from about the level of the cap dolomite of the formation are common in the bed of the creek in the upper part of the type section (Fig. 14).

Large striated, faceted, and polished, white, pink, and red quartzite boulders up to 1 m across indicate the likely presence of the formation in the northwestern flank of the Vaughan Springs Syncline. Here the out-

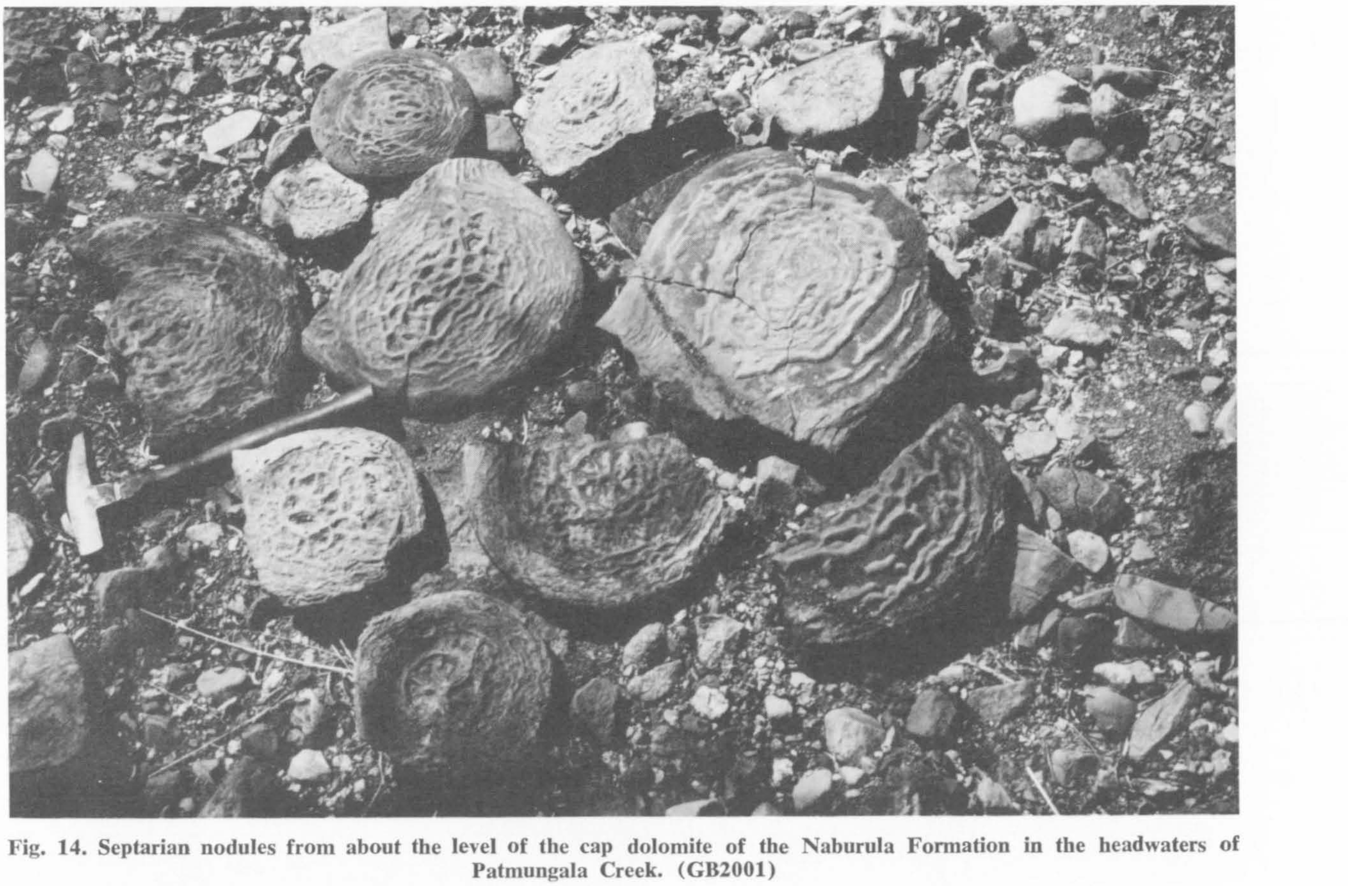
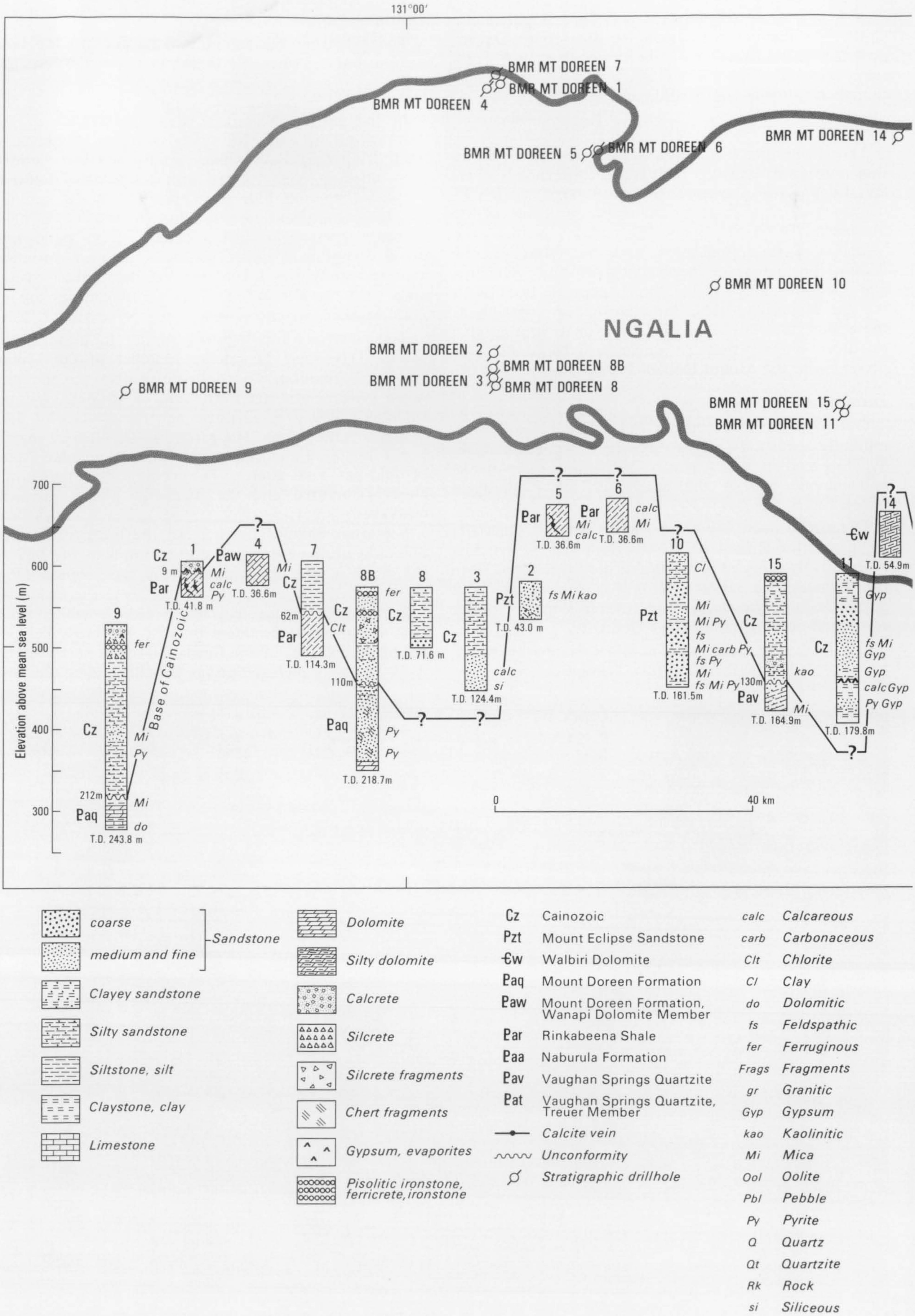


Fig. 14. Septarian nodules from about the level of the cap dolomite of the Naburula Formation in the headwaters of Patmungala Creek. (GB2001)



131°00′
BMR MT DOREEN 7
BMR MT DOREEN 1
BMR MT DOREEN 4
BMR MT DOREEN 5
BMR MT DOREEN 6
BMR MT DOREEN 14
BMR MT DOREEN 10
NGALIA
BMR MT DOREEN 2
BMR MT DOREEN 8B
BMR MT DOREEN 3
BMR MT DOREEN 8
BMR MT DOREEN 9
BMR MT DOREEN 15
BMR MT DOREEN 11
Elevation above mean sea level (m)
700
600
500
400
300
Base of Cainozoic
9 Cz fer Mi Py 212m Mi Ꞓaq do T.D. 243.8 m
1 Cz 9 m Ꞓar Ꞓaw Mi calc Py T.D. 41.8 m
4 Mi T.D. 36.6m
7 Cz 62m Ꞓar T.D. 114.3m
8B fer Cz Clt 110m Ꞓaq Py Py T.D. 218.7m
8 Cz T.D. 71.6 m
3 Cz T.D. 124.4m
2 Pzt fs Mi kao calc si T.D. 43.0 m
5 Ꞓar T.D. 36.6m
6 Ꞓar Mi calc calc Mi T.D. 36.6m
10 Cl Pzt Mi Mi Py fs Mi carb Py fs Py Mi fs Mi Py T.D. 161.5m
15 Cz kao 130m Ꞓav Mi T.D. 164.9m
11 Cz Gyp fs Mi Gyp Gyp calc Gyp Py Gyp T.D. 179.8m
14 Ꞓw T.D. 54.9m
0 40 km
coarse
medium and fine
Sandstone
Clayey sandstone
Silty sandstone
Siltstone, silt
Claystone, clay
Limestone
Dolomite
Silty dolomite
Calcrete
Silcrete
Silcrete fragments
Chert fragments
Gypsum, evaporites
Pisolitic ironstone, ferricrete, ironstone
Cz Cainozoic
Pzt Mount Eclipse Sandstone
Ꞓw Walbiri Dolomite
Ꞓaq Mount Doreen Formation
Ꞓaw Mount Doreen Formation, Wanapi Dolomite Member
Ꞓar Rinkabeena Shale
Ꞓaa Naburula Formation
Ꞓav Vaughan Springs Quartzite
Ꞓat Vaughan Springs Quartzite, Treuer Member
Calcite vein
Unconformity
Stratigraphic drillhole
calc Calcareous
carb Carbonaceous
Clt Chlorite
Cl Clay
do Dolomitic
fs Feldspathic
fer Ferruginous
Frags Fragments
gr Granitic
Gyp Gypsum
kao Kaolinitic
Mi Mica
Ool Oolite
Pbl Pebble
Py Pyrite
Q Quartz
Qt Quartzite
Rk Rock
si Siliceous

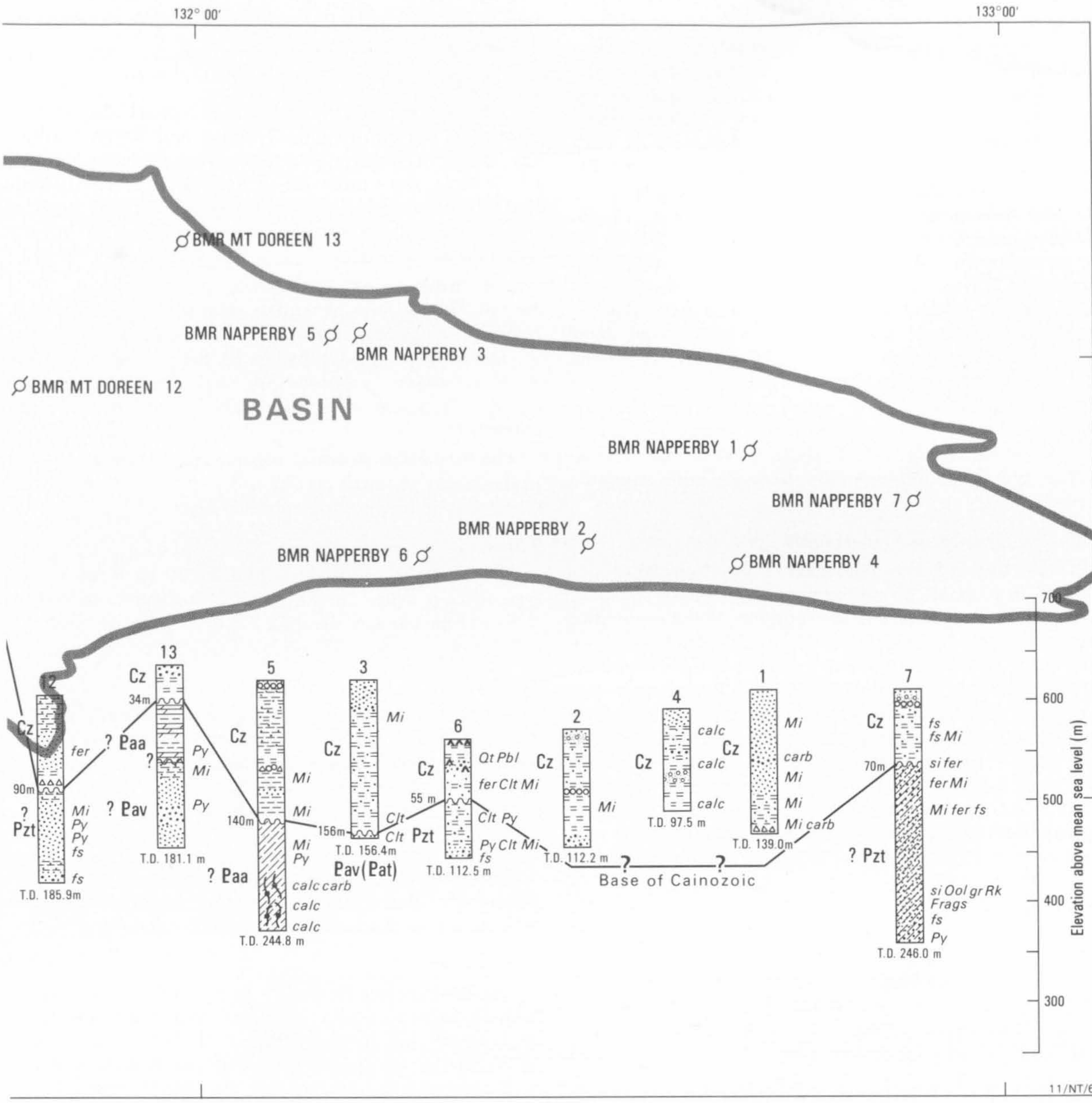


Fig. 15. Locations and simplified graphic logs of shallow stratigraphic drillholes.

crop is almost entirely covered by scree shed from adjacent high ridges of Vaughan Springs Quartzite. Poor outcrops of the formation in a few small creeks consist of white and ferruginised siltstone, and poorly sorted quartz granule to boulder conglomerate with a highly ferruginised red sandy and silty matrix. Striations are well displayed on the surfaces of the embedded phenocrysts of red and white quartzite. Other phenoclasts comprise schist, and glauconitic sandstone from the Treuer Member of the Vaughan Springs Quartzite.

Black siltstone beneath Cainozoic sediments penetrated in BMR Napperby No. 5 in the eastern part of the basin (Fig. 15) is most probably part of the Naburula Formation, but may be partly Rinkabeena Shale. The closest outcrops of the formation lie at the type section, 90 km to the east. The siltstone is dark grey to black, finely micaceous, thin-bedded, and includes small calcite veins, bituminous and pyritic aggregates and streaks, and small slump structures. It dips at 45-50° to the southwest (i.e., basinwards), and a true thickness of 105 m was penetrated.

Age

An Adelaidean age for the Naburula Formation is suggested both by continent-wide correlation and by isotopic dating of Precambrian diamictites in Western and South Australia (Bofinger, 1967; Preiss & others, 1978; Coats & Preiss, 1979; Wells, 1981; Plumb, 1981). The Naburula Formation records the older of two periods of widespread Adelaidean glaciations, which produced characteristic lithological associations and successions that can be recognised over large parts of the Australian continent including the Adelaide Geosyncline, the Officer and Georgina Basins, and the Kimberley Block of Western Australia.

Correlation

The Naburula Formation is correlated with the Areyonga Formation of the Amadeus Basin (Fig. 7), parts of the Sturtian sequence in the Adelaide Geosyncline—the Sturt Tillite and equivalents of the later Sturtian glacial phase (Preiss & Forbes, 1981)—and the Mount Cornish Formation and lower part of the Yardida Tillite in the Georgina Basin (Walter, 1980). The sequence of a basal diamictite followed by dark grey to black shale and a dark grey upper marker dolomite is common to most sequences of the older of the two Adelaidean diamictites (Preiss & others, 1978). Faceted and striated yellow-grey siltstone clasts are common to the diamictites of both the Areyonga and Naburula Formations, and may be characteristic of the older of the Adelaidean tillites in central Australia.

The diamictite of the formation may be equivalent to the basal diamictite of the Central Mount Stuart Formation. However, Preiss & others (1978) have drawn attention to lithological similarities between these diamictites and the tillites of the earlier Sturtian glacial phase (Preiss & Forbes, 1981)—the Pualco Tillite and Yudnamutana Subgroup—of the Adelaide Geosyncline.

Palaeogeography and environment

Diamictites of the Naburula Formation were deposited in response to a continent-wide glacial episode. The source and direction of transport of the diamictite is not known, but the wide variety in composition of the clasts indicates that large areas of the basement, as well as the pre-Naburula Ngalia Basin sequence, were eroded. Tectonism may have been responsible for major uplifts and caused the onset of continent-wide glaciation (Burek & Wells, 1979). A more intense glacial phase may have prevailed during the Naburula Formation, as its correlatives appear to be more widespread than the younger Adelaidean tillites. The texture of the deposit suggests a periglacial environment.

Rinkabeena Shale

Definition

The Rinkabeena Shale consists of a uniform sequence of green shale with subordinate siltstone. Its name is from Rinkabeena Bore (lat. 22°42′05″S, long. 132°12′20″E), in the eastern zone.

History

The Rinkabeena Shale was originally mapped as the lower part of the Mount Doreen Formation. Regional relations and correlations indicate that the shale is probably disconformably overlain by the diamictite of the Mount Doreen Formation; the shale was separated and named the Rinkabeena Shale by Wells (*in* Preiss & others, 1978).

Type locality and section

The type section of the Rinkabeena Shale is in the headwaters of Patmungala Creek at latitude 22°17′30″S, longitude 131°19′05″E. In the type section the formation consists predominantly of green shale with some interbeds of siltstone; it is slightly calcareous in places especially towards its base.

Contacts

In the type section the Rinkabeena Shale is overlain, probably disconformably, by the Mount Davenport Diamictite Member of the Mount Doreen Formation and conformably overlies the Naburula Formation. It may be unconformably in contact with the Albinia Formation in parts of the Vaughan Springs Syncline where the Naburula Formation was either removed by erosion or not deposited.

Distribution and outcrop

Outcrops extend intermittently around the eastern closure of the Patmungala Syncline and roughly follow the trend of Patmungala and Gum Creeks in their headwaters. Poor outcrops of laminated green siltstone that occur towards the base of conglomeratic beds of the Mount Doreen Formation in the Vaughan Springs Syncline are probably part of the Rinkabeena Shale.

The Rinkabeena Shale was penetrated in BMR Mount Doreen Nos. 5 and 6 (south flank of the Patmungala Syncline), in BMR Mount Doreen Nos. 1 and 7 (Davis Gap), and possibly in BMR Napperby No. 5. Fragmentary outcrops of shale in the Vaughan Springs Syncline are tentatively identified with the formation.

The formation weathers recessively. It crops out only in the banks of small creeks and underlies valley floors. Otherwise it forms low, rounded rises.

Thickness

The Rinkabeena Shale is about 100 m thick in the type section, which includes 15 m measured in section WX-2 (Fig. 16; see also MS-2); elsewhere its thickness is unknown.

Lithofacies

The formation mainly comprises a uniform sequence of shale. Dark grey, finely micaceous (biotite) well-sorted laminated graded siltstone, in part calcareous and pyritic and in places cut by thin quartz and calcite veins, was intersected in the drillholes.

Age

Regional correlations of the diamictites lying stratigraphically above and below the Rinkabeena Shale indicate an Adelaidean age for the formation.

Correlation

The Rinkabeena Shale lies in a similar stratigraphic position to and can be correlated with the lower shale interval in the Aralka Formation (Preiss & others, 1978) in the northeastern part of the Amadeus Basin. It is probably equivalent to the upper part of the Yardida Tillite (Walter, 1980; Fig. 7), and has a similar lithology and stratigraphic position to the Tapley Hill Formation of the Adelaide Geosyncline (table XI in Preiss & Forbes, 1981).

The disconformity between the Aralka Formation and the overlying Olympic Formation corresponds to the probable disconformity between the Mount Davenport Diamictite Member of the Mount Doreen Formation and the Rinkabeena Shale.

Palaeogeography

The Rinkabeena Shale was probably deposited in a shallow-marine environment. Correlatives of the shale in the eastern Amadeus Basin are interbedded with shallow-marine carbonate rocks.

Mount Doreen Formation

Definition

The Mount Doreen Formation as redefined (Wells *in* Preiss & others, 1978) consists predominantly of diamictite with subordinate dolomite and shale. These rock types constitute the three members of the for-

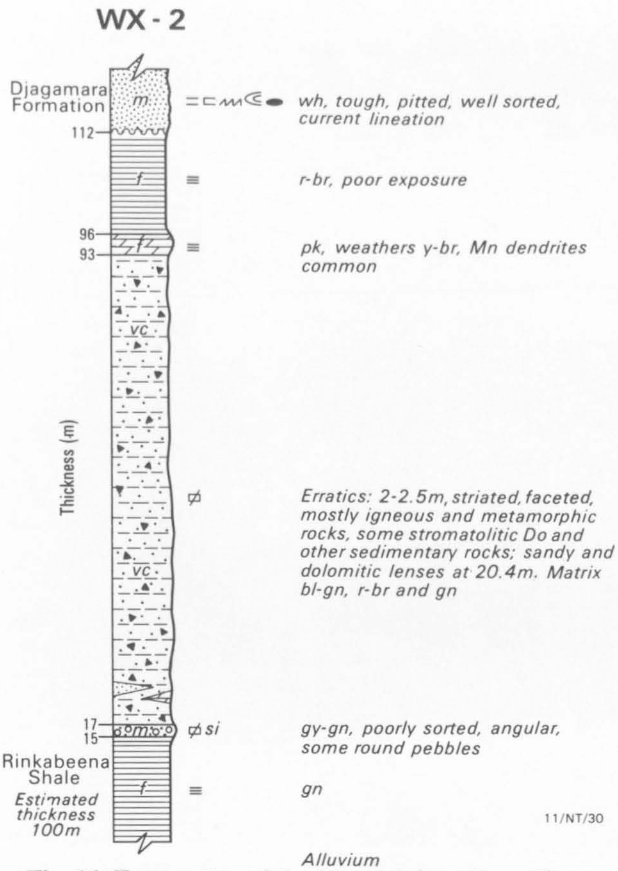


Fig. 16. Type section of the Mount Doreen Formation.

mation: the Newhaven Shale Member at the top, overlying the Wanapi Dolomite Member, which in turn overlies the Mount Davenport Diamictite Member at the base. These members are described separately below.

The formation is named after Mount Doreen, a prominent topographic feature about 20 km north of the central northern margin of the basin.

History

The Mount Doreen Formation was described previously by Wells & others (1968, 1972), Wells (1972, 1976), and Cooper & others (1971) as consisting of red shale at the top underlain successively by thin beds of pink dolomite, diamictite, and green shale. Regional considerations indicate that a disconformity is probably present between the diamictite and the green shale at the base. Wells (*in* Preiss & others, 1978) proposed that the green shale be defined as the Rinkabeena Shale, and that the name Mount Doreen Formation be retained for the remainder of the sequence.

Type section

The type section, WX-2 (Fig. 16; see also MS-2) is about 5 km south-southeast of Mount Djagamara, in the eastern part of the Naburula Hills.

Contacts

The Mount Doreen Formation lies probably disconformably on the Rinkabeena Shale, and unconformably on the Vaughan Springs Quartzite and the Albinia Formation. It is unconformably overlain by the Djagamara Formation and Mount Eclipse Sandstone. Regional stratigraphic relations suggest that it unconformably overlies the Naburula Formation.

The unconformity of the Mount Doreen Formation with the Vaughan Springs Quartzite is inferred; the contact is invariably obscured by debris shed from the steep ridges of quartzite.

The unconformity with the Djagamara Formation is present at the eastern closure of the Patmungala Syncline, in the core of the Vaughan Springs Syncline, in the eastern part of the Treuer Range, and at Davis Gap. The unconformity with the Mount Eclipse Sandstone is present in the western part of the Treuer Range.

The upper unconformable contact with the Djagamara Formation is well-exposed in the type section, and locally the basal beds of the Djagamara Formation consist of a subangular dolomite cobble conglomerate (Fig. 17), about 1.5 m thick, with a matrix of fine-grained glauconitic sandstone. The phenoclasts are derived from the dolomite near the top of the Mount Doreen Formation.

The unconformable contact of the Mount Doreen Formation with the Yuendumu Sandstone shown in the rock relationship diagram of the geological map is inferred from the regional distribution and relative ages of the formations.

Distribution and outcrop

The sparse exposures lie within a narrow strip of country about 75 km long at the northern margin of the basin in the western zone. The largest outcrops occur in an arcuate line around the eastern nose of the Patmungala Syncline; elsewhere there are small poor exposures on scree slopes or at the base of steep scarps.

Interpretation of seismic data suggests that it occurs extensively in the subsurface in the western zone, but there are no data from either seismic investigation or outcrop to indicate whether or not it extends into the central and eastern zones.

Thickness

Thicknesses of 81+ m (WX-1) and 97+ m (WX-2) were measured in the Patmungala Syncline, but in each section the basal part of the formation is obscured. No more than about 50 to 100 m of the formation is exposed in the Treuer Range. In the Vaughan Springs Syncline (sections EX-11 and EX-12, see MS-2) the thicknesses are only approximate because of poor exposure and concealed contacts.

Lithofacies

The formation comprises three members in the eastern scarp of the Naburula Hills, where the type section has been described; elsewhere outcrops are poor and members have not been differentiated. Facies changes occur in the formation over short distances, although diamictites are present in most of the exposures. In the Vaughan Springs Syncline, the rock types comprise diamictite—which is mostly covered by a scree of erratics derived from the formation—coarse-grained arkose, and some fine-grained yellow-brown laminated dolomite. In the Treuer Range between Davis Gap and Vaughan Springs, the formation comprises diamictite, red siltstone, pink stromatolitic dolomite, and poorly sorted and bedded pink dolomitic and calcareous chert-conglomerate with a friable sandy matrix.

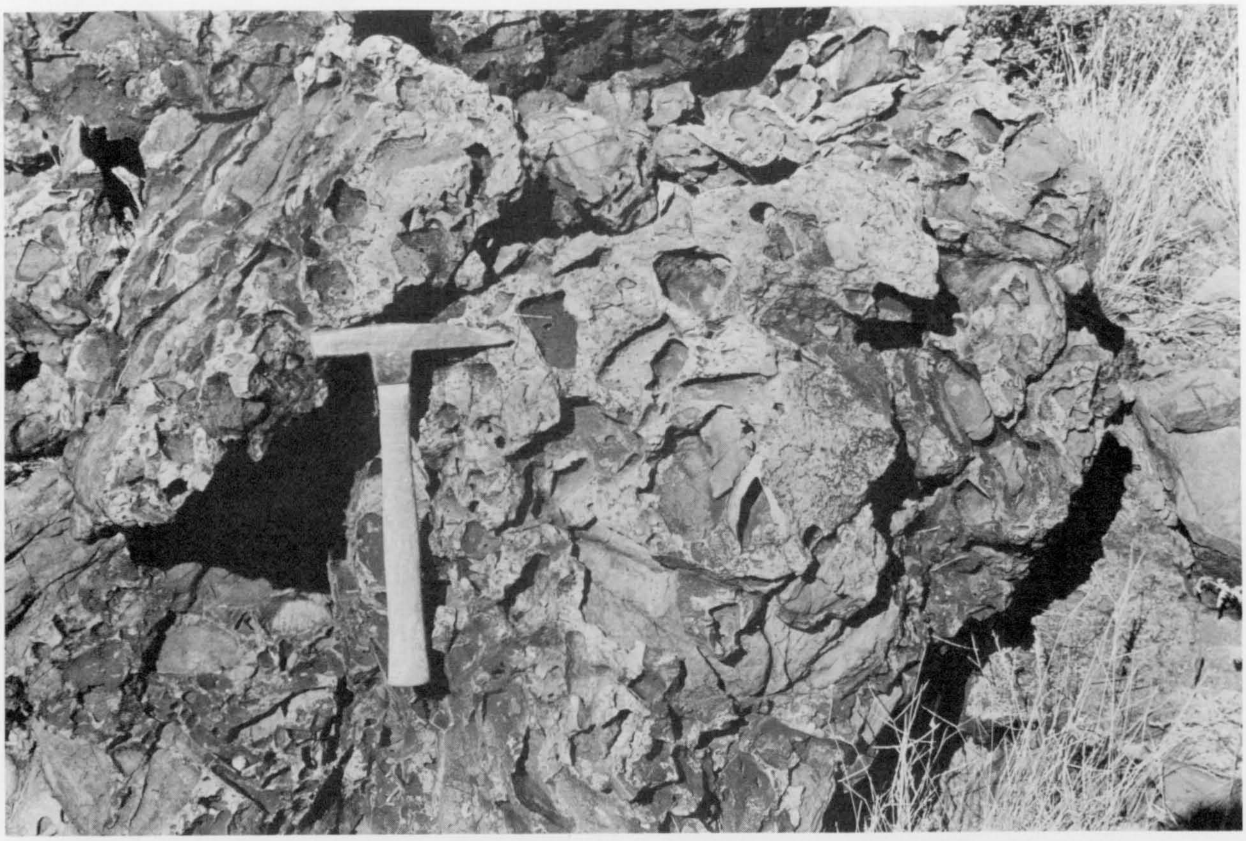


Fig. 17. Dolomite cobbles, derived from the Wanapi Dolomite Member, in basal conglomerate of the Djagamara Formation at the unconformable contact with the Mount Doreen Formation in the eastern Naburula Hills. (M516/30)

Rock types intersected in the subsurface include: thin-bedded tough light grey, red-brown, and grey-green limestone, probably near the top of the Mount Doreen Formation, in BMR Mount Doreen No. 4, near Davis Gap; oolitic and pyritic chert, dark grey dolomite, light grey sandstone, and dark grey siltstone in BMR Mount Doreen No. 8B, near the southern basin margin; and dolomite, limestone, red-brown siltstone, and coarse to fine-grained sandstone from the top of the formation in BMR Mount Doreen No. 9, also near the southern basin margin.

Age

The Mount Doreen Formation contains no fossils apart from the stromatolites in the Wanapi Dolomite Member in the Treuer Range, and remanié stromatolites in the dolomite phenoclasts from the diamictite. It lies below Ordovician and above Adelaidean formations. An Adelaidean age is indicated by its similarity to the younger of two Adelaidean glacial sequences in the Amadeus Basin, Kimberley Block, and Adelaide Geosyncline (Preiss & others, 1978).

Correlation

The Mount Doreen Formation is correlated with the following younger Adelaidean glacial sequences: the Olympic Formation and Pioneer Sandstone in the Amadeus Basin (Wells & others, 1967, 1970; Preiss & others, 1978; Wells, 1981); the Egan Formation and its equivalent in the Kimberley Block (Dow & Gemuts, 1969; Plumb, 1981); and the Marinoan Yerelina Subgroup and the Elatina and Nuccaleena Formations in the Adelaide Geosyncline (Forbes, 1971). It also correlates with the Little Burke Tillite in northwestern Queensland (de Keyser, 1972), and the Black Stump Arkose, Wonnadinna Dolomite (Walter, 1980), and Oorabra Arkose in the southwestern Georgina Basin (Fig. 7).

The generally ubiquitous association of lithologically characteristic marker beds of dolomite above the diamictite, and the implications of these marker beds for regional correlations, are discussed by Preiss & others (1978).

The arkosic sediments at the base of the Yuendumu Sandstone are similar to some of the arkosic rocks that occur near the top of the Mount Doreen Formation in the Vaughan Springs Syncline and may be the same age.

Palaeogeography and environment

The basal part of the formation has a glacial origin and is lithologically similar to Adelaidean tillites elsewhere in Australia that rest on or crop out near glaciated pavements. Most of the formation was probably formed in a periglacial environment (Wells, 1981).

Stromatolitic dolomite in the upper part of the sequence suggests a marine incursion during the late depositional history of the formation.

The erratics of the boulder beds indicate that the provenance included rocks of the Arunta Block and the older Adelaidean rocks of the Ngalia Basin sequence. Most of the quartzite erratics are derived from the Vaughan Springs Quartzite, but others have originated from unit 3 of the basement. Other erratics of sedimentary rocks are from formations that are unknown in the Ngalia Basin sequence.

Mount Davenport Diamictite Member

Definition

The Mount Davenport Diamictite Member is here defined as a polymictic boulder, cobble, and pebble conglomerate which comprises the lower part of the Mount Doreen Formation. The name is derived from Mount Davenport, at the southwestern end of the Treuer Range (lat. 22°21′30″S, long. 130°46′10″E), in the western zone.

History

The member was originally recognised as a distinct unit of the Mount Doreen Formation, but has not been formally defined until now.

Type locality and section

The type section, WX-2 (Fig. 16; see also MS-2), is located in the eastern slopes of the Naburula Hills (lat. 22°17′10″S, long. 131°18′55″E) and is the same as the type section of the Mount Doreen Formation.

Contacts

The Mount Davenport Diamictite Member is conformably overlain by the Wanapi Dolomite Member, and overlies the Rinkabeena Shale probably disconformably and the Vaughan Springs Quartzite and Albinia Formation unconformably; in places it is overlain with an angular unconformity by the Mount Eclipse Sandstone.

Distribution and outcrop

The Mount Davenport Diamictite Member occurs in sporadic outcrops along the northern margin of the Ngalia Basin as far west as Albinia Spring and as far east as the Naburula Hills. The outcrop is generally poor and mostly obscured by a thin scree of clasts derived from the member.

Thickness

The thickness in the type section is 77 m. An incomplete sequence of 61 m was measured in a section about 2 km farther north (WX-1; Fig. 5; Table 2). Most other exposures are incomplete, so that no information is available on the regional variation in thickness of the member.

Lithofacies

In the type section the member consists of a polymictic boulder, cobble, and pebble conglomerate with subrounded erratics—commonly striated and faceted, and up to 4 m across—randomly distributed in a matrix mostly of blue-green and some red-brown, poorly sorted siltstone containing abundant angular quartz and rock granules. The erratics are predominantly of metamorphic and igneous rocks, of which granite and pink and grey quartzite are the most common. The smaller clasts consist of many metamorphic and igneous rocks, and a few sedimentary clasts, which include dolorudite, dolomite, silicified sandstone, and rare stromatolitic pink dolomite replaced in large part by jasper. In places the matrix is mainly dolomite.

Thin lenses of poorly sorted pebbly dolomitic sandstone, poorly sorted pebbly siliceous sandstone, sandy dolomite, and angular feldspathic sandstone commonly occur near the base of the diamictite.

The texture and compsition of the rock types in the member at the type section closely fit the description of a tillite. However, the evidence for a glacial origin for the conglomerates at several other localities is inconclusive; for example in places outside the type section, large striated erratics are absent, and the member consists of dolomitic chert-pebble conglomerate. For this reason the non-genetic term 'diamictite' is preferred for the name of the member.

The age, correlation, and and paleogeography of the member are discussed under the Mount Doreen Formation.

Wanapi Dolomite Member

Definition

The Wanapi Dolomite Member is defined as a prominent, widespread but thin sequence of dolomite which occurs in the upper part of the Mount Doreen Formation.

The name is derived from Wanapi Escarpment, a prominent breakaway south of the Naburula Hills. The Wanapi Escarpment lies between latitudes 22°20′10″ and 22°23′00″S, and longitudes 131°16′45″ and 131°18′50″E.

History

The dolomite has been described previously but not formally defined.

Type locality and section

The type section, WX-2 (Fig. 16; see also MS-2) is on the eastward-facing scarp of the Naburula Hills at latitude 22°17′10″S, longitude 131°18′55″E.

Contacts

The Wanapi Dolomite Member is conformably overlain by red shale of the Newhaven Shale Member and conformably overlies the Mount Davenport Diamictite Member. In the Treuer Range it is overlain with an angular unconformity by the Djagamara Formation and the Mount Eclipse Sandstone.

Distribution and outcrop

The Wanapi Dolomite Member is present in practically all outcrops of the Mount Doreen Formation. It occurs from as far west as Albinia Spring to the Naburula Hills in the east. It crops out as distinct benches just below the eastern escarpment of the Patmungala Syncline, and elsewhere forms low ridges and rises. In outcrop, sections through the member are mostly incomplete and sporadic.

Dolomite of the member was intersected in BMR Mount Doreen No. 4 drillhole, near Davis Gap, and probably in BMR Mount Doreen No. 9, at the south end of Waite Creek. The dark grey dolomite in BMR Mount Doreen No. 8B, 12 km west-northwest of Newhaven, may be from the Wanapi Dolomite Member or alternatively the upper marker dolomite of the Naburula Formation.

Thickness

The Wanapi Dolomite Member is 3 m thick in the type section in the Naburula Hills, and 4.3 m thick in a section about 2 km farther north (WX-1; Fig. 5, Table 2). It appears to maintain this order of thickness in the known outcrops, but its poor exposure precludes any estimate of regional thickness variations.

Lithofacies

The member is predominantly fine-grained pink laminated dolomite containing small grains and dendrites of manganese oxide, and iron oxide pseudomorphs probably after pyrite; it is silicified in part and weathers yellow-brown. Stromatolites are common in dolomite identified with the member in poor outcrops in the Treuer Range, chiefly in the Bigrlyi Pass area. Walter & Bauld (in press) have reported evaporites—in the form of gypsum and anhydrite pseudomorphed by dolomite and barite—with a coarse-grained dolomitic matrix in the stromatolitic dolomite. Well-exposed stromatolitic dolomite occurs 5.5 km west (lat. 22°13′25″S, long. 130°58′50″E) and about 5 km east (lat. 22°12′55″S, long. 131°04′45″E) of Bigrlyi Pass.

The age, correlation, and palaeogeography are discussed under the Mount Doreen Formation.

Newhaven Shale Member

Definition

The Newhaven Shale Member is defined as a unit of red shale. It comprises the upper part of the Mount Doreen Formation. It is named after Newhaven homestead (lat. 22°43′25″S, long. 131°09′55″E), at the southern margin of the basin in the western zone.

History

The shale has been described previously as part of the undivided Mount Doreen Formation.

Type locality and section

The type section, WX-2 (Fig. 16; see also MS-2), is located in the eastern part of the Naburula Hills (lat. 22°17′10″S, long. 131°18′55″E).

Contacts

In its type section the Newhaven Shale Member is unconformably overlain by the Djagamara Formation, and conformably overlies the Wanapi Dolomite Member of the Mount Doreen Formation.

Distribution and outcrop

The Newhaven Shale Member crops out in the eastern part of the Naburula Hills and near the western end of the Wanapi Escarpment. Outcrops are mostly incomplete and sporadic and are confined to the northern part of the Ngalia Basin in the western zone. The shale weathers recessively and underlies valley floors; it crops out only in creek banks and on steep scarp slopes.

Thickness

The Newhaven Shale Member is 17 m thick in the type section in the Naburula Hills, and 16 m was measured in a section about 2 km farther north (WX-1; Fig. 5, Table 2). Its poor exposure and eroded upper surface preclude any estimate of regional thickness variations.

Lithofacies

The member consists of a uniform sequence of red shale, and a few thin interbeds of pink dolomite near the base. In places the topmost beds are yellow-brown and fawn, and are probably leached beneath the unconformity.

The age, correlation, and palaeogeography of the member are discussed under the Mount Doreen Formation.

ADELAIDEAN TO CAMBRIAN

Yuendumu Sandstone

Definition

The Yuendumu Sandstone is here defined as predominantly fine to coarse-grained, red-brown sandstone with subordinate quartzwacke, arkose, and arkosic sandstone. It is named after Yuendumu Native Settlement.

Type section and locality

The type section, EX-7 (Fig. 18; see also MS-3), is 4 km south of Yuendumu Native Settlement.

Contacts

At the type section the Yuendumu Sandstone lies with a low-angle unconformity on the Vaughan Springs Quartzite, but the topmost beds of the section are obscured by Cainozoic deposits. About 5 km farther west the Yuendumu Sandstone is probably unconformably overlain by the Walbiri Dolomite; the possibility of structural complications in this area, close to the Yuendumu Thrust, cannot be entirely ruled out, and a fault or thrust might have truncated parts of the formation, giving the appearance of an unconformity. Inferred unconformable contacts with the Mount Doreen Formation and Djagamara Formation are shown in the rock relationship diagram in Plate 1. Photointerpretation and palaeomagnetic and field data together suggest the presence of an unconformity in the formation (Burek & others, 1979a).

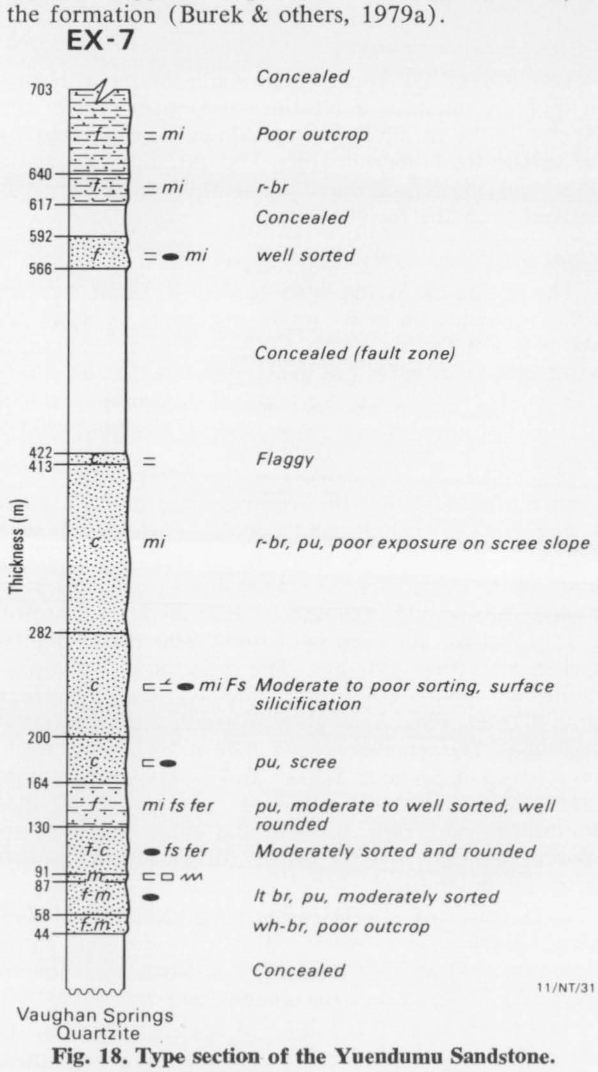


Fig. 18. Type section of the Yuendumu Sandstone.

History of investigations

Rivereau (1965) informally referred to the formation as unit b, and Cook & Scott (1967) referred to it as unit B. Burek & others (1979a) undertook magnetostratigraphic investigations of the formation.

Distribution and outcrop

The Yuendumu Sandstone crops out in a narrow belt extending latitudinally for about 36 km at the central northern edge of the Ngalia Basin on the north flank of the Walbiri Ranges. The subsurface extent of the formation is not known, but its limited distribution in outcrop suggests that it is confined to the deeper portion of the central zone of the basin.

Outcrops of the Yuendumu Sandstone mostly form rounded hills whose smooth profiles are broken in a few places by low poorly defined pinnacles forming the highest points. Its topmost part forms low cuestas, particularly where the dip of the beds is low.

Thickness

The maximum known thickness of the formation is at least 700 m, which was measured in the type section. Although a fault cuts the upper part of the formation along the section line, the measured thickness is nevertheless considered to be close to the true thickness. Two other sections were measured through incomplete exposures of the formation—EX-10 (555+ m) and NX-1 (280+ m). There is no evidence available to indicate regional thickness changes.

Age

The Yuendumu Sandstone ranges in age from late Adelaidean to earliest Cambrian. This age range is supported by its unconformable relation with the Lower Cambrian or lower Middle Cambrian Walbiri Dolomite, by its lithological similarity to the Adelaidean-Lower Cambrian Arumbera Sandstone (Wells & others, 1970; Cowie & Glaessner, 1975) of the Amadeus Basin, and by a comparison of palaeomagnetic polarity patterns of the Eninta, Arumbera, and Yuendumu Sandstones (Kirschvink, 1978; Burek & others, 1979a). The uppermost beds of the formation at building-stone quarries south of Yuendumu Native Settlement contain soft-bodied trace fossils the same as those found in the uppermost Arumbera Sandstone (Appendix 5).

Lithofacies

The predominant rock type is medium-grained red-brown silty sandstone; subordinate rock types include quartzwacke, arkosic sandstone, and arkose.

The basal part of the formation comprises dark red-brown and brown sandstone and quartzwacke—mostly medium-grained, silty, cross-bedded, and slumped—with some interbedded coarse-grained feldspathic granule conglomerate, and medium-grained pale brown medium-bedded sandstone.

The sandstone above the unconformity near the middle of the formation is tough, coarse-grained, arkosic, cross-bedded, and thick-bedded, and has a pale yellow weathered surface. Interbeds comprise granule conglomerate, and large clay pellets are common in places. The toughness of the sandstone is caused by silicification due to weathering.

The uppermost beds are thin-bedded fine-grained red and red-brown fissile micaceous sandstone in which slump structures and trace fossils are preserved.

The formation shows no marked lateral lithological changes.

Correlation

Palaeomagnetic studies of rocks which straddle the Cambrian/Precambrian boundary in central Australia (Kirschvink, 1978; Burek & others, 1979a), and the discovery of earliest Cambrian fossils (Wells & others, 1967, 1970; Glaessner, 1969; Glaessner & Walter, 1975; Walter, 1980), have enabled reasonably precise correlations between central Australian sedimentary basins.

The upper Adelaidean lower Yuendumu Sandstone is correlated with unit I of the Arumbera Sandstone of (Wells & others, 1967*, plate 18) in the Amadeus Basin; with the red-brown sandstone in the upper part of the Central Mount Stuart Formation in its type section (described by Offe, 1978), which contains a late Adelaidean soft-bodied fauna; and with the Pound Quartzite of the Adelaide Geosyncline (Fig. 7).

The lowest Cambrian upper Yuendumu Sandstone is correlated with units II and III of the Arumbera Sandstone in the Amadeus Basin, and with a sandstone containing trace fossils at the base of the Red Heart Dolomite (Walter & others, 1979), the upper Mount Baldwin Formation as redefined by Walter (1980), and the Donkey Creek beds (Walter, 1980) at Barrow Creek and Mount Octy — all in the Georgina Basin. Equivalent beds in the Adelaide Geosyncline include the Uratanna and Parachilna Formations (Fig. 8), which contain earliest Cambrian trace fossils.

Palaeogeography and environment

The late Adelaidean to Early Cambrian palaeogeography of central Australia was largely controlled by the Petermann Ranges Orogeny (Wells & others, 1970), whose main effects were felt along the southern margin of the Amadeus Basin. The basement and basin sediments uplifted in this area provided the source of the detritus for the continental, transitional, and marine sediments that spread northwards, apparently as far as the Ngalia Basin, and formed a contiguous body with the Yuendumu Sandstone.

The earliest arkosic deposits in the formation were locally derived from granitic basement and possibly deposited under continental conditions. The upper part of the formation was deposited under shallow-marine conditions, as implied by the presence of trace fossils. Uplift and rejuvenation of local source areas are indicated by beds of arkosic sandstone above a possible unconformity near the middle of the formation.

CAMBRIAN

Walbiri Dolomite

Definition

The Walbiri Dolomite is here defined as predominantly intraclastic and oolitic dolomite, with minor dolomitic siltstone, sandstone, and fossiliferous shale mainly in the basal part, and interbeds of stromatolitic dolomite and sandstone. It crops out in the Walbiri Ranges, from whence its name is derived.

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* Wells & others (1967, p. 32) documented four lithological units under the description of the Arumbera Sandstone, but showed only three informal units (1 to 3) on their map (plate 18) and measured sections (plates 11 and 12); the lower two lithological units described in the text were combined into unit 1 for the purposes of mapping. In a later paper (Burek & others, 1979a) these units are referred to as units I to III.

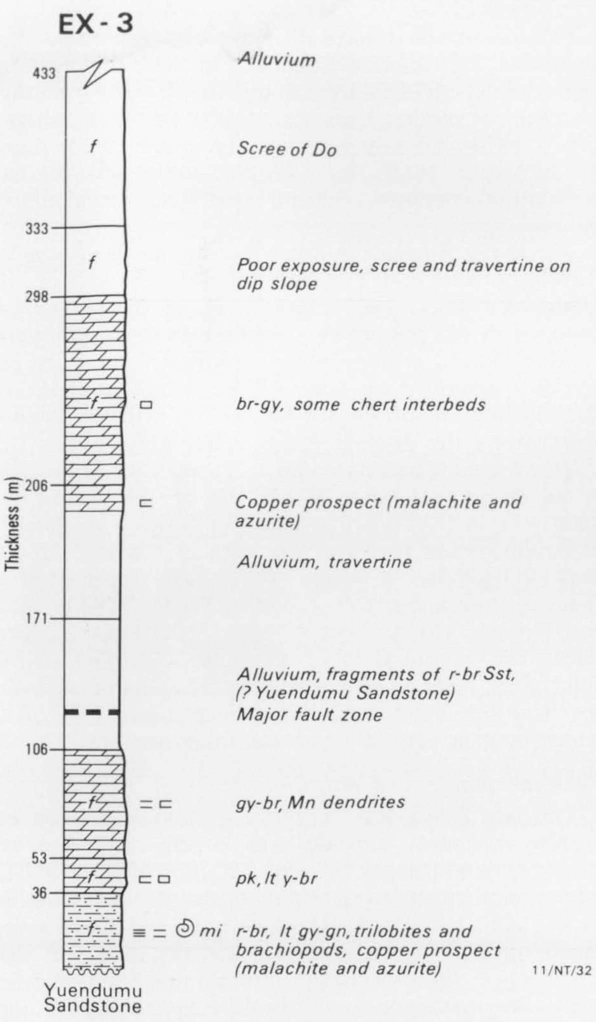


Fig. 19. Type section of the Walbiri Dolomite.

Type section

The type section, EX-3 (Fig. 19; see also MS-4), is about 3 km north-northwest of White Point Bore, on the north flank of the Walbiri Ranges. The upper part of the section is concealed, and a small fault has repeated part of the sequence.

History

Cook & Scott (1967) included the formation in a fossiliferous carbonate-lutite sequence which they informally referred to as unit C. The carbonate-rich beds, which are confined to the lower part of this sequence, are defined as the Walbiri Dolomite.

Distribution and outcrop

Outcrops of the Walbiri Dolomite are confined to a strip about 26 km long on the northern flank of the Walbiri Ranges.

The dolomite of the formation forms low rounded hills with a few north-facing low scarps; the siltstone and shale generally form the floor of valleys or occur on short scree slopes; and the interbedded sandstone forms small strike ridges. The distribution of the formation in outcrop suggests that its subsurface extent is small and probably restricted to the central northern portion of the basin; it is probably truncated towards the southern margin of the basin by the unconformity at the base of the Mount Eclipse Sandstone. It may also be present in the subsurface in the interpreted thick Palaeozoic sequence in the western zone (Plate 2).

Thickness

The maximum thickness of the Walbiri Dolomite is about 250 m. There is no apparent regional variation in thickness, although locally at the type section it appears to thin westwards.

Three incomplete sections have been measured in the formation (Fig. 5, MS-4): NX-1 (164+m), NX-2 (148+m), and EX-3 (the type section, 433+m); in the type section, part of the sequence has been repeated by faulting, and the true thickness is estimated to be about 250 m. In each measured section the top of the formation is obscured.

In DDH 1, a diamond drillhole about 0.5 km southeast of Djuburula Peak, the top of the Walbiri Dolomite was intersected at a depth of 71.6 m, and 173.1 m of the formation was penetrated. In DDH 2, about 120 m north of DDH 1, the top of the formation was encountered at 53.3 m, and 38.4 m of the formation was penetrated (Grainger, 1969).

About 55 m of the formation was intersected in BMR Mount Doreen No. 14 drillhole, about 6.4 km southwest of Yuendumu Native Settlement (Evans & Nicholas, 1970).

Lithofacies

About 80 percent of the formation in outcrop comprises pale grey thick-bedded and massive pelletal dolomite. The remainder is red-brown and grey-green siltstone and shale, and pale grey and pale brown medium and coarse-grained sandstone.

The basal beds in the formation comprise interbedded green and blue-grey, partly dolomitic siltstone; micaceous siltstone; fossiliferous shale; medium-grained, partly dolomitic, feldspathic, and micaceous friable sandstone; red oolitic dolomite; and glauconitic dolomite. This sequence is overlain by blue-grey, poorly thick-bedded aphanocrystalline, partly intraclastic and oolitic dolomite containing oncolites.

The upper part of the formation in outcrop is mainly blue-grey and some pink dolomite with interbeds of pink stromatolitic dolomite, red siltstone, medium-grained dolomitic sandstone, and cross-bedded, thick-bedded medium-grained siliceous sandstone. Much of the dolomite in the well-exposed outcrops of the middle part of the formation is sandy, containing quartz and feldspar grains, and is commonly oolitic, intraclastic, and fossiliferous, notably near Penhalls Bore, where phosphatic brachiopods are common.

The uppermost beds of the Walbiri Dolomite intersected in two diamond-drillholes (DDH 1 and 2) about 0.5 km southeast of Djuburula Peak consist of a sequence of dolomite, silty and sandy dolomite, siltstone, dolomitic siltstone, calcareous siltstone, and minor sandstone and calcareous sandstone (Grainger, 1969). Quartz veinlets, pods of barite, manganese dendrites, and streaks of black unidentified material are present in these rocks. Bedding-planes are either horizontal or inclined at a low angle to the south. The dolomite is generally massive, fine-grained, and grey, blue, or light brown. Silty dolomite is abundant, and minor intervals of sandy dolomite are composed of rounded medium-grained quartz grains in fine-grained dolomite. Some intervals have numerous cavities up to

2-3 cm in diameter, commonly lined with crystals of dolomite or more rarely calcite.

The sandstone interbeds, which commonly grade into the contiguous dolomite beds, are generally pink or light brown and medium-grained, although some are fine and others coarse-grained and micaceous. The sandstones commonly have a calcareous cement and are composed of a framework of poorly sorted subrounded and angular quartz grains with very minor amounts of feldspar grains, biotite flakes, and rock fragments.

Both the siltstone and carbonate rocks contain dark carbonaceous and manganiferous laminae and streaks less than 5 mm thick. They are usually concordant, but in places cut across bedding-planes and form what appear to be replacement structures. Iron oxide staining is commonly associated with the dark material.

In BMR Mount Doreen No. 14 the Walbiri Dolomite comprises red-brown tough dolomitic siltstone (Evans & Nicholas, 1970).

Age

A probable late Early Cambrian or possibly early Middle Cambrian (Ordian) age is indicated by the fossils (J. Gilbert-Tomlinson, formerly BMR, personal communication). They include phosphatic brachiopods from the upper part of the formation exposed near Penhalls Bore, and three genera of brachiopods (*Botsfordia*, *Lingulella*, and an unidentified orthid), at least two hyolithids, and unidentifiable trilobite fragments from the base of the formation exposed at the type section.

Correlation

The lithological sequence in the Walbiri Dolomite is similar to the lower Middle Cambrian Giles Creek Dolomite of the Pertaoorrta Group in the Amadeus Basin (Fig. 8). The lateral and chronostratigraphic equivalent Tempe Formation farther west in the Amadeus Basin lies stratigraphically between Cambrian red-brown sandstones; the association of red-brown sandstones with lower Cambrian carbonate rocks is common to both the Pertaoorrta Group in the central part of the Amadeus Basin and the Cambrian sequence at the northern margin of the central zone of the Ngalia Basin.

Formations of early Middle Cambrian age in the Wiso Basin that may be equivalent at least in part to the Walbiri Dolomite include the Ordian Montejinni Limestone, Hooker Creek Formation, and Lothari Hill Sandstone (Kennewell & Huleatt, 1980). Formations of similar age in the Northern Territory portion of the Georgina Basin are the Hay River Formation (Walter & others, 1979), and Sandover beds.

Contacts

In the Walbiri Ranges the formation probably lies unconformably on the Yuendumu Sandstone, and apparently conformably below the Bloodwood Formation. The top of the formation is obscured by sand, but an apparently conformable boundary with the Bloodwood Formation was intersected in diamond drillholes near White Point (Grainger, 1969).

The boundary between the Walbiri Dolomite and the underlying Yuendumu Sandstone at and near the type section appears to be a transgressive contact, although faulting cannot be entirely ruled out because the outcrops are within a kilometre of the Yuendumu Thrust. At the eastern end of the outcrop, fossiliferous shale and interbedded siltstone, pink dolomite, and sandstone at the base of the Walbiri Dolomite overlie the Yuendumu Sandstone. A little farther west the basal sequence is overlapped by stratigraphically higher beds of thick-bedded dolomite. An unconformity between the Djagamara Formation and Walbiri Dolomite is inferred from regional relations, as indicated on the rock relationship diagram of Plate 1.

Environment and palaeogeography

Intraclastic and oolitic carbonate rocks, glauconite, stromatolites, and the abundant fauna imply that the Walbiri Dolomite was deposited in a shallow-marine environment.

The central Australian basins in Early Cambrian times were connected to a meridional intercontinental sea that extended from the Bonaparte Gulf in the north to the Adelaide Geosyncline in the south (Wells & others, 1970; Cook, 1982). Evidence from lithofacies in the Amadeus Basin suggests that provenance areas lay to the south and west, and that the opening to the sea was mainly to the east and northeast. During Walbiri Dolomite sedimentation, the Ngalia Basin may have been part or an arm of a large shallow embayment that was inundated by the sea, which extended over large areas beyond the present limits of the basin.

Bloodwood Formation

Definition

The Bloodwood Formation is here defined as red-brown and some pale green fossiliferous micaceous siltstone and subordinate red sandstone. Its name is derived from Bloodwood Bore, in the eastern zone, about 28 km southeast of Yuendumu Native Settlement.

History

Rivereau (1965) distinguished the formation as unit c_1, but Cook & Scott (1967), who also used informal nomenclature, included it with unit C, a fossiliferous carbonate-lutite sequence. The upper, predominantly arenaceous part of this unit is defined as the Bloodwood Formation.

D. Woolley (formerly with the Resident Geologist's Office, Alice Springs) made lithological descriptions of the formation, and was the first to discover fossils in the formation, in outcrops 4.8 km west of White Point Bore. Additional fossils were collected by A. W. Lindner and N. W. Hamilton (American Overseas Petroleum Ltd) from 2.8 km northwest of Djuburula Peak, and at a later date by BMR.

Type section

The type section is a composite of section NX-3 (Fig. 20; see also MS-5), measured near Djuburula Peak on the northern flank of the Walbiri Ranges, and the lower part of the formation penetrated in DDH 1, which is about 1.3 km northwest of White Point.

Contacts

At the type section the Bloodwood Formation is overlain by the Mount Eclipse Sandstone with an angular unconformity. In drillholes near White Point the Bloodwood Formation is apparently conformable and gradational with the Walbiri Dolomite.

The Bloodwood Formation is faulted against the formation that succeeds it in the sequence, the Djaga-

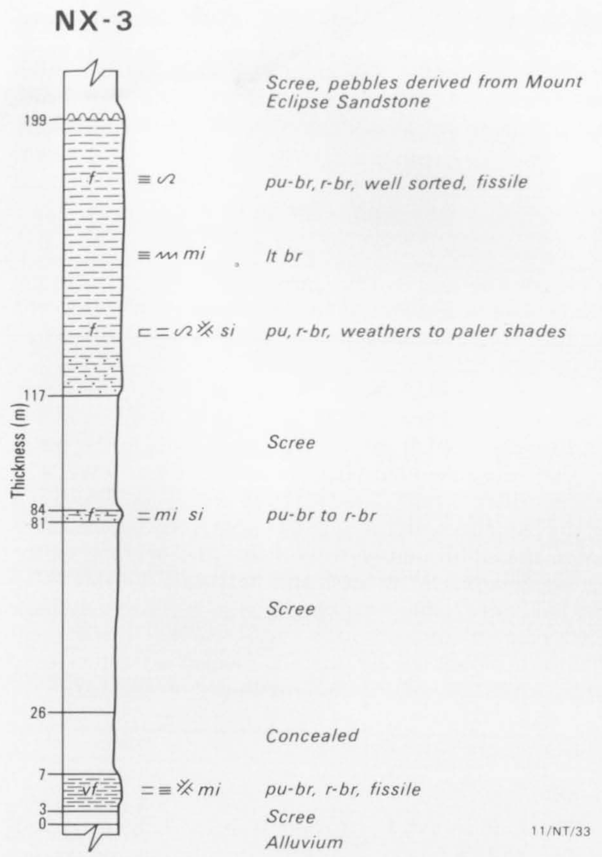


Fig. 20. Type section (upper part) of the Bloodwood Formation.

mara Formation, and the nature of the sedimentary contact between them can only be inferred. Elsewhere the base of the Djagamara Formation is invariably an unconformity, and, as there is a suggestion of a considerable hiatus between the formations, the Djagamara Formation is probably unconformable on the Bloodwood Formation.

Distribution and outcrop

The Bloodwood Formation crops out only at Djuburula Peak and intermittently to the west for about 13 km on the northern flank of the Walbiri Ranges; in the west the small scattered outcrops are poorly exposed. Its subsurface distribution is probably restricted to the northern part of the basin in the eastern zone, although it may be present in the subsurface in the western zone.

The formation forms distinctive flat-topped hills which have steep marginal slopes with well-rounded convex profiles. The smooth profiles are caused by the homogeneous, poorly bedded fine-grained sediments constituting the formation.

Thickness

The formation has a maximum thickness of about 270 m. It apparently wedges out at an unknown distance to the south, probably by truncation beneath an unconformity.

Two sections (the upper part of the type section, NX-3, 199 m; and NX-4, 158+ m) were measured in the formation (MS-5), but both are incomplete because superficial Cainozoic sediments cover the basal portion of the formation and the top is an unconformity. Two diamond-drillholes spudded in the formation near White Point penetrated 71.6 m of the formation (DDH 1) and 53.3 m (DDH 2; Grainger, 1969).

Lithofacies

The dominant lithology is a purple-brown to red-brown siltstone, which is fine-grained, micaceous, thin-bedded and laminated, well-sorted, fissile, and in places graded-bedded; some beds have convolute lamination and current ripple marks. Fine-grained sandstone is a minor lithology.

Cored sequences in the basal part of the formation near White Point (Grainger, 1969) consist of red and chocolate-brown micaceous current-laminated siltstone with minor mudstone beds and some intraformational breccia. Graded beds and contorted current laminations are present.

Age and fossils

A. A. Öpik (formerly BMR, personal communication) assigned an Early Cambrian age to the sparse, poorly preserved fossils, which include pennatulaceans, the mollusc *Helcionella* (related to *H. rugosa* (Hall)), and the trace fossils *Protichnites* and *Rusophycus* from outcrops 1.2 km northwest and 2.8 km west-northwest of Djuburula Peak.

J. Gilbert-Tomlinson (formerly BMR, personal communication) has suggested that the forms in the Bloodwood Formation are all somewhat similar to those in the basal portion of the Pacoota Sandstone of the Amadeus Basin; this part of the Pacoota Sandstone is Trempealeauan (latest Cambrian; Wells & others, 1970). A correlation with the Pacoota Sandstone is not favoured because of their dissimilar lithologies.

The conformable and gradational contact between the Bloodwood Formation and the Walbiri Dolomite implies that both have a similar age—i.e., late Early Cambrian or early Middle Cambrian.

Palaeogeography

The fossils suggest shallow-marine, possibly intertidal conditions of deposition. The abundant redbeds in the formation suggest that subaerial conditions may have prevailed at times.

Correlation

The redbed lithology and the Cambrian age suggest a correlation with part of the facies of the Pertaoorrta Group in the central zone of the Amadeus Basin: the Arumbera, Eninta, Illara, and Petermann Sandstones (Wells & others, 1965; 1970, fig. 15) are predominantly red-brown sandstones similar to the Bloodwood Formation. An Early Cambrian age for the Bloodwood Formation would indicate equivalence with the Eninta Sandstone and upper parts (units II and III) of the Arumbera Sandstone, a correlation that appears to be unlikely. If, as seems more probable, it is Middle Cambrian in age or younger, then a correlation with the ?Middle Cambrian Illara Sandstone is suggested.

Possible correlatives in the Wiso Basin may include parts of the ?Middle Cambrian Lothari Hill Sandstone and Point Wakefield beds (Fig. 8; Kennewell & Huleatt, 1980).

?ORDOVICIAN

Djagamara Formation

Definition

The Djagamara Formation is defined here as grey and white medium and fine-grained massive and thick-bedded to laminated sandstone, and, in places, thick interbeds of green and dark grey siltstone near the middle of the formation. The sandstone is in part highly silicified and glauconitic, and has abundant clay pellets. The name is derived from Djagamara Peak in the Naburula Hills, in the western zone.

History of investigations

The Djagamara Formation has been previously referred to informally as unit d by Rivereau (1965) and as unit D by Cook & Scott (1967).

Type section

The type section, WX-5 (Fig. 21; see also MS-6), was measured at Djagamara Peak, in the eastern Naburula Hills.

Contacts

The Djagamara Formation everywhere lies unconformably on the Mount Doreen Formation, and is overlain, apparently conformably, by the Kerridy Sandstone near White Point and unconformably by it or younger rocks elsewhere.

At the type section the Djagamara Formation lies unconformably between the Kerridy Sandstone and the Mount Doreen Formation. Although the upper contact is only slightly angular there is evidence of considerable erosion at the top of the Djagamara Formation: at Djagamara Peak the Kerridy Sandstone rests on resistant beds of glauconitic sandstone, and about 1 km to the southwest it overlies green siltstone about 60 m stratigraphically lower in the Djagamara Formation.

Abundant fragments of the Wanapi Dolomite Member incorporated in the lower beds of the Djagamara Formation (Fig. 17) indicate a basal unconformity in the Naburula Hills.

East of White Point the contact of the Djagamara Formation and Kerridy Sandstone is apparently conformable, but angular unconformities are exposed in the cores of eroded anticlines southeast of the Walbiri Ranges. One kilometre west of White Point, pre-Late Devonian erosion has completely stripped the Kerridy Sandstone from an exhumed hill of the Djagamara Formation which the Mount Eclipse Sandstone overlies with a pronounced angular unconformity (Fig. 38).

In the Vaughan Springs Syncline and in isolated outcrops along the Treuer Range, the unconformable contacts between the Djagamara Formation and the Mount Eclipse Sandstone and Mount Doreen Formation are mostly poorly exposed or concealed.

The unconformable contacts of the Djagamara Formation with the Bloodwood Formation, Walbiri Dolomite, and Yuendumu Sandstone shown on the rock relationship diagram (Plate 1) are inferred.

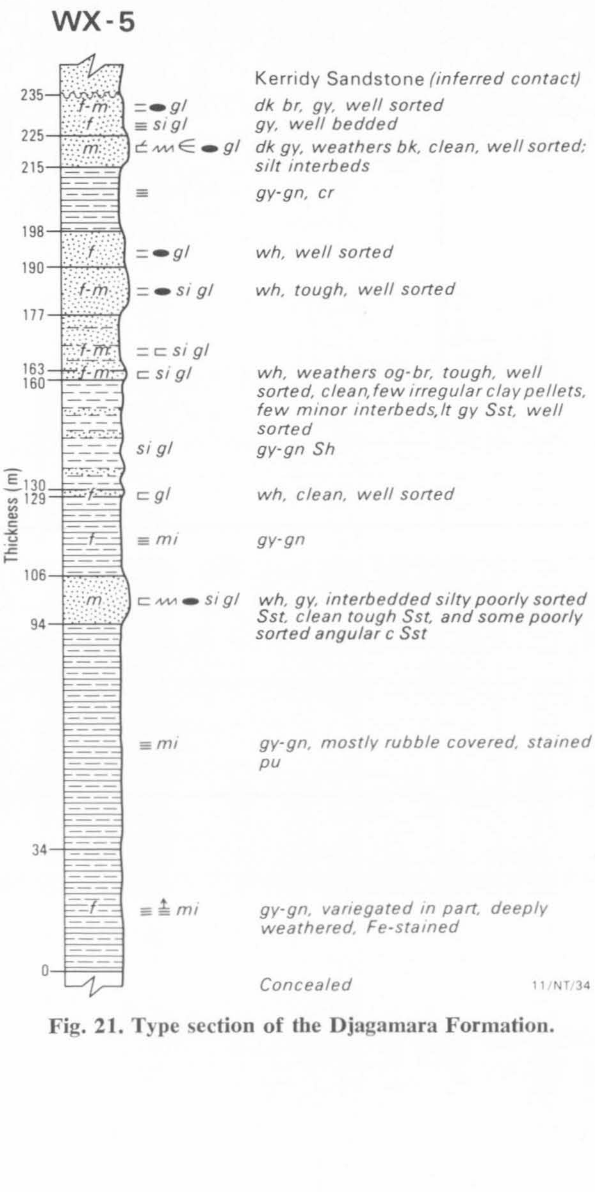


Fig. 21. Type section of the Djagamara Formation.

Distribution and outcrop

Discontinuous outcrops occur over a distance of 120 km along the northern margin of the basin.

The silicified sandstone beds are moderately resistant to erosion and most form prominent ridges. The more friable, massive sandstone and the interbedded siltstone weather recessively; exposures of the siltstone beds are present only in creek beds or on the slopes of the steeper scarps.

Thickness

The preserved sequences in the formation for the most part do not vary greatly in thickness (MS-6): 290 m in the Naburula Hills (WX-1, 3); 227 m to the west in the Vaughan Springs Syncline (EX-13); and 320 m in the east near White Point (EX-1), which is the thickest exposure in the formation although the base is faulted. The formation thins rapidly southwards from Djagamara Peak (235+ m; WX-5) and only 52 m is preserved on the south flank of the Naburula Hills (EX-6). It is probably truncated to the south by the unconformity at the top of the formation.

Lithofacies

Sandstone and siltstone predominate in the Djagamara Formation in the eastern Naburula Hills. The siltstone, which comprises the middle of the formation, is uniform in lithology; the dark grey fresh rock weathers green in outcrop. Sandstone in the upper part of the formation is mostly laminated to thin-bedded, glauconitic, and tough; some of the medium-bedded sandstone contains trace fossils (Fig. 22), ripple marks, and flow casts, and the thickest beds are generally silicified; pitted surfaces are caused by weathering of glauconite and clay pellets. Sandstone at the base of the formation is fine and medium-grained, glauconitic, thin to medium-bedded, and contains current lineation, current crescents, clay pellets, and pitted weathered surfaces; similar sandstone occurs as interbeds in the siltstone.

In the Walbiri Ranges, medium and thin-bedded well-sorted tough silicified sandstone with numerous small clay pellets and large ripple marks is interbedded with thick-bedded friable well-sorted sandstone with

Fig. 22. Probable invertebrate tracks in the Djagamara Formation at Djagamara Peak. (GA728)

fewer clay pellets and minor platy thin-bedded tough sandstone; siltstone interbeds are lacking and glauconite is uncommon.

Age

On superpositional data only, the age of the formation falls in the interval from Early Cambrian (the older age estimate for the underlying Bloodwood Formation) to Ordovician or possibly Devonian (the younger age estimate for the overlying Kerridy Sandstone).

A K-Ar age determination on glauconite in sandstone from near the top of the formation at Djagamara Peak gave a date of 447 m.y. (Cooper & others, 1971), which is early Late Ordovician (Caradocian) on the geological time scale of Van Eysinga (1975). However, Cooper & others considered that an age 5 percent higher (475 m.y., Early Ordovician) would have been acceptable, and that some argon might have been lost.

Tracks and trails present in the prominent ledge-forming sandstone at Djagamara Peak (Fig. 22) are not age-diagnostic.

Correlation

The Djagamara Formation is correlated with the Cambro-Ordovician sandstones of the Larapinta Group in the Amadeus Basin; it is lithologically most similar to the Pacoota Sandstone, the basal formation of the group (Fig. 8). If the Djagamara Formation is the same age as the Pacoota Sandstone, then probable correlatives in the Georgina Basin include part of the Tomahawk beds and Kelly Creek Formation. The formation may be equivalent in part to unit 2 of the Hanson River beds (Kennewell & Huleatt, 1980) of the Wiso Basin.

Palaeogeography

The Djagamara Formation was probably deposited in a shallow-marine environment. The flow casts indicate strong current action during sedimentation, and the well-sorted and rounded grains suggest considerable transport and probably winnowing of the sediments. Glauconite is considered to form under conditions of slow sedimentation in partly restricted environments, and its presence can be used along with other evidence to suggest a marine origin for the enclosing beds (Galliher, 1935; Burst, 1958; McRae, 1972).

The main source of detritus for the Amadeus Basin Ordovician sediments was uplifted landmasses composed of Proterozoic rocks that lay along the basin's southern margin. The Djagamara Formation was probably continuous with part of the Ordovician Larapinta Group of the Amadeus Basin, and hence the provenance may have been common to both basins.

ORDOVICIAN OR DEVONIAN

Kerridy Sandstone

Definition

The Kerridy Sandstone is here defined as moderately sorted red-brown and purple medium to coarse-grained silty and in part arkosic sandstone and subgreywacke with minor interbedded siltstone. Its name is from

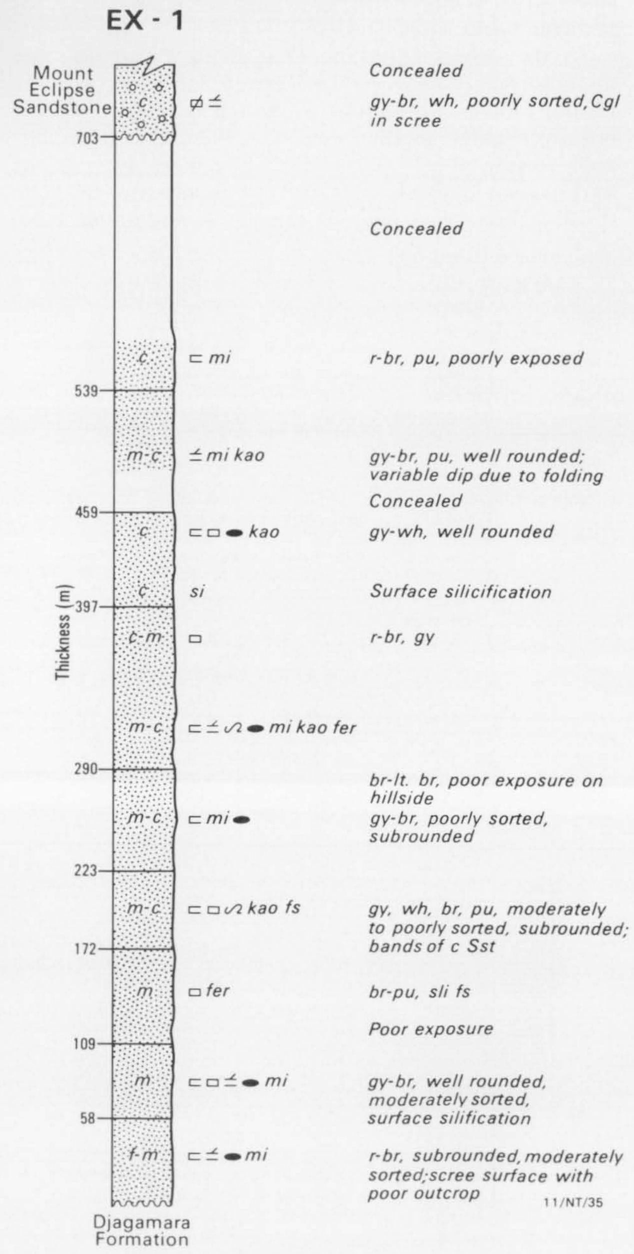


Fig. 23. Type section of the Kerridy Sandstone.

Keridi (formerly Kerridy) Waterhole, 16 km south of Yuendumu Native Settlement, in the central zone.

History of investigations

The Kerridy Sandstone was referred to informally as unit e by Rivereau (1965) and as unit E by Cook & Scott (1967).

Type locality and section

The type locality is in the eastern part of the Walbiri Ranges, and the type section EX-1 (Fig. 23; see also MS-7), is 0.4 km southeast of White Point in the central zone.

Contacts

In the breached anticlines in the eastern part of the Walbiri Ranges and in outcrops at the eastern nose of the Patmungala Syncline, angular unconformities separate the Kerridy Sandstone from the Djagamara Formation and the Mount Eclipse Sandstone. At the type section, however, the lower contact with the Djagamara Formation appears to be conformable, but the upper contact with the Mount Eclipse Sandstone is an angular unconformity, as elsewhere.

Distribution and outcrop

The largest outcrop area of the Kerridy Sandstone comprises discontinuous north-facing low scarps trending eastwards for about 25 km, and low ridges in breached anticlines in the Walbiri Ranges farther south. An arcuate line of low hills and ridges occurs around the eastern nose of the Patmungala Syncline, and isolated low outcrops occur 12 km south of Keridi Waterhole and in a small mesa of flat-lying beds at Djabangardi Hill.

The subsurface distribution of the formation is unknown, but it may be present in the subsurface in the western zone.

The southern extent of the formation is not known; it has probably been eroded from the southern part of the basin and truncated by the unconformably overlying Mount Eclipse Sandstone. All the sediments down to the Vaughan Springs Quartzite have been removed below this unconformity along part of the southern margin.

Thickness

The maximum thickness is 703 m at the type section, EX-1. Local changes in thickness are due partly to varying original thickness and partly to erosion before the Mount Eclipse Sandstone was deposited.

Lithofacies

The predominant rock type in the formation is a medium to coarse-grained medium-bedded silty sandstone.

In the type section the sandstone and subgreywacke are poorly to moderately sorted and medium to coarse-

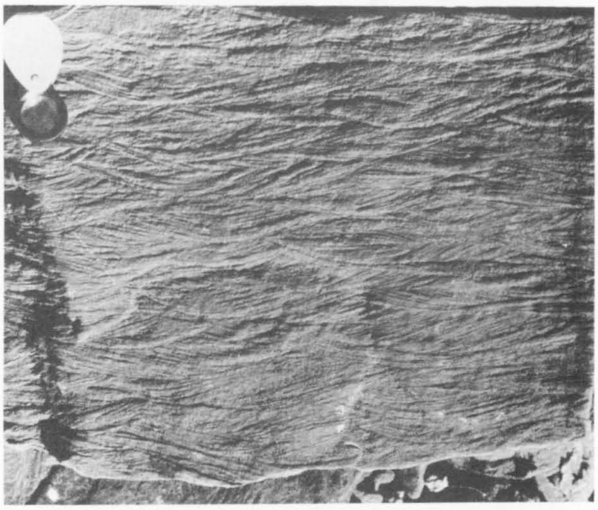


Fig. 24. Festoon cross-lamination in the Kerridy Sandstone in the eastern Naburula Hills. (M547/7)

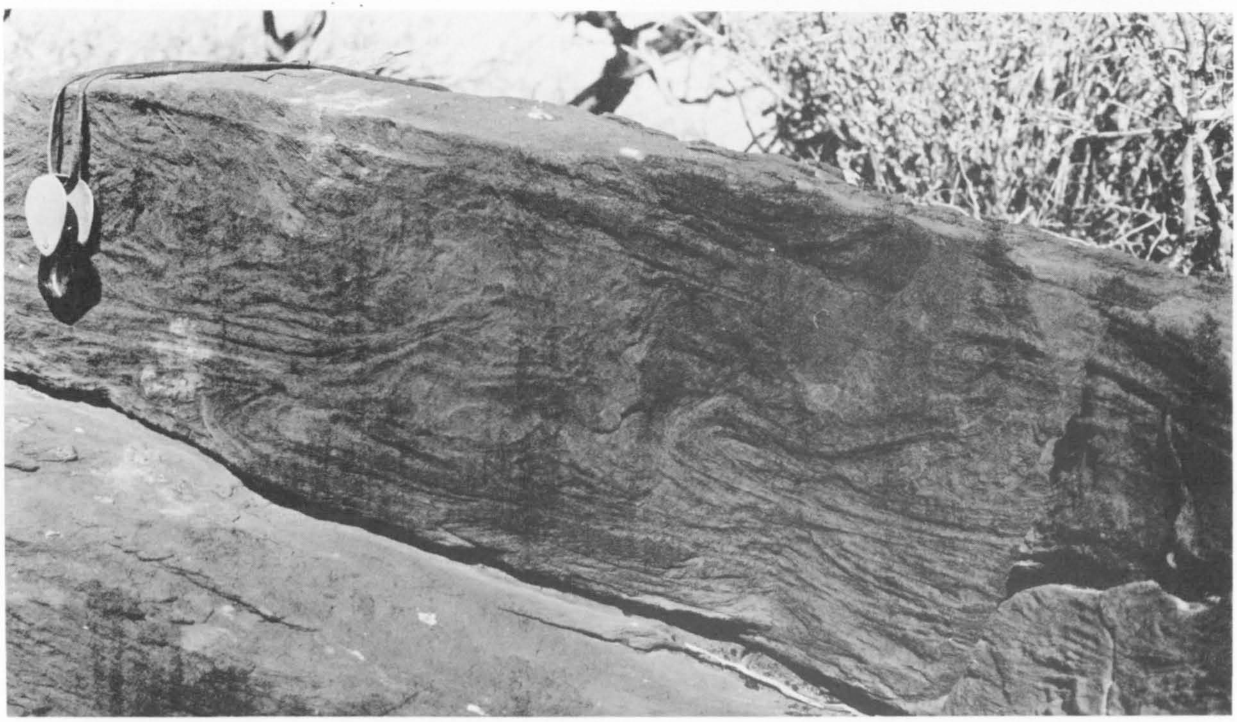


Fig. 25. Convolute lamination in the Kerridy Sandstone in the eastern Naburula Hills. (M547/8)

grained, and consist mainly of subangular to subrounded quartz grains and clay pellets; the composition of the sandstone and subgreywacke indicate a range from submature to immature arenites. Throughout the Walbiri Ranges the lithology varies little from that in the type section. However, in the Patmungala Syncline the sandstone is purple and red-brown, mostly coarse-grained and micaceous, poorly bedded, poorly sorted, moderately friable, calcareous, and silty, and contains some angular feldspar grains, large clay pellets, and a few thin interbeds of dark red-brown, silty dolomite. The only sedimentary structures evident in the formation are cross-bedding, festoon cross-lamination (Fig. 24), and convolute lamination (Fig. 25).

The sediments in the Walbiri Ranges have a silica cement—a product of diagenesis or weathering — whereas a carbonate cement is predominant in the Patmungala Syncline. The sandstone beds, particularly those in the Walbiri Ranges, commonly weather into blocks with very irregular shapes ('skeletal' weathering) owing to the partial silicification of zones along joint planes; the silicified zones are resistant to erosion, whereas the sandstone in the core of the joint block remains relatively friable.

Age

No fossils have been found in the formation. Its stratigraphic position above the Djagamara Formation and Walbiri Dolomite and below the Mount Eclipse Sandstone indicates an early or middle Palaeozoic age. Its apparent conformable relation with the probable Ordovician Djagamara Formation south of Yuendumu suggests that it may be only slightly younger than this formation.

Correlation

The Kerridy Sandstone is lithologically dissimilar to most of the mid-Palaeozoic formations of the Amadeus, Wiso, and Georgina Basins. If it is Ordovician, then it may represent a proximal facies of the Carmichael Sandstone, the youngest formation of the Larapinta Group of the Amadeus Basin. A younger age for the formation, supported by the evidence of unconformity at its base in the majority of exposures, would indicate a correlation with the Devonian Mereenie Sandstone of the Amadeus Basin, with parts of the Dulcie Sandstone and Cravens Peak beds of the Georgina Basin, and possibly with parts of the Lake Surprise Sandstone in the Wiso Basin (Kennewell & Huleatt, 1980); see Fig. 8).

A fossil fish fauna from the basal part of the Dulcie Sandstone, and the Cravens Peak beds in the Georgina Basin, and doubtfully from the Mereenie Sandstone in the Amadeus Basin (G. Young, BMR, personal communication; Turner & others, 1981), suggests an age close to the Emsian-Eifelian boundary (Fig. 8).

Palaeogeography and environment

The lithology and sedimentary structures preserved in the Kerridy Sandstone suggest deposition in a fluviatile or possibly deltaic environment.

Cook (*in* Wells & others, 1970) has suggested that deposition of the Carmichael Sandstone reflects a recession of the sea during the Late Ordovician in central Australia, mainly by severing marine connections to the north. If the Kerridy Sandstone is a correlative of the Carmichael Sandstone, then its suggested fluviatile environment would be compatible with a withdrawal of the sea north of the Amadeus Basin; however, a deltaic environment for parts of the Ngalia Basin during Kerridy Sandstone sedimentation cannot be entirely ruled out.

The alternative correlation of the Kerridy Sandstone with the Mereenie Sandstone would extend the area envisaged for the large desert that was established around and probably within the Amadeus Basin during the Devonian (Cook *in* Wells & others, 1970).

DEVONIAN TO CARBONIFEROUS

Mount Eclipse Sandstone

Definition

The Mount Eclipse Sandstone is here defined as predominantly arkosic sandstone and subgreywacke with interbeds of pebble, cobble, and boulder conglomerate and subordinate siltstone and shale. The sandstone is mostly coarse-grained, subangular, poorly sorted, in part micaceous or calcareous, thinly to massively bedded, and shows medium-scale cross-stratification with an abundance of planar and trough cross-stratified units; it is red-brown to pale grey where fresh, but weathers pale orange-brown. Oligomictic conglomerate with quartzite phenoclasts is common, but in places limestone-pebble conglomerate is present. The siltstone and shale are red or green, mostly micaceous, and both the sandstone and finer clastics are commonly carbonaceous.

The formation name is derived from Mount Eclipse, 34 km southwest of Yuendumu Native Settlement in the central zone.

History of investigation

Rivereau (1965) distinguished the formation as a unit of possible late Palaeozoic age, Pz. Cook & Scott (1967) informally referred to the formation as unit F.

Type section

The nominated type section, which was not measured in detail, is on the northern flank of the Mount Eclipse Syncline, about 23 km west-southwest of Yuendumu Native Settlement; this is the thickest and most complete exposure of the formation.

Contacts

The Mount Eclipse Sandstone unconformably overlies most of the older formations of the Ngalia Basin. The top of the formation is eroded and is commonly covered by Cainozoic units.

The basal unconformity is generally well exposed. Angular contacts with the Vaughan Springs Quartzite are present in the Treuer Range and in an isolated outcrop in the centre of the basin 40 km southwest of Yuendumu Native Settlement. Shallow drilling (Wells, 1976) has indicated that this unconformity is present in the subsurface along at least part of the basin's southern margin.

The formation also rests unconformably on the Mount Doreen, Bloodwood, and Djagamara Formations, and on the Kerridy Sandstone, in several places along the northern margin.

Considerable pre-Carboniferous relief is evident in the area of Djagamara Peak and White Point (Figs. 38, 42), where angular contacts of the Mount Eclipse Sandstone with three formations (Bloodwood and Djagamara Formations and Kerridy Sandstone) are visible.

Distribution and outcrop

Outcrops of the Mount Eclipse Sandstone occur mainly along the northern part of the Ngalia Basin as far as Waite Creek in the west and Napperby Creek in the east. Quaternary sand and undifferentiated Cainozoic deposits cover a considerable portion of the Mount Eclipse Sandstone in the southern part of the basin.

The more massive beds in the formation are moderately resistant to erosion and generally crop out as low hills and ranges or as prominent strike ridges, and in prominent mesas where the beds are horizontal.

An outlier of sandstone at McEwin Hills in the west, about 100 km outside the basin margin, is correlated with the Mount Eclipse Sandstone.

Thickness

The thickest preserved sections of the Mount Eclipse Sandstone occur in the northern part of the central and western zones of the basin. Interpretation of seismic reflection horizons indicates that the Naburula Fault Trough (Plate 2) in the western zone contains up to 2200 m of the formation; its thickness in the central zone, estimated from exposures on the northern flank of the Mount Eclipse Syncline, is about 2400 m.

Seven sections (EX-1, 6, 8, 9, 13; WX-3, 4) were measured in the basal part of the formation (MS-7).

Lithofacies

The most common and characteristic rock type is arkosic sandstone with scattered pebble to cobble-size phenoclasts of quartzite and other rock types. The presence of phenoclasts distinguishes the formation from some older sandstone units which it otherwise resembles.

The sandstone is mostly coarse-grained. Its commonest constituents are quartz and feldspar, with some muscovite, clay minerals, and rock fragments. The quartz content invariably exceeds 50 percent, but the feldspar content is variable. In outcrop the quartz grains are commonly coated with iron oxide and cemented by silica, and most of the feldspar has been weathered to clay, but a few fresh grains commonly remain. Locally a calcite cement is present. The

Fig. 27. Probable invertebrate track (about 3 cm wide) in the basal Mount Eclipse Sandstone at Djuburula Peak. (GA465)

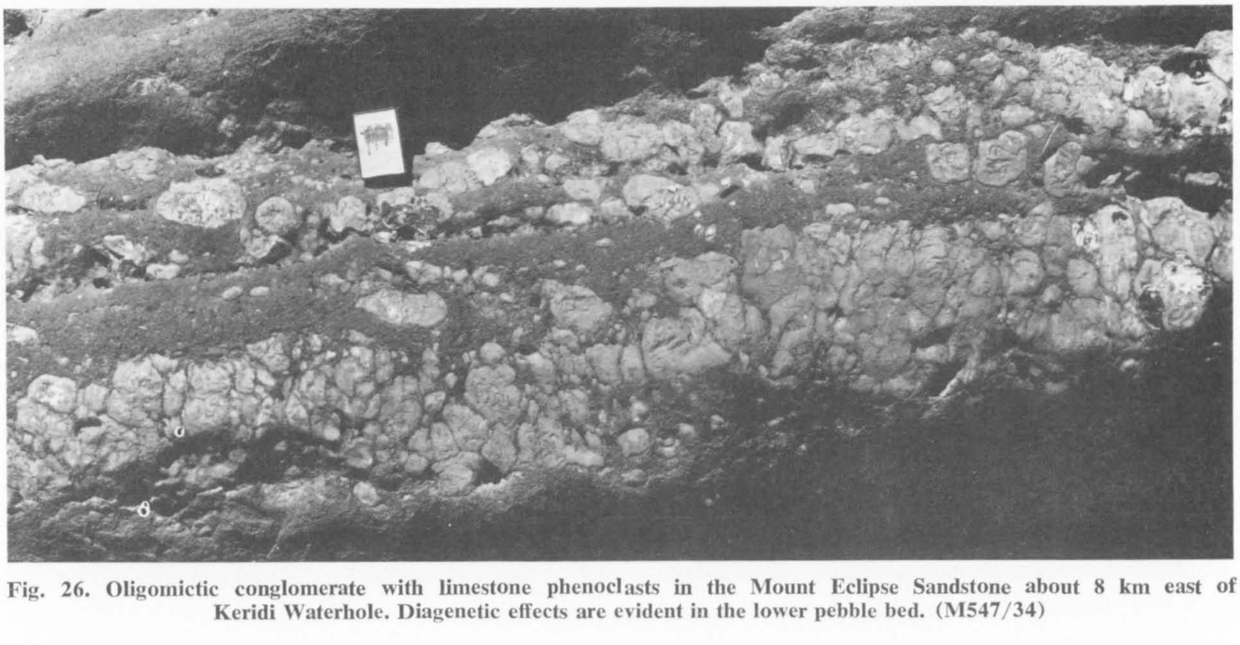


Fig. 26. Oligomictic conglomerate with limestone phenoclasts in the Mount Eclipse Sandstone about 8 km east of Keridi Waterhole. Diagenetic effects are evident in the lower pebble bed. (M547/34)

boundaries of most quartz grains have been modified by pressure solution, and quartz overgrowths are common.

Most phenoclasts are randomly distributed throughout the formation, but in a few areas—notably the Treuer Range near the headwaters of 12 Mile Creek, south of Smiths Gift Bore, and in an isolated outlier 19 km south-southwest of Napperby homestead—boulder and cobble conglomerates 2-3 m thick constitute part of the sequence. The boulders are commonly ellipsoidal or ovoid.

At the Treuer Range locality the phenoclasts consist mainly of vein quartz, orthoquartzite, and metaquartzite. Pebbles of reddish brown and dark grey recrystallised limestone occur at a few localities in the Walbiri Ranges, north and south of Mount Eclipse, east of Keridi Waterhole (Fig. 26), and east of 12 Mile Creek in the Treuer Range. They are generally in

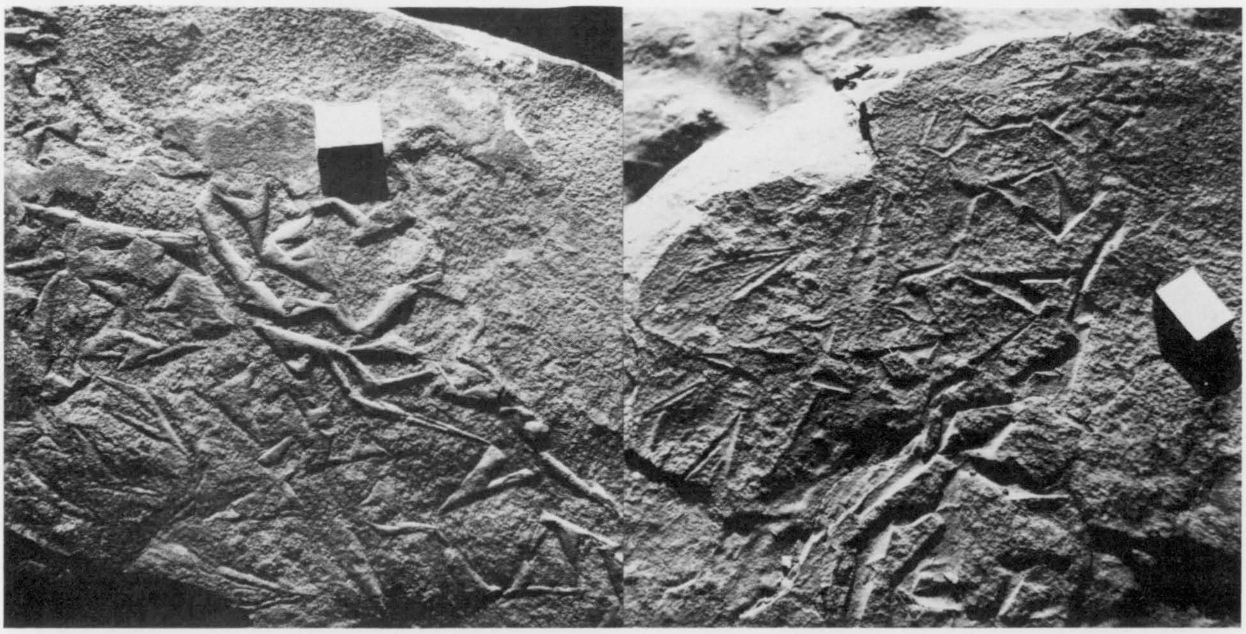


Fig. 28. Angular casts and moulds of desiccated siltstone plates in the basal Mount Eclipse Sandstone at Djuburula Peak. (GA466, 467)

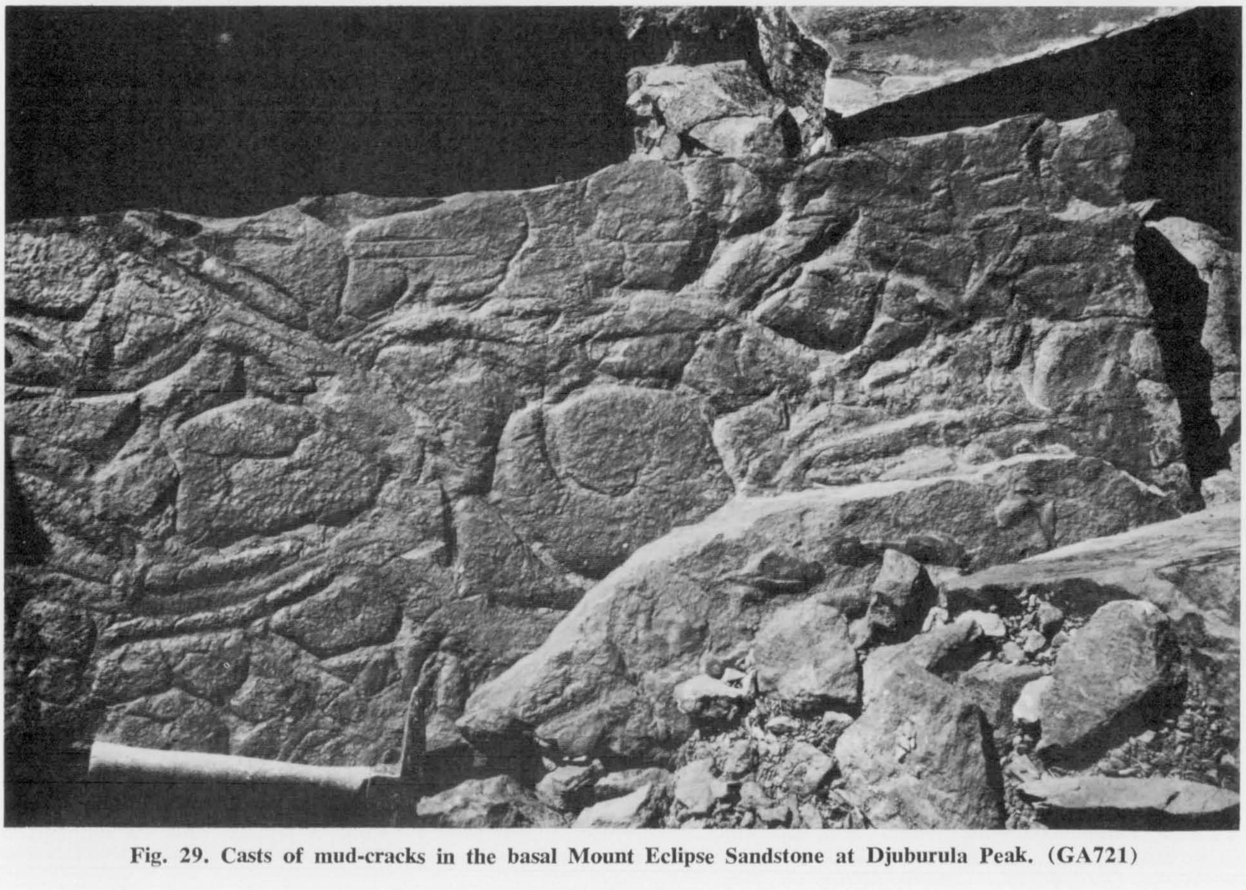


Fig. 29. Casts of mud-cracks in the basal Mount Eclipse Sandstone at Djuburula Peak. (GA721)

a dark grey-brown calcareous matrix. A pebble of reddish-brown recrystallised limestone collected from the formation about 4 km south of Mount Eclipse contains fragments of bryozoans, echinoderms, and indeterminate organic remains of post-Tremadocian Ordovician age (Joyce Gilbert-Tomlinson, formerly BMR, personal communication); no rocks of this lithology or indisputably of this age have been found in situ in the Ngalia Basin, although they may be present in the subsurface in the interpreted Palaeozoic sequence in the western zone of the basin (Plate 2). Rounded and ellipsoidal pellets in the formation contain angular quartz grains and resemble phosphatic pellets recorded by Cook (1972, plate 2 in fig. 2) in the Stairway Sandstone of the Amadeus Basin. Similar pellets also occur in the late Lower Ordovician Nora Formation of the southern Georgina Basin.

The Mount Eclipse Sandstone is characteristically cross-stratified; the most common type is planar cross-stratification (McKee & Weir, 1953). The sets are generally wedge-shaped or tabular; the sizes of the cross-strata vary, but the most common is medium-scale cross-stratification, 0.5 m to 6 m long. The orientations of most of the cross-strata suggest that the dominant current direction was from the northeast.

The basal few metres of the Mount Eclipse Sandstone at Djuburula Peak differ significantly in several respects from the predominant lithology of the formation. The sandstone there is red and red-brown, fine and medium-grained with a few coarse sand streaks, medium to thick-bedded, and poorly sorted, and contains a substantial proportion of silt and clay. Chert pebbles outnumber quartzite pebbles. Quartz grains have overgrowths, and coatings of iron oxides, and are irregular; the high proportion of iron oxides (up to 5% in the sandstone), and the finer grainsize, may be caused by local derivation of material from the underlying Bloodwood Formation, although weathering or diagenetic effects cannot be discounted. Interference and asymmetrical ripple marks, mud-cracks, and small-scale low-angle, thinly cross-bedded units are common. Bedding-plane features include trace fossils (Fig. 27), angular casts and moulds (Fig. 28), casts of mud-cracks (Fig. 29), slump structures, and probable gas pits (Fig. 30). The angular casts and moulds are believed to have formed by the desiccation of a thin siltstone and clay layer, differential contraction, curling upwards of the desiccated plates, and the subsequent sediment filling of the intraplate areas.

Similar lithologies to that in the basal section at Djuburula Peak are present at least 300 m above the base of the unit east of Penhalls Bore (section EX-9), where they also include laminated fine-grained calcareous sandstone with interbeds of chocolate-brown micaceous siltstone. These beds generally contain small clay pellets. Sedimentary structures include slumps, cross-stratification, scour-and-fill structures, erosion channels, and current lineation. The cross-strata in this restricted interval indicate that sediment transport was from the northwest. The basal sandstone at Djuburula Peak may be continuous with the similar sandstone east of Penhalls Bore; relief on the depositional surface would explain their apparently different stratigraphic levels.

At McEwin Hills, at least 120 m of medium-grained red-brown sandstone correlated with the Mount Eclipse Sandstone is preserved in a southwest-plunging syncline which has an irregular floor of Precambrian schist. Estimates from photointerpretation suggest that its thickness may be up to 300 m. The sandstone is in part richly micaceous, and the lowermost beds contain fragments of schist up to 6 mm across of similar lithology to the underlying basement. Current lineation and cross-bedding sets up to 1.2 m thick are common, and indicate transport of detritus from the east-northeast. The sandstone is mostly thin-bedded, silty, kaolinitic, and locally enriched in secondary iron oxide. Thin coarse-grained sandstone interbeds are present, and subangular white quartz fragments up to 8 cm and angular clay pellets occur locally.

In the northernmost outcrops at McEwin Hills, where the beds are vertical, the sandstone is silicified, tough, and cut by numerous quartz veinlets. Locally the contact with the underlying basement is irregular, and relief is of the order of 12 to 15 m.

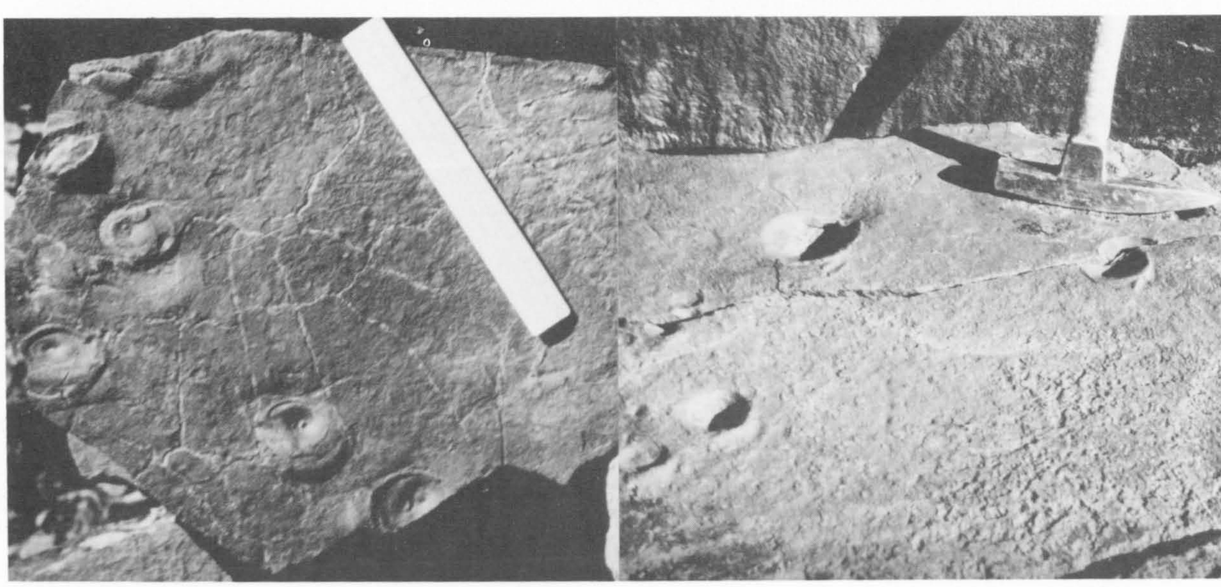


Fig. 30. Probable gas pits preserved in the basal Mount Eclipse Sandstone at Djuburula Peak. The scale in the photograph at left is a 12-inch ruler. (GA736, 743)

Sandstones (including quartz arenite, arkosic arenite, lithic arenite, and lithic greywacke), micaceous siltstone, claystone, and quartz-cobble conglomerate of the formation were intersected in shallow stratigraphic drillholes (Evans & Nicholas, 1970; Wells, 1974). The fresh rock at depth includes fossiliferous carbonaceous shale; grey, white, and green-grey siltstone; and grey and greenish-grey sandstone with fresh white and pink feldspar. Some sandstone and siltstone interbeds are red and brown, similar to rocks in outcrop, and the colour is probably primary. Deeply weathered rocks of the formation persist in places to depths of 200 m. The unweathered rock is tough, in contrast to the more friable rocks in outcrop. Carbonaceous laminae and pyrite in the formation are confined to the subsurface. Quartz, feldspar, siliceous oolite, granite, and quartzitic rock fragments occur in Napperby No. 1; the oolite may be derived from the Walbiri Dolomite.

Plant fossils—mostly fragments of bark, trunks, and stems—are common, particularly in the upper part of the formation. Leaf impressions are less abundant but are in places sufficiently well-preserved to be specifically identifiable (Appendix 6).

Age

Plant macrofossils and spores indicate that the formation ranges in age from Late Devonian (late Famennian) to Late Carboniferous; alternatively there may be a disconformity within the formation representing a considerable time break.

Plant fragments from the upper part of the formation 6.5 km south-southeast of Djambidjimba Mesa are Late Carboniferous in age (Appendix 6). A single specimen of *Leptophloem ?australe* from the basal part of the Mount Eclipse Sandstone about 5.5 km east of Bigrlyi Pass indicates a Late Devonian or Early Carboniferous age. Other, non-diagnostic plant fossils were collected from the western Naburula Hills, central and southern Walbiri Ranges, 40 km southwest of Yuendumu Native Settlement, Djambidjimba Mesa, 7 km west of Waite Creek, and 13 km east-southeast and 17 km northeast of Mount Doreen homestead.

Relatively fresh carbonaceous sandstone from seismic shot-hole samples and diamond-drillcores have yielded recognisable sporomorphs. A rich spore assemblage collected from roughly the exposed middle part of the formation at Central Pacific Minerals' Walbiri prospect (samples NT 63 and WP 1 to 10) in the Walbiri Ranges is probably Visean in age and belongs to the *Anapiculatisporites largus* Assemblage (D. Burger & E. M. Kemp, BMR, personal communication). G. Playford (University of Queensland, personal communication 1979) has confirmed this identification, and reported a similar flora in a sample collected from the interval 479.6-479.75 m in Afmeco DDH-DAV 1 (at about lat. 22°17′45″S; long. 131°14′45″E). He reported as follows:

> This productive sample contains a spore assemblage that is similar in many respects to (i) the palynoflora I have reported from the Ducabrook Formation of the Drummond Basin (Playford, 1977, 1978); and (ii) the assemblage from the upper Bonaparte beds/Tanmurra Formation of the Bonaparte Gulf Basin (Playford, 1971). In other words, this Mount Eclipse palynoflora is of late Early Carboniferous (Visean) age and is attributable to the *Anapiculatisporites largus* Assemblage of the *Granulatisporites frustulentus* Microflora (Playford & Helby *in* Kemp & others, 1977).

Samples from a drillhole near isolated outcrops about 3 km west-southwest of Smiths Gift Bore have yielded a Late Devonian spore assemblage (D. Burger & E. M. Kemp, personal communication)—including the diagnostic *Retispora lepidophyta*, which occurs in late Famennian strata world-wide, and *Brochotriletes textilis*—probably from beds near the base of the formation; other associated spores have a moderately long range.

Correlation

The Mount Eclipse Sandstone is correlated with part of the Pertnjara Group of the Amadeus Basin (Fig. 8) on the basis of lithology and tectonic setting, and it has a similar stratigraphic position to part of the Lake Surprise Sandstone in the Wiso Basin (Kennewell & Huleatt, 1980).

Palaeontological evidence shows that the lower part of the Mount Eclipse Sandstone is about the same age as beds high in the Pertnjara Group in the Amadeus Basin and the upper part of the Dulcie Sandstone in the Georgina Basin. The Pertnjara Group contains spores (Hodgson, 1968; Playford, Jones, & Kemp 1976) and fish remains (*Bothriolepis* and *?Phyllolepis*; Gilbert-Tomlinson, 1968; Young, 1974) indicating an age in the Frasnian to pre-late Famennian time interval. The upper part of the Dulcie Sandstone contains *Phyllolepis* Agassiz and *Bothriolepis* Eichwald (Hills, 1959; Gilbert-Tomlinson, 1968), suggesting a Frasnian-Famennian age.

Unfossiliferous non-marine sedimentary rocks of the Lucas Formation, Pedestal beds, and Chuall beds are tentatively regarded by Blake (1978) as correlatives of the Pertnjara Group of the Amadeus Basin, and so may be about the same age as the Mount Eclipse Sandstone. Blake & others (1979) have identified the sandstone at McEwin Hills with the Pedestal beds.

Palaeogeography and environment

The absence of proven marine organisms, the well-developed cross-stratification, the sedimentary structures, and the plant fossils suggest that the formation is continental in origin and probably formed mainly in fluvial and piedmont environments. The abundance of feldspar, the coarse subangular grains, and the immature nature of the sandstone indicate the proximity of a provenance composed mainly of igneous and metamorphic crystalline basement rocks. Many of the fragments and mineral grains were undoubtedly derived from the older sedimentary formations of the basin, as well as from Precambrian basement rocks.

The preliminary data from palaeocurrent directions and grainsize distribution suggest that provenance areas lay to the north of the present northern margin of the Ngalia Basin, but whether uplifts of about the same age to the south also provided any detritus is not certain.

GEORGINA BASIN OUTLIERS

Central Mount Stuart Formation

Several outliers of the Central Mount Stuart Formation, which Walter (1980) has included in the Georgina Basin sequence, occur in the northeast. The formation is a dominantly arenite sequence with abundant redbeds in its type section, but includes sandstone, conglomerate, siltstone, arkose, orthoquartzite, greywacke, dolomite, limestone, shale, and tillite. Tillite is locally present at or near the base of the formation, and trace and body fossils occur in the upper red sandstone of the formation.

History

Smith & Milligan (1964) originally named the unit the Central Mount Stuart beds, and Offe (1978) redefined it as a formation. Walter (1980) included the formation (minus the basal diamictite) in the Mopunga Group of the Georgina Basin sequence.

Type section

The type section is on the southern side of Central Mount Stuart (lat. 21°54′50″S, long. 133°27′10″E), about 100 km north of the eastern end of the Ngalia Basin. The thickness of the formation in the type section is 800 m and is illustrated in a graphic log by Stewart & others (1980).

Distribution

Several outliers of the Central Mount Stuart Formation occur to the north and northeast of the Ngalia Basin at Crown Hill, Nancy Hill, and near Tea Tree Settlement (Plate 1); they form features of moderate relief. The formation rests unconformably on quartz-mica schist, quartz-feldspar porphyry, and other rocks of the Arunta Block.

Lithofacies

At Crown Hill, and in nearby low hills a little farther northeast, about 150 m of sandstone, siltstone, conglomerate, and tillite are preserved in a tilted, partly downfaulted block in basement rocks. The tillite occurs in a lens up to 30 m thick at the base of the formation at Crown Hill. The purple-brown, poorly sorted siltstone matrix contains erratics up to 2.5 m of granite, quartzite, and many other rock types; a few erratics are faceted and some have indistinct striae. The tillite unconformably overlies Precambrian quartz-mica schist, and is conformably overlain by several tens of metres of interbedded siltstone, sandstone, and coarse-grained arkosic conglomerate.

Tillite also crops out at Nancy Hill, between beds of massive quartz sandstone. It is lithologically similar to the tillite at Crown Hill, except that its phenoclasts are smaller (max. 45 cm), are represented by fewer rock types, and rarely have striated surfaces. The tillite is overlain by thick, partly sandy, laminated siltstone beds that resemble varves. The intervening sandstone beds through the sequence are mostly medium-grained, tough, well sorted and rounded, thick-bedded, and silicified; they contain limonite pseudomorphs after pyrite, minor pebble beds and laminae of coarse quartz grains, and, in places, cross-bedding and interference ripple marks. A basal conglomerate unconformably overlies deeply weathered Precambrian basement rocks along the east flank of Nancy Hill, and a second conglomerate occurs higher in the sequence above the tillite.

Sandstone almost identical to the sandstone beds at Nancy Hill, but containing no tillite, unconformably overlies Precambrian granite 11 km north of Tea Tree. The sequence of sandstone, conglomerate, shale, siltstone, and quartzite in a ridge 5 km farther southeast is dissimilar to other exposures of the formation in NAPPERBY, although some rock types can be matched. The predominant sandstone is pink and brown, fine to coarse-grained, silty, micaceous, and feldspathic, and the silicified sandstone contains limonite pseudomorphs after pyrite. The remaining rock types comprise granule conglomerate, siltstone, tough quartzite, and shale which is friable, slumped, laminated in places, and shows flame structures where overlain by sandstone.

Contacts

Only the unconformable basal contacts of the Central Mount Stuart Formation with rocks of the Arunta Block are exposed in the outliers to the north and northeast of the Ngalia Basin; no contacts with younger formations are known in the region. A little farther east near the margin of the Georgina Basin, both upper and lower contacts and lateral relations with other formations have been demonstrated. These are discussed below as they have a direct bearing on assigning an age to the formation.

Palaeogeography and environment

The Central Mount Stuart Formation was deposited in the region of a postulated structural high which lay between the present sites of the Ngalia and Georgina Basins (Shaw & others, 1975). In places, beds high in the sequence rest on basement, which must therefore have had considerable relief during deposition of the formation.

The tillite at the base of the formation was probably deposited in discontinuous spreads on an irregular basement surface across the area. It lenses out abruptly over short distances, and there is insufficient evidence to suggest any particular direction of movement of the sediments. Alternatively the top of the tillite may mark a hiatus within the formation and an interval of erosion when the tillite may have been completely removed from some areas. Correlation of the tillite with the older of two Sturtian glacial phases in South Australia (Preiss & Forbes, 1981; see below) would imply a major hiatus within the formation, but this is far from certain.

The redbeds of the formation may have accumulated under transitional marine and continental or deltaic continental conditions close to a source on the postulated structural high (Shaw & others, 1975).

Flute casts, mud-cracks, and other sole marks in the arenaceous rocks of the formation indicate shallow-marine or transitional environments, and many siltstone laminae are contorted and broken and indicate either contemporaneous brecciation of underlying laminae by turbulent shallow water (Grainger, 1969) or possibly desiccation.

Age

Tillite in the lower part of the Central Mount Stuart Formation indicates an Adelaidean age for the outliers in NAPPERBY because it is similar to that elsewhere in the Adelaidean of central Australia. Equivalent tillite in the formation outside NAPPERBY, mainly in the areas around Central Mount Stuart and Mount Skinner, lies below beds containing late Precambrian fossils (Preiss & others, 1978; Walter, 1980). The soft-bodied late Precambrian Mount Skinner fauna occurs in the lower half of the Central Mount Stuart Formation in ALCOOTA (Wade, 1969), and 450-500 m above the base of the formation in the type section at Central Mount Stuart (Walter *in* Offe, 1978). Beds from the overlying Donkey Creek beds in BARROW CREEK and at Mount Octy contain earliest Cambrian trace fossils, including trilobite trails (Daily, 1974).

Correlation

Preiss & others (1978) suggested that the best lithological comparison for the tillite at the base of the central Mount Stuart Formation at Nancy Hill is with the ferruginous diamictite of the Holowilena Ironstone, which records the first phase of Sturtian glaciation in South Australia (Preiss & Forbes, 1981). If this comparison is correct, then a correlation with the tillite of the Naburula Formation in the Ngalia Basin and with the Areyonga Formation in the Amadeus Basin is indicated (Fig. 7).

In BARROW CREEK the Central Mount Stuart Formation is overlain by the Donkey Creek beds (Walter, 1980) a sequence of brown, grey, or red glauconitic quartz sandstone, arkose, and brown or white siltstone which contains Early Cambrian trace fossils; regional correlations suggest that the contact may be a paraconformity (Walter, 1980). Smith & Milligan (1964) originally identified this younger unit as the Grant Bluff Formation, and Shaw & others (1975) suggested that it is lithologically more similar to the Mount Baldwin Formation. Walter (1980) considered that it is lithologically distinct from both these units. The trace fossils in it indicate a correlation with the upper part of the Mount Baldwin Formation, with the upper (unit III) Arumbera Sandstone of the Amadeus Basin, and by inference with the upper Yuendumu Sandstone.

A sequence comprising the Central Mount Stuart Formation underlain by rocks similar to the Grant Bluff Formation was penetrated in drillholes near Mount Skinner, in ALCOOTA. However, the similarity of some of the sandstones in both the Central Mount Stuart Formation and Grant Bluff Formation has been noted by Shaw & others (1975) and Offe (1978), and the two formations are, at least in part, time equivalent.

A sketch section showing the relation of the Central Mount Stuart Formation to other formations in central Australia is shown in Figure 31.

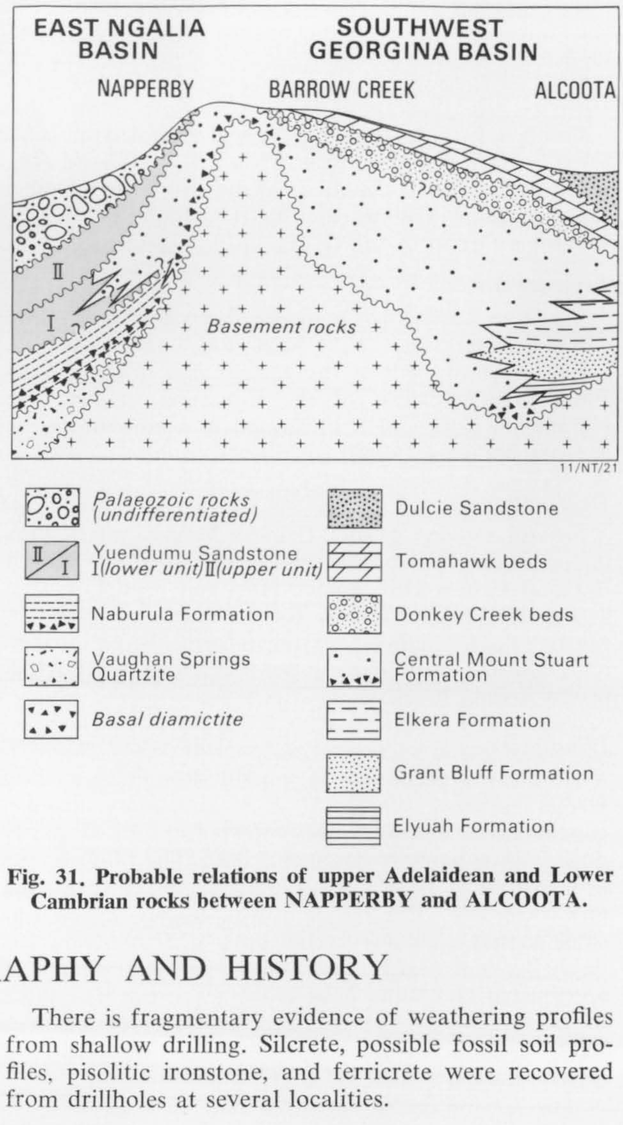


Fig. 31. Probable relations of upper Adelaidean and Lower Cambrian rocks between NAPPERBY and ALCOOTA.

CAINOZOIC STRATIGRAPHY AND HISTORY

Cainozoic units as much as 212 m thick, including evaporites and deep weathering zones, obscure the major part of the Ngalia Basin and surrounding basement rocks. Apart from the superficial deposits, their nature is known only from widely separated stratigraphic drillholes and sparse outcrops, and they have been dated in only two areas. The elevation of the base of the Cainozoic varies by as much as 500 m. This may be caused by a combination of relief on the depositional surface and Late Tertiary tilting and faulting.

Weathering profiles

Silcrete, ferricrete, and other chemically altered rocks constitute a duricrust capping on formations of the Ngalia Basin in many areas along the northern margin of the Walbiri Ranges, around the Vaughan Springs Syncline, in the Patmungala Syncline, and in the Treuer Range. Thick weathered crusts and laterite are more common over many of the exposures of Precambrian crystalline basement rocks north of the basin.

There is fragmentary evidence of weathering profiles from shallow drilling. Silcrete, possible fossil soil profiles, pisolitic ironstone, and ferricrete were recovered from drillholes at several localities.

Sediments

The Cainozoic sediments comprise silty and clayey sands with subordinate sand, clay, and lignite. Clay, chiefly kaolinite and illite (Table 3), and in places carbonaceous, is more common in the east. Silty and pebbly sands constitute the bulk of the sequence in the west, but overlie the clay sequences in the east.

At Vaughan Springs, Cainozoic deposits exposed in two prominent mesas (Fig. 32) comprise white pebbly sand at the base passing upwards into a vuggy ferruginous silicified silty sandstone and ironstone. The deposit is at least 30 m thick and is probably the remnant of a much larger sheet of sediment of possibly fluvial origin; it is probably a correlative of similar arenaceous sediments penetrated in the shallow stratigraphic drillholes in the western zone.

The most widespread superficial Cainozoic deposit is aeolian red sand of the sand plains and in longitudinal dunes, which are mostly fixed by vegetation and generally less than 5 km long by up to 9 m high. Sand is ubiquitous over the central, western, and southern parts of the Ngalia Basin.

Alluvium, grading from unsorted gravel in upland areas to clay in ephemeral lakes and claypans of terminal floodouts, is most common over the eastern zone of the basin. Red earths cover a much larger area than the alluvial deposits but are similarly widely distributed over the eastern part of the basin; they

TABLE 3. DIFFERENTIAL THERMAL ANALYSIS RESULTS

Well name and no.	*Sample depth m (ft)*	*Formation or age*	*Minerals identified and approximate percentages*
BMR Napperby No. 1	138.68 (455′)	Cainozoic	75% Kaolinite, 25% illite
BMR Napperby No. 1	138.71 (455′1″)	Cainozoic	Kaolinite, some illite
BMR Napperby No. 1	138.24 (453′6″)	Cainozoic	50% Kaolinite, 50% illite
BMR Napperby No. 2	56.59 (185′8″)	Cainozoic	5% Kaolinite, 95% illite
BMR Napperby No. 2	57.25 (187′10″)	Cainozoic	10% Kaolinite, 90% illite
BMR Napperby No. 2	57.61 (189′)	Cainozoic	20% Kaolinite, 80% illite
BMR Napperby No. 3	156.29 (512′9″)	Treuer Member	Quartz
BMR Napperby No. 4 (SP 486)	68.73 (225′6″)	Cainozoic	Illite, calcareous (finely disseminated)
BMR Napperby No. 4 (SP 486)	70.41 (231′)	Cainozoic	Kaolinite, calcareous
BMR Napperby No. 4 (SP 486)	71.58 (234′10″)	Cainozoic	Kaolinite, calcium carbonate
BMR Napperby No. 4 (SP 486)	94.49 (310′)	Cainozoic	Kaolinite
BMR Napperby No. 4 (SP 486)	95.71 (314′)	Cainozoic	Illite
BMR Napperby No. 4 (SP 486)	96.32 (316′)	Cainozoic	Illite
BMR Mount Doreen No. 2 (SP 1545)	37.64 (123′6″)	Mount Eclipse Sandstone	Kaolinite
BMR Mount Doreen No. 2 (SP 1545)	39.62 (130′)	Mount Eclipse Sandstone	Kaolinite
BMR Mount Doreen No. 2 (SP 1545)	40.44 (132′8″)	Mount Eclipse Sandstone	Kaolinite
BMR Mount Doreen No. 1 (SP 1622)	4.6–9.1 (15′–30′)	Proterozoic?	Unknown

SP—BMR seismic shot-point reference number.
Analyses by BMR.

Fig. 32. Cainozoic pebbly sandstone capped by dark-toned silicified sandstone and ironstone in two prominent mesas (middleground) at Vaughan Springs. These sediments wedge out over a prominent ridge of the Vaughan Springs Quartzite (foreground and background). (GB2859)

generally support and are easily recognised on air-photographs by a thick cover of mulga and low shrubs.

Calcrete is concentrated in low areas, mainly around playa lakes in the southern and western regions of the basin. Common opal has been found with the calcrete in the area south of the Vaughan Springs-Yuendumu road near the Naburula Hills. Calcrete occurs at depths of up to 100 m in some drillholes, (Fig. 15; Wells, 1974; Evans & Nicholas, 1970).

Superficial evaporites in saline playas consist generally of a crust of halite about a centimetre thick underlain by grey foetid sand and silt which commonly contain large gypsum crystals; highly saline groundwater is generally a few centimetres below the surface of the playas. Analyses of some of the evaporites are given on p. 70. Evaporites — mostly consisting of gypsum with variable quantities of sand, silt, and clay, and less than 5 m thick — occur at shallow depths in several drillholes. In one drillhole (BMR Mount Doreen No. 11) over the central southern part of the Ngalia Basin, gypsum with grey-green clay occurs over about 2 m at a depth of 130 m.

Colluvium consisting principally of scree and talus deposits is common in elevated areas where there is an abrupt change of relief.

Age and correlation

Lignite in BMR Napperby No. 1 yielded an assemblage of Tertiary pollen which, when compared with the palynological zonal schemes established in southern Australia (Wopfner & others, 1974), suggests a middle Eocene age (Kemp, 1976) and can be referred to the *Proteacidites confragosus* Zonule. The palynomorph assemblage resembles those which have been described from the Eyre Formation of northern South Australia, and includes non-marine dinoflagellate cysts and abundant pollen of aquatic plant groups, suggesting deposition in a lacustrine environment. Relatively high *Nothofagus* and podocarpaceous pollen counts suggest that humid conditions prevailed, at least locally, although seasonal aridity cannot be ruled out.

Sediments similar to those overlying the Ngalia Basin sequence occur in the Tertiary Tea Tree Basin (O'Sullivan, 1973; Edworthy, 1966, 1968), northeast of the Ngalia Basin. These are postulated to have accumulated mostly in fluvial cycles on an irregular, lateritised Precambrian basement. They are up to about 320 m thick, and spores from lignite and carbonaceous clays in the sequence have been dated as possibly middle Miocene (W. Harris, personal communication *in* O'Sullivan, 1973). The components of the microfauna suggest subtropical rainforest communities dependent on high rainfall conditions. Correlatives occur in the lower units of the Etadunna Formation and in the Namba Formation, both in the Lake Frome area.

Tertiary sediments that are broadly similar to those in the Ngalia Basin area have been described from the central western part of ALCOOTA (Woodburne, 1967; Shaw & others, 1975), the Amadeus Basin (Wells & others, 1967, 1970), and the Hale River Basin, in the northern half of ALICE SPRINGS (Clarke, 1975).

The mid-Eocene microflora in BMR Napperby No. 1 is older than most known fossiliferous intervals in neighbouring basins. The carbonaceous pre-silcrete sediments of the Amadeus Basin, which are thought to be Eocene-Miocene in age (Lloyd, 1968) may include equivalents of the Napperby microflora.

Cainozoic palaeogeography and history

The principal events that have been interpreted mainly from drillhole data (Fig. 15) are summarised as follows.

(1) Fine-grained silts and clays accumulated in lake basins, mainly in the east, which supported a luxuriant vegetation at times — as in the mid-Eocene.

(2) Fluviatile sediments accumulated in the west in the valleys of streams that might have drained into a palaeodrainage system which terminated in the Joseph Bonaparte Gulf (van de Graaff & others, 1977). The fluviatile regime spread across the Ngalia Basin and adjacent areas, including those underlain by lacustrine deposits. The provenance at this time commonly included Precambrian granitic terrains.

(3) Climatic changes and hiatuses during the Cainozoic are recorded by the presence of ferricrete, silcrete, calcrete, and evaporites at different levels encountered in the drilled sequences.

(4) Tertiary tilting and faulting, involving renewed movements on old fault planes (Burek, Wells, & Loeffler, 1979b), produced a relief on what was otherwise probably a peneplaned surface. Previously formed silcrete surfaces that now occur on the bevelled quartzite ridges lie several hundred metres above equivalent sediments in the Cainozoic continental sequences.

(5) A relatively recent arid phase is indicated by Quaternary red sands, which are widespread across the area, and by the establishment of playa lakes.

(6) A subsequent amelioration of climate is indicated by the present stabilisation of the dunes by vegetation.

BASIN STRUCTURE

SUMMARY

The Ngalia Basin is a remnant of Adelaidean and lower and upper Palaeozoic rocks preserved in a structural downwarp in the Precambrian Arunta Block. The regional structure is essentially a faulted asymmetrical syncline with its deepest part towards the northern margin of the basin. This margin is mostly faulted (Plate 1; Fig. 33), either by thrusts or high-angle reverse faults; blocks of crystalline basement rocks and superincumbent sediments were upthrown and in places thrust several kilometres southwards over the basin sediments. Consequently folding and faulting in the sediments were comparatively intense in the north, and the structure of the sediments is clearly defined in a well-exposed strip along the northern part of the central and western zones (Fig. 34, front cover). The intensity of folding in this strip increases from south to north. The southern flank of the basin, which is generally sharply defined by a well-exposed unconformable contact of a narrow strip of sediments with the predominantly crystalline basement rocks, is inclined gently northwards or in a few places has been tilted and disrupted by block-faulting. The western margin is mostly poorly defined; obscuring Cainozoic

Fig. 33. The eastern zone of the Ngalia Basin wedging out eastwards from the lower centre to the upper right. The southern margin is formed by the Stuart Bluff Range (A)—the thin line north of Lake Lewis (a salt lake)—and the Hann Range (B). The northern margin is outlined roughly by the scarp line south of the Reynolds Range (C). The length of the coverage of the photograph from top to bottom is about 200 km. (NASA *Gemini V* photo taken in 1965, S-65-4 5567; G9264)

sediments reduce the basin outcrop to only a few widely separated inliers (Fig. 35). The eastern margin is truncated by an overthrust.

Most fold axes trend westerly and are commonly doubly plunging. Wavelengths of the folds along the northern margin of the basin average about 3 km.

Faults are either parallel to or form the basin margins, especially in the north, where overthrusts are most common and upward displacement is generally on the north side except where a reversal has been caused by later movement. In the south, normal faulting was more common and overthrusting played only a minor role.

The only known incompetent beds in the Ngalia Basin sequence occur in the Treuer Member of the Vaughan Springs Quartzite (Fig. 36), but they have apparently played no significant role in controlling the structural expression and style in the basin.

Unconformities and record of diastrophism in outcrop

Ten unconformities have been documented in the Adelaidean and Palaeozoic sedimentary rocks of the Ngalia Basin. The unconformities are evidence of the magnitude and extent of diastrophic movements (Fig. 37), and the present structural fabric of the basin sediments is the result of the cumulative effect of these movements.

A major unconformity at the base of the Ngalia Basin sequence documents the last major diastrophic period in the Arunta Block. The unconformity was folded by later movements, and its truncated edge now defines most of the basin's southern margin. The northern margin is also defined in a few places by the unconformity, which drops as much as 4 km towards the south within a few kilometres.

The unconformity at the base of the Naburula Formation in the west records a period of diastrophism (*Vaughan Springs Movement*) that probably also contributed in part to the unconformity between the Vaughan Springs Quartzite and the Yuendumu Sandstone in the central zone. The diastrophism resulted in broad vertical (epeirogenic) movements, and there is good evidence both from outcrop and from seismic records for block-faulting. The uplift was of sufficient magnitude for the Adelaidean sediments to be completely removed in some areas. The Vaughan Springs Movement can be correlated with the Areyonga Movement in the Amadeus Basin (Fig. 37).

The probable disconformity between the Rinkabeena Shale and the Mount Doreen Formation may record a movement (*Rinkabeena Movement*) of late Adelaidean age. It is probably the same age as the movement which produced an unconformity between the Aralka and Olympic Formations in the eastern Amadeus Basin, and is probably also equivalent to the Souths Range Movement, which is recorded by unconformity between the Pinyinna and Winnall beds in the southern Amadeus Basin.

An unconformity at the base of the Yuendumu Sandstone records diastrophism that is correlated in part with the Petermann Ranges Orogeny. A possible un-

Fig. 34. The folded sequence at the northern margin of the Ngalia Basin in the Treuer Range. Prominent ridges of the Adelaidean Vaughan Springs Quartzite (5 km long in the photograph) are separated from folded Devono-Carboniferous Mount Eclipse Sandstone by a narrow valley underlain by Adelaidean rocks and Palaeozoic sandstone. Metasedimentary rocks and granite plutons of the Arunta Block underlie the pediplain in the background. (M525/9)

conformity of smaller magnitude within the formation may record a later pulse of this orogeny. Movements during this orogeny probably contributed in part to the unconformity between the Djagamara and Mount Doreen Formations in the western zone.

The probable unconformity between the Yuendumu Sandstone and the Walbiri Dolomite in the east was caused by a broad vertical movement (*Yuendumu Movement*), and may be partly represented in the unconformity between the Djagamara Formation and the Mount Doreen Formation in the west. The magnitude of the unconformity cannot be gauged accurately because of its limited exposure. Locally the movement does not appear to have been severe because the Yuendumu Sandstone is not completely removed. If the Yuendumu Sandstone was originally deposited over the western zone of the basin, then the diastrophism must have been of more regional extent. The unconformity is dated as probably Early Cambrian and does not appear to have any equivalent in the Amadeus Basin.

The early Middle Cambrian to Early or Late Ordovician hiatus in the sedimentary sequence in the central zone implies an unconformity and diastrophism (*Bloodwood Movement*), although contacts of formations at the inferred unconformity are concealed by structure.

The unconformity between the Djagamara Formation and the Mount Doreen Formation in the western part of the Ngalia Basin spans the period from late Adelaidean to probably Early or Late Ordovician. The unconformity probably records several periods of movement, including the Bloodwood Movement. The extent and magnitude of the unconformity in the western zone are not known with any precision because two older periods of diastrophism, the Yuendumu Movement and Petermann Ranges Orogeny, are probably recorded by the unconformity. The presence of the Mount Doreen Formation everywhere below the unconformity suggests that this was the base-level of erosion of the uplifted blocks.

An unconformity between the Kerridy Sandstone and the Djagamara Formation records a period of diastrophism (*Djagamara Movement*) accompanied by folding which probably took place in the Silurian. The unconformity is less apparent in the east, indicating that the effects of the diastrophism were more

Fig. 35. Mount Morris, a prominent outlier of the Vaughan Springs Quartzite unconformably overlying basement rocks at the western extremity of the Ngalia Basin. A smaller outcrop of the Vaughan Springs Quartzite unconformable on basement rocks lies about 700 m to the north (right-hand edge of photograph). (GA731)

severe in the west. The Djagamara Movement is probably equivalent to the Rodingan Movement in the Amadeus Basin.

An unconformity at the base of the Mount Eclipse Sandstone (Fig. 38) records a period of major faulting and folding (*Kerridy Movement*). The unconformity occurs basinwide, and was responsible for the removal of almost all the pre-Late Devonian sediments over large parts of the marginal areas of the basin. The magnitude of the unconformity indicates that the Kerridy Movement was the most intense period of diastrophism to interrupt the Ngalia Basin sedimentation, and reactivation of the basement took place at the same time. The age of the Kerridy Movement could be Middle Devonian. The magnitude of the unconformity and the influence of the Kerridy Movement on the basin configuration indicate a possible correlation with the Middle to Late Devonian Pertnjara Movement in the Amadeus Basin.

The unconformity at the top of the Mount Eclipse Sandstone records the last major diastrophic event in the Ngalia Basin (*Mount Eclipse Orogeny*). It was the most intense movement in the basin and caused further reactivation of the basement. The unconformity is present basinwide, but is most pronounced in the north. The youngest dated beds deformed by the Mount Eclipse Orogeny are Late Carboniferous and occur in the upper part of the Mount Eclipse Sandstone. The orogeny is therefore no older than Late Carboniferous. The close similarity of the structural styles developed as a result of the Alice Springs Orogeny (see below) and the Mount Eclipse Orogeny, and the proximity of the two structural provinces, suggest that the two orogenic events were synchronous.

The Alice Springs Orogeny is defined as the event during which the Pertnjara Group in the Amadeus Basin was folded (Wells & others, 1970). Because the youngest dated beds deformed during this orogeny are Late Devonian, this does not indicate that the orogeny necessarily began in the Late Devonian, as implied by Playford & others (1976). Two lines of reasoning insinuate that it began later. Firstly, isotopic dates on retrogressively metamorphosed rocks from the Arunta Block fall into a broad group ranging from about 360 to 320 m.y. (mid-Late Devonian to early Late Carboniferous), which suggests that the Alice Springs Orogeny could be as young as Late Carboniferous. Secondly, Playford & others (1976) suggested that a cover 2 km thick would have been needed to

Fig. 36. Folds in incompetent beds of the Treuer Member of the Vaughan Springs Quartzite near the Napperby Thrust 5 km west-southwest of Napperby homestead. (GA1553)

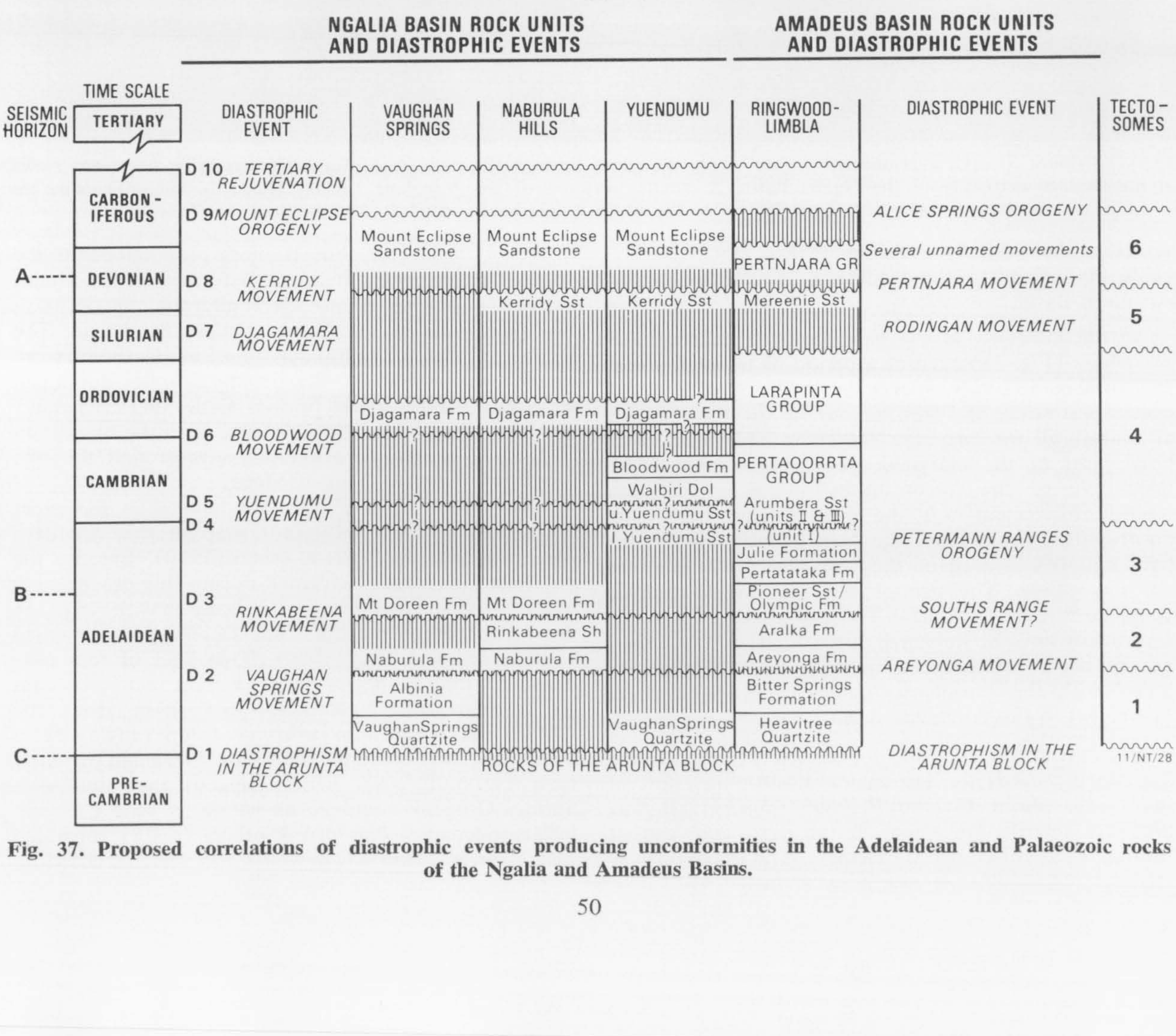


Fig. 37. Proposed correlations of diastrophic events producing unconformities in the Adelaidean and Palaeozoic rocks of the Ngalia and Amadeus Basins.

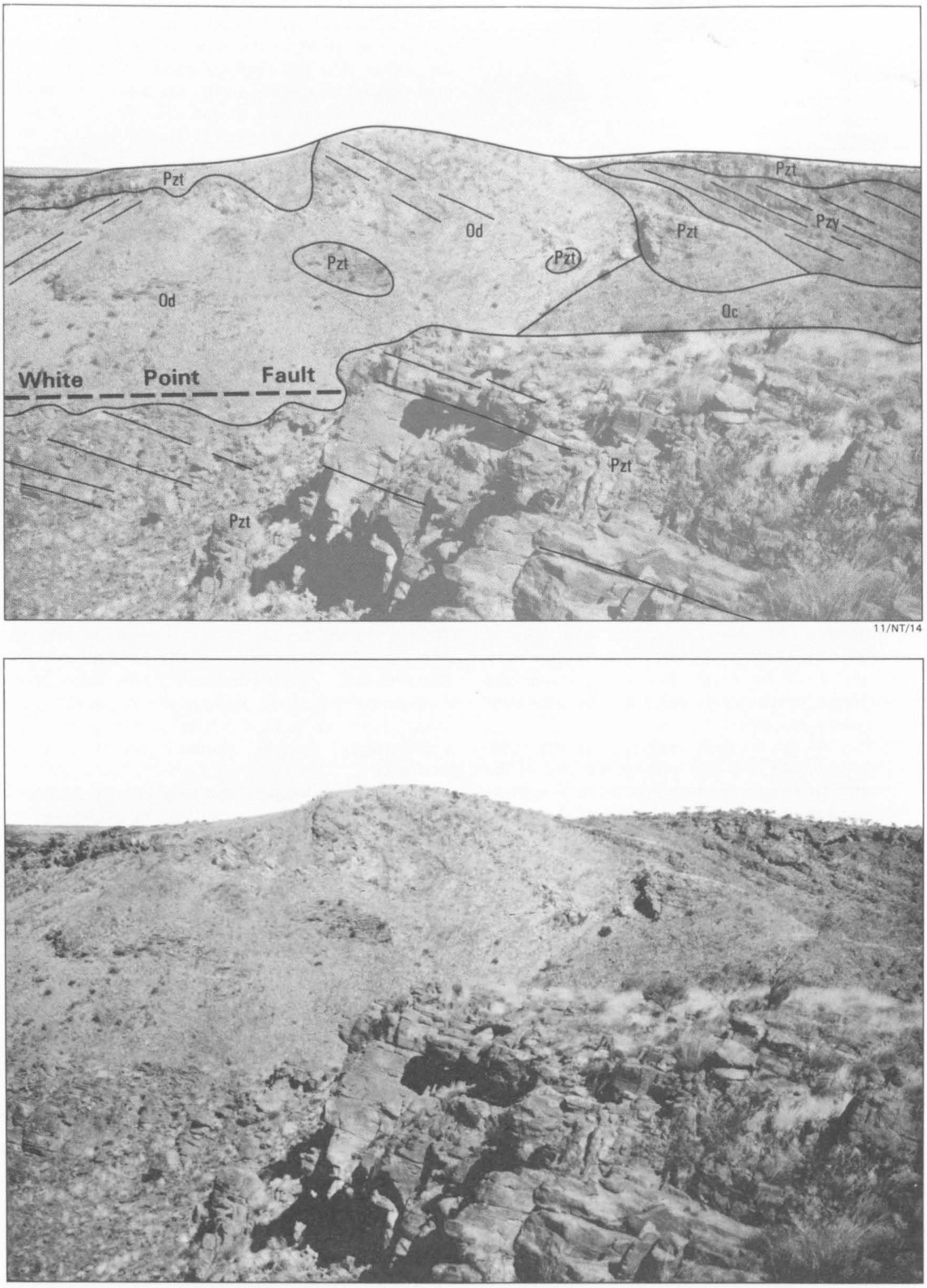


Fig. 38. Exhumed middle Palaeozoic topography—mainly a result of the Kerridy Movement. The light-toned hill of sandstone of the Djagamara Formation is draped by the darker-toned Mount Eclipse Sandstone. An angular unconformity separates west-dipping beds of the Kerridy Sandstone and south-dipping beds of the Mount Eclipse Sandstone (top right). The White Point Fault separates the Mount Eclipse Sandstone (foreground) from the Djagamara Formation. The view is southwards from near Djagamara Peak. (GA717)

account for the rank of coal material in the upper part of the Pertnjara Group; most of this overburden has been removed by erosion following the Alice Springs Orogeny, but it may have ranged up into the Carboniferous.

Mild diastrophism superimposed a relief on the relict Palaeozoic landscape probably sometime in the Tertiary. Most of the prominent topographic features owe their existence to uplifts caused by rejuvenated movements on old fracture planes.

STRUCTURAL INFORMATION FROM GEOPHYSICAL DATA

Information on the gross structure of the Ngalia Basin has been obtained mainly from the regional and detailed aeromagnetic, gravity, and seismic surveys. The geophysical results have been particularly useful in providing structural information in areas away from the well-exposed strip of outcrops along the northern basin margin.

Magnetic basement

Contours on magnetic basement, derived by E. P. Shelley (BMR, personal communication 1972) from the results of the surveys by Carter (1960) and Hartman (1963), are shown in Figure 39. The initial interpretation of the magnetic results by Hartman provided the first regional appraisal of the form and structural trends of the basin. The magnetic basement depth contours may be modified and a more detailed quantitative interpretation of the magnetic anomalies obtained when the results of the BMR aeromagnetic survey over the basin in 1976 are analysed.

The analysis of the earlier regional magnetic results showed contours to magnetic basement that indicate two deep asymmetric lobes corresponding to the western and eastern zones of the basin. Magnetic basement close to the northern faulted margin of the basin was estimated to be about 5 km deep. Subsequent seismic work has confirmed that the sedimentary section extends down to about this depth, suggesting that the magnetic basement is close to the basement of the sedimentary section.

The structure of the western extremity of the basement was interpreted to be a half-graben and that of the eastern extremity a narrow graben. Magnetic basement in the graben was considered to be deep; however, Hartman (1963) indicated that estimates of depths to magnetic basement there would be unreliable because of the narrowness of the graben, the lack of geological control, and the lack of definitive magnetic anomalies for interpretation.

A qualitative analysis of the most recent magnetic results confirms that the magnetic basement is shallow in the south and deepens northwards as the basin deepens. The magnetic pattern associated with complex faulting at the central southern part of the margin of the basin extends northwards into the basin, suggesting that the faults probably also extend in this direction. Long-wavelength magnetic anomalies are superimposed on the broad contour pattern, which reflects magnetic basement generally; they are probably related to basement highs in a series of horst blocks which may extend southeastwards to the Stuart Bluff Range.

Gravity surveys

BMR reconnaissance gravity surveys (Flavelle, 1965; Whitworth, 1970) have provided information on the regional setting of the Ngalia Basin in relation to the surrounding basement rocks, delineated the main gravity provinces in the area, and shown that the main gravity trends within the basin generally parallel its margins. Detailed gravity surveys made by PAOC (Hudson & Campbell, 1965) and Magellan (Hickey, 1969, 1970; Sabitay, 1971; Pratt, 1971; Gibson, 1971; and Pfitzner, 1974) provided information on structures within the basin and leads for follow-up seismic surveys. The results of the gravity surveys have been integrated in the Bouguer anomaly map shown in Plate 2.

Magellan computed a regional gravity field from the results of the reconnaissance surveys, and removed its effect from the results of the detailed gravity surveys, in order to produce maps of the residual gravity field. The non-uniform distribution of the data, on closely spaced stations along widely spaced north-south traverses, involves a bias whereby predominantly east-west-trending elongate residual gravity contours are produced.

Parts of the Bouguer anomaly gravity profiles which show distinctive gravity signatures of geological features are illustrated in Figure 40. The profiles are plotted with a common vertical scale, but each profile is reduced to an arbitrary datum so as to place it about the traverse. The Bouguer anomaly results along the traverses assist in tracing major faults and other structural features, and in delineating fault blocks over which seismic results are generally poor. Fault blocks at the southern margin are particularly well defined on the gravity profiles. Bouguer anomaly profiles are

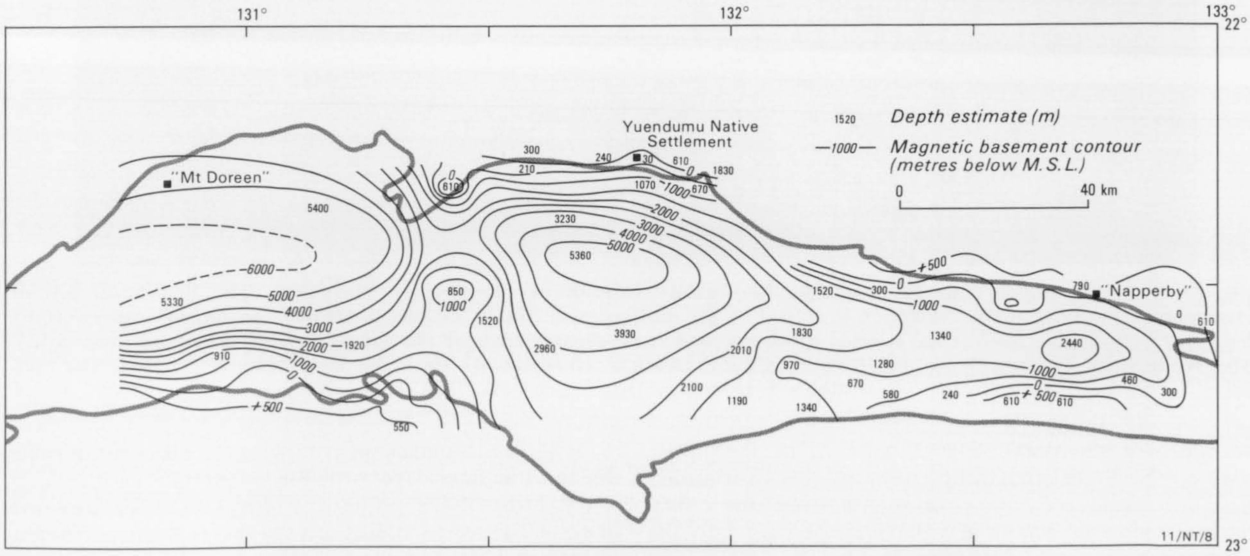


Fig. 39. Interpreted depths to magnetic basement (after Hartman, 1963).

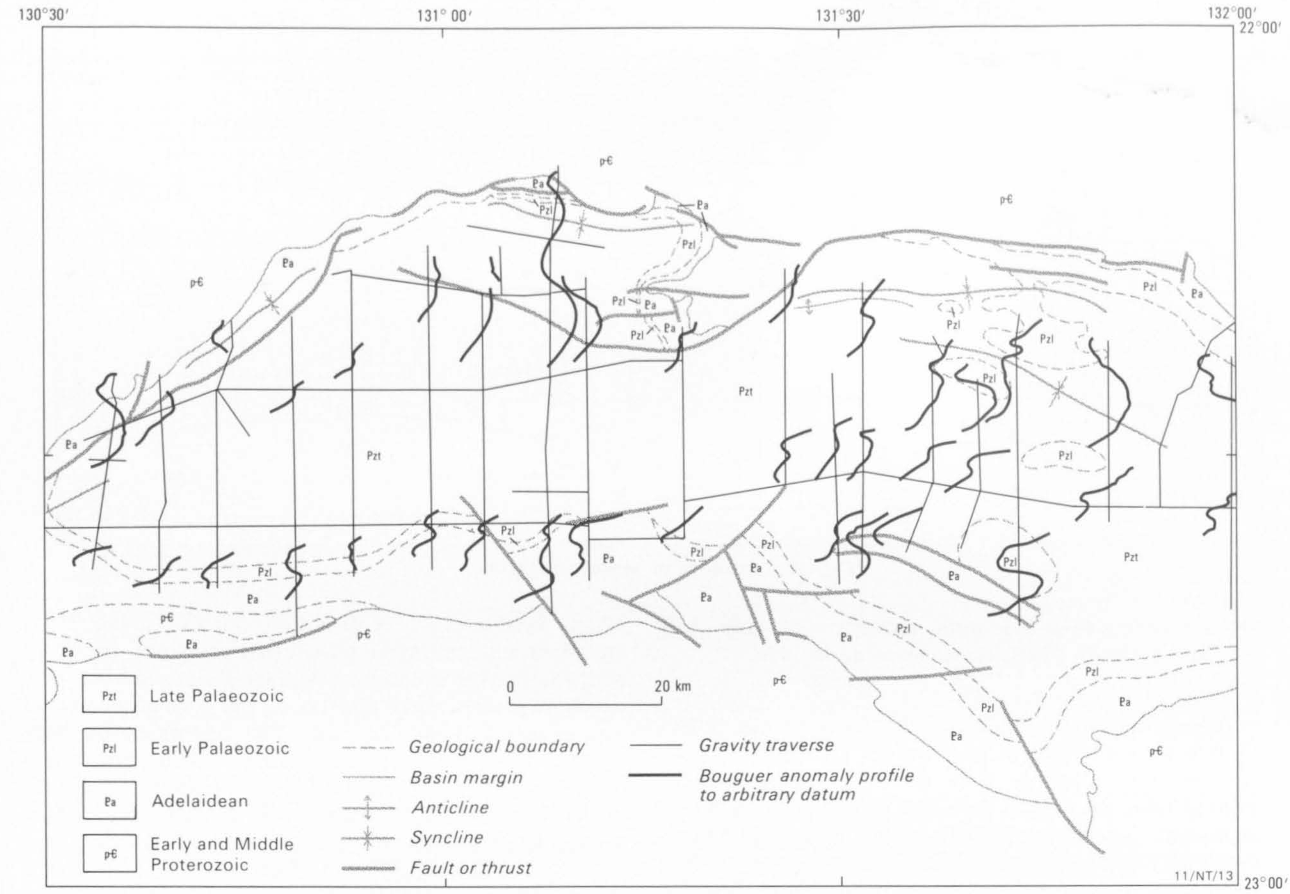


Fig. 40. Bouguer anomaly profiles and structural interpretation.

also shown together with seismic cross-sections in areas where they provide an aid to interpretation (Plate 3). The lack of reliable density information, particularly from the deep sediments and from basement generally, precludes the use of the gravity results for other than qualitative interpretation. However, S. P. Mathur (*in* Moss & Jones, 1974) interpreted the gravity results over the Waite Creek Thrust, in the western part of the basin, in order to investigate the influence of the fault on the gravity field; he found that the gravity effect is related to basement uplift combined with overthrusting.

Seismic surveys

Surveys by PAOC (Hudson & Campbell, 1965), BMR (Moss & Jones, 1974), and Magellan (Krieg, 1972) provide a regional network of traverses throughout the basin. The locations of the seismic traverses in relation to the generalised structure and solid geology of the Ngalia Basin are shown in Plate 2 and differentiated in Figure 41. Details of equipment and recording and processing techniques used on the surveys are included in the survey reports.

Seismic reflection sections, obtained using single-fold or six-fold CDP continuous reflection profiling techniques, provide information on structures in the basin. Seismic reflection events vary in quality and continuity. They generally range from good away from faults to poor over faults, over upthrust blocks, near the margins of the basin, and near outcrops. The quality and continuity are generally better along traverses in the western zone of the basin, where several prominent reflection horizons can be traced for considerable distances. In the central zone the overall reflection quality is much poorer, and difficulties are experienced in tracing shallow horizons.

Seismic velocity information

Expanded spreads and refraction traverses were recorded, in order to obtain velocity information that would assist in correlating reflection horizons from different traverses in the basin and with geological formations (Moss & Jones, 1974). Krieg (1972) compared the results from the expanded spreads with additional information obtained from the velocity analysis of common depth-point reflection data from ten locations. He derived a time-depth relation for the basin by averaging the time-depth curves from the velocity analysis. His computed depths to the seismic reflectors derived from the average curve differed by up to ± 20 percent from those computed from the expanded spreads, particularly in areas where the section is thin. We have further analysed the expanded-spread information in order to derive more appropriate time-depth conversion information which would also be suitable for migrating the seismic data. Using the expression $V_i = V_o + kZ$ (where V_i = instantaneous velocity, V_o = initial velocity, Z = depth, and k is a variable factor) we concluded that the most appropriate generalised velocity function for the Ngalia Basin is one in which V_o = 3800 m/s and k varies linearly with the time T (in seconds) of the deepest reflection. In the eastern central zone of the basin, $k = 1.85 - 0.74T$, and, in the western zone, $k = 1.94 - 0.88T$, where T is in seconds. A comparison of depths computed using this method with those from all expanded

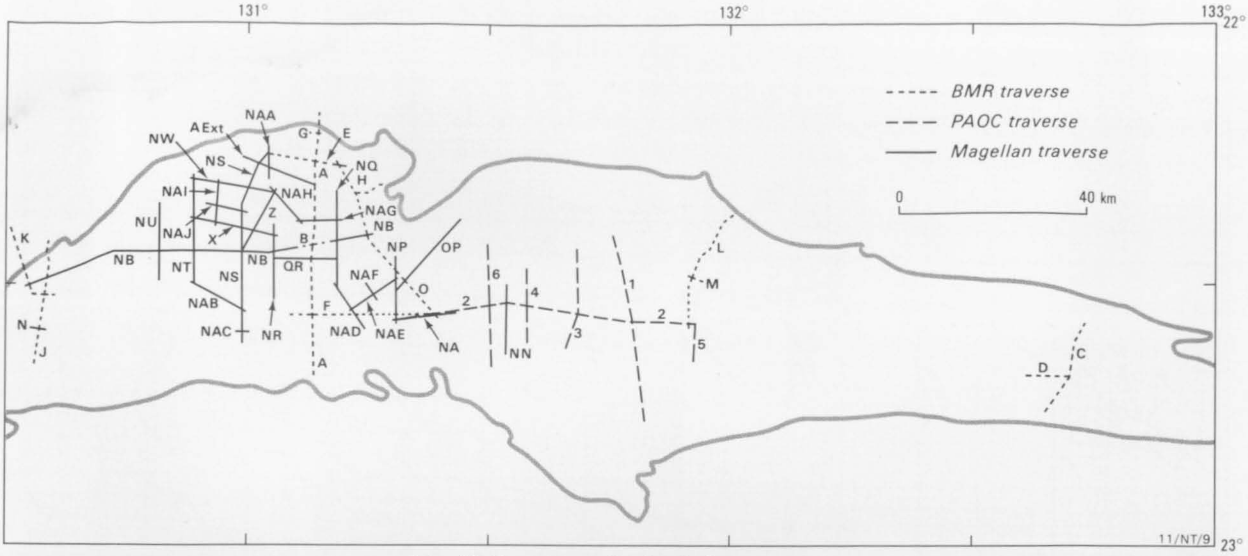


Fig. 41. Locations of seismic traverses.

spreads indicated a maximum difference of only ± 7 percent; generally there is excellent agreement.

Seismic interpretation

In the study for this Bulletin the main seismic reflection horizons were picked on all reflection cross-sections, and attempts were made to correlate them over as wide an area as possible. However, only three prominent seismic reflections can be traced almost continuously over most of the western zone of the basin. The deepest reflection can be followed into the central and eastern zones of the basin, but the shallower reflections cannot be readily identified, except in the Mount Allan area, where a major unconformity has been delineated and the shallowest prominent reflector has been identified. The three prominent reflections were timed and correlated along as many traverses as possible.

Horizon C, the deepest reflection, is tentatively identified with the Vaughan Springs Quartzite/basement contact. There is, however, some uncertainty in this identification, and the reflection may be from different levels of the Vaughan Springs Quartzite, from the Treuer Member, or from the basement. In the Amadeus Basin the deepest reflection corresponds to the top of the Heavitree Quartzite, which masks any possible deeper reflections. By analogy this suggests that the deepest reflection in the Ngalia Basin is from the top of the Vaughan Springs Quartzite. However, projection of the reflection along traverse L to Mount Allan (Plate 3) and along traverse H (Plate 3) to the Vaughan Springs Quartzite outcrops in the Naburula Hills supports its identification with the base of the Vaughan Springs Quartzite/basement contact in those areas.

The quality and continuity of the reflection ranges from fair to poor. It is poorest in areas where diffractions originating mainly from faults interfere with the reflection. Correlation of the reflection along the seismic traverses in many areas is made only on the basis of its position as the deepest reasonably continuous reflection.

Horizon B, the intermediate reflection, is the best defined of the three main reflections in the western zone of the basin. It is generally continuous, is of good quality, and has a distinctive seismic signature which facilitates its correlation across faults. It is identified with the Mount Doreen Formation, probably with the marker dolomite (Wanapi Dolomite Member) which is present near the top of the formation except where removed by erosion. The identification was made by extrapolating the horizon southwards along traverses A (Plate 3) and J (section B-B3, Plate 1) to its intersection in two shallow boreholes, BMR Mount Doreen Nos. 8B and 9 (both of which penetrated the Mount Doreen Formation), and along traverse H to outcrops of the Mount Doreen Formation on the southern flank of the Patmungala Syncline. The reflection could not be traced into the eastern part of the basin, possibly indicating either a facies change in or poor preservation of the Mount Doreen Formation.

Horizon A, the shallowest reflection, is weak but relatively continuous, and is the least well defined of the three main reflections in the western zone of the basin. It coincides with the major unconformity at the base of the Mount Eclipse Sandstone, and marks the upper limit of major pre-Carboniferous faulting. The interval above the horizon is defined by its correspondence to outcrops of the Mount Eclipse Sandstone. Seismic reflections in this interval are more discontinuous and of higher frequency and lower amplitude than those below; they may be from siltstone beds within the Mount Eclipse Sandstone. In the north the horizon is identified by extrapolating it to the point of contact between the Mount Eclipse Sandstone and the Djagamara Formation at the surface on the southern flanks of the Patmungala Syncline. It is roughly identified at the southern end of traverse J by projecting Horizon B and adding the known thickness of the Djagamara Formation.

Time contour maps were produced for Horizons A, B, and C (Plate 2). The reflection times on all seismic cross-sections were adjusted with reference to a common datum of 600 m above MSL, and all time ties were checked at traverse intersection points. The time contour maps, which were produced mainly for correlation purposes, are included here because they show the reflection times which were interpreted from the reflection cross-sections and used in the production of depth-contoured information.

Migrated-depth contour maps were produced for Horizons A, B, and C (Plate 2). Reflections along seismic traverses were migrated into their apparently correct subsurface positions using a computer program varied as described previously for application of velocity function $V_i = V_o + kZ$. Except for Horizon C near major faults, the migration process had little effect on the positions of the three horizons. The migrated-depth contour maps were produced by plotting the depths and positions on traverses on the base-maps and hand-contouring the data. Three-dimensional migration was not practical because of the non-uniform areal grid spacing of the data points. Machine-contouring was not practical for the same reason, and also because of the presence of faults. The migrated-depth contours indicate the main structural provinces in the basin.

Isopach maps of Intervals A-B and B-C (Plate 2) were produced for the western zone by subtracting depths of the shallower horizon from depths of the deeper horizon on the migrated-depth contour maps. These, together with palinspastic reconstructions, provide information on the structural development of the basin.

Structural Provinces

The thicknesses and structures of the upper Palaeozoic, lower Palaeozoic (including the Kerridy Sandstone), and Adelaidean rocks are defined generally over the whole or parts of the western, central, and eastern zones of the basin by the three prominent reflection horizons—A, B, and C. The contours of these horizons and their main structural trends are shown in Plate 2.

Four structural provinces are defined from the seismic structure contours on Horizons A, B, and C in the western zone, a fifth province from Horizon C in the central zone, and a sixth province from the structural relation of the basin/basement contact apparent in outcrop at the northern margin. They are the Davis and Waite Creek Thrust Nappes, the Naburula Fault Trough, the Stanley Platform, the Newhaven Fault Blocks, and the Mount Doreen Salient (Plate 2). The boundaries of the provinces in the western zone are mainly defined by major thrusts and faults: the Yuendumu Thrust, the Waite Creek Thrust, and the subsurface Mount Doreen Fault. The structural divisions in the western zone are shown in seismic cross-section traverse A (Plate 3), the main north-south transbasin traverse.

The broad outlines of the structural provinces defined by the seismic structure contours are consistent betwen the three horizons—A, B, and C—but deformation is greatest at the deepest level. At Horizon C the intensity of folding is greater and there are also a larger number of faults than at the shallower A and B horizons. Movement on the Yuendumu Thrust persisted above Horizon A but activity on the Mount Doreen Fault is not recorded at this level; a possible exception is a small northwest-trending fault—apparent at the eastern end of the Horizon A contour map—which may be a reactivated portion of the Mount Doreen Fault.

Davis Thrust Nappe and Mount Doreen Salient

The allochthonous block of basement rocks and folded sediments at the northern margin of the basin above the Yuendumu Thrust constitutes the Davis Thrust Nappe. The position of the northern boundary of the Davis Thrust Nappe is not known; the sedimentary component of the nappe is bounded in the north by the Treuer Fault Zone or the sediment-basement unconformity. The sediments crop out in a prominent homocline along this northern margin. The Mount Doreen Salient (Krieg, 1972) comprises Precambrian basement rocks of the Davis Thrust Nappe at the central northern margin of the basin. The salient and corresponding re-entrant of sedimentary rocks have been formed by erosion of the westward-plunging Davis Anticline and Patmungala Syncline to the north. The eastern portion of the allochthon has been removed.

The structure contours on Horizon C indicate that the greatest sedimentary thicknesses (more than 3000 m) are preserved in the thrust nappe near the Treuer Fault Zone and Yuendumu Thrust.

Waite Creek Thrust Nappe

The Waite Creek Thrust Nappe comprises the sediments and basement granite of the upper plate of the Waite Creek Thrust. It extends from Mount Carey to Vaughan Springs, and its main structural component apparent in outcrop is the Vaughan Springs Syncline.

The northern margin of the Waite Creek Thrust Nappe lies in the Arunta Block at an unknown distance north of the Vaughan Springs Syncline. Its position may correspond to the prominent quartz-filled fault zone about 15 km north of Vaughan Springs and parallel to the Waite Creek Thrust. Metamorphic rocks are displaced against granite along this fault zone, and the contact is shown by a very marked change in the pattern of total magnetic intensity contours (Plate 2).

The Waite Creek Thrust forms the northern margin of the basin in the westerly part of the western zone. It strikes northeast, cutting diagonally across the predominantly east-trending structural grain of bedding and other major thrusts, and may have formed during a late phase of the main episode of thrusting.

Naburula Fault Trough

A north-northwest-trending downfaulted block of sediments lying south of the Davis Thrust Nappe is termed the Naburula Fault Trough. It is bounded to the north partly by the Yuendumu Thrust and partly by the unconformable contact with basement, and to the south by the Mount Doreen Fault and the Newhaven Fault Blocks. Its eastern limit is not known, but its western limit appears to be defined by the Waite Creek Thrust.

The linear northern margin of the Ngalia Basin formed by the Yuendumu Thrust in the central zone is interpreted to be the exposed margin of the Naburula Fault Trough, although there is no seismic coverage in the north of the trough here to indicate basement structure.

A large westerly plunging syncline with a maximum depth of about 4100 m to Horizon C is evident in the west of the Naburula Fault Trough, and the depth to Horizon A in the syncline indicates that at least 2200 m of the Mount Eclipse Sandstone is preserved in the western zone of the basin. A small roughly circular platform with a mean depth of about 3600 m to Horizon C separates the syncline from a northerly inclined uniform slope in the east. Thinning of the sedimentary section over the platform adjacent to the Yuendumu Thrust is evident at all three levels; this suggests that a topographic high, probably fault-controlled, persisted for a long time in this area. The adjacent slope, which has an average dip of about 7°, passes eastwards into a broad syncline with a maximum depth to Horizon C of about 4700 m—the deepest part of the basin known on seismic evidence. The axis of this syncline corresponds in part to the axis of the Bloodwood Syncline evident in outcrop.

The Yuendumu Thrust is absent from the basin margin north of the eastern end of the Bloodwood Syncline. This is partly because erosion has proceeded to a deeper structural level than in the western and most of the central zones of the basin and partly because displacement on the thrust decreases eastwards. The northern margin of the Naburula Fault Trough here is an unconformable contact with basement. A terrace separates the northern, faulted flank of the Bloodwood Syncline from the dip slope of the unconformable northern margin of the basin (traverse L and line 5, Plate 3).

Lineaments bounding the Naburula Fault Trough

Yuendumu Thrust. The Yuendumu Thrust forms the northern margin of both the Ngalia Basin and the Naburula Fault Trough between the Mount Doreen Salient and 5 km northwest of Mount Allan. A subsurface extension of it to the west forms the boundary between the Naburula Fault Trough and the Davis Thrust Nappe. Its greatest displacement is on the southern edge of the Mount Doreen Salient; the thrust intersects progressively younger formations westwards from Yuendumu, and the Mount Eclipse Sandstone comprises the exposed footwall where the thrust

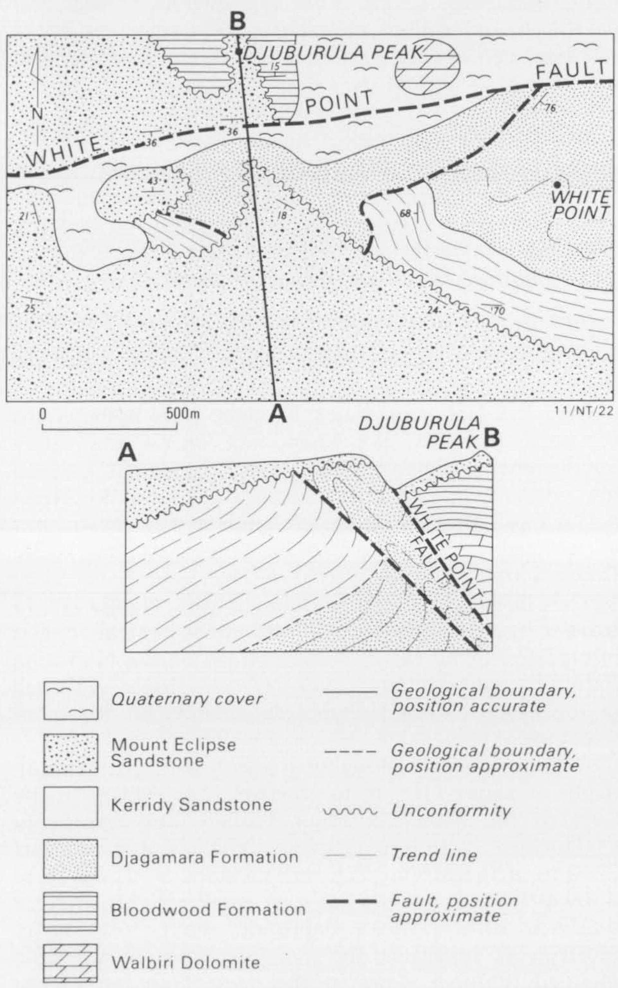


Fig. 42. Sketch map and cross-section of the White Point Fault Zone.

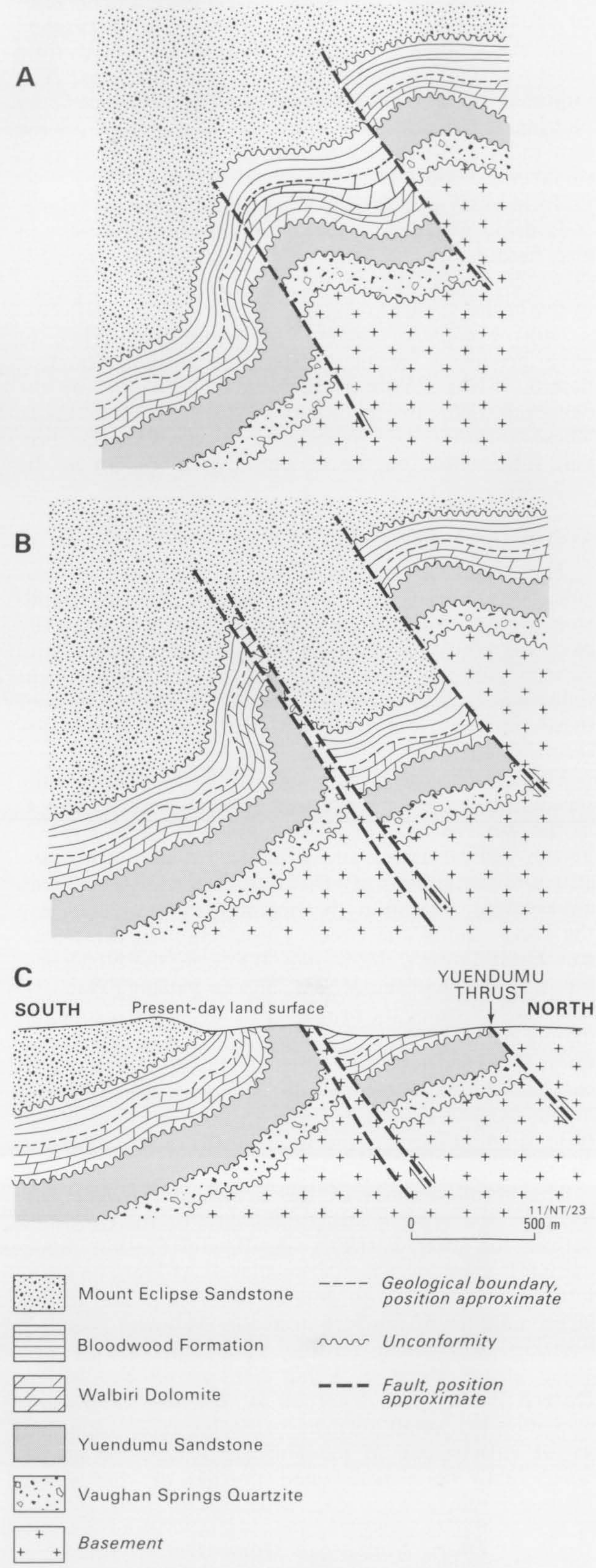


Fig. 43. Diagrammatic cross-sections showing stages in the interpreted structural evolution of the area south of 20 Mile Bore.

changes to a southwest strike and curves around the Mount Doreen Salient.

Structures exposed in several places along and near the exposed eastern part of the Yuendumu Thrust attest to the complex history and magnitude of movements generated along the zone. These structures are the White Point Fault Zone (Fig. 42); a complex zone south of 20 Mile Bore (Fig. 43); and a well-exposed area of intensely deformed Vaughan Springs Quartzite at the eastern outcrop end of the Yuendumu Thrust (Fig. 44).

In the area between Djuburula Peak and White Point, the White Point Fault separates the Walbiri Dolomite, Bloodwood Formation, and Mount Eclipse Sandstone from the Djagamara Formation. Tightly folded Djagamara Formation, in a small fault slice between the White Point Fault and a probable thrust a little farther south, has been displaced over the Kerridy Sandstone. The folds have amplitudes of about 100 m and their axial planes dip to the north. By contrast the Bloodwood Formation and Walbiri Dolomite of the northern block were only slightly tilted by the faulting.

The Djagamara Formation and Kerridy Sandstone originally present to the north of the White Point Fault were uplifted during the Kerridy Movement and eroded before the Mount Eclipse Sandstone was deposited. Rejuvenation of the White Point Fault, by the Mount Eclipse Orogeny and possibly also by Cainozoic movements, upfaulted the northern block, causing the steep dips in the Mount Eclipse Sandstone on the north side of the White Point Fault. The considerable relief of the ?Devonian erosion surface (Fig. 38), shown by the marked differences in elevation of the unconformity at the base of the Mount Eclipse Sandstone, was accentuated by the rejuvenated faulting. Late movement on the White Point Fault must have been reversed because the elevation of the base of the Mount Eclipse Sandstone at the closest point where contacts are visible differs by 70 m on either side of the fault (AB, Fig. 42).

Figure 43 shows the structural development of a thrust zone which includes the Yuendumu Thrust in the area 8 km southeast of 20 Mile Bore. Repetition of the sedimentary sequence and the position of the intervening granite outcrop are explained by a combination

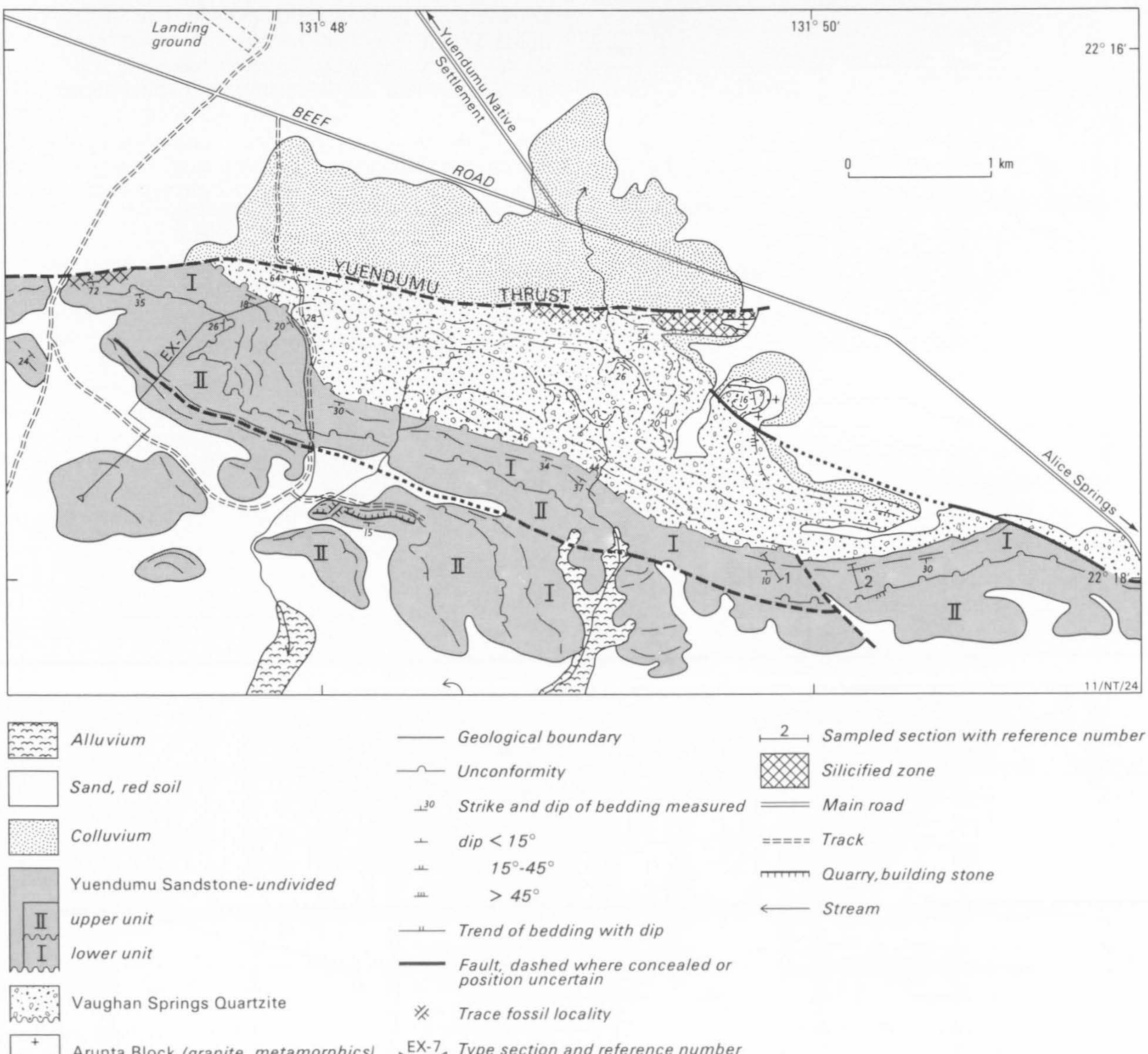


Fig. 44. Sketch map of the geology at the eastern end of the Yuendumu Thrust south of Yuendumu Native Settlement (after Burek, Walter, & Wells, 1979).

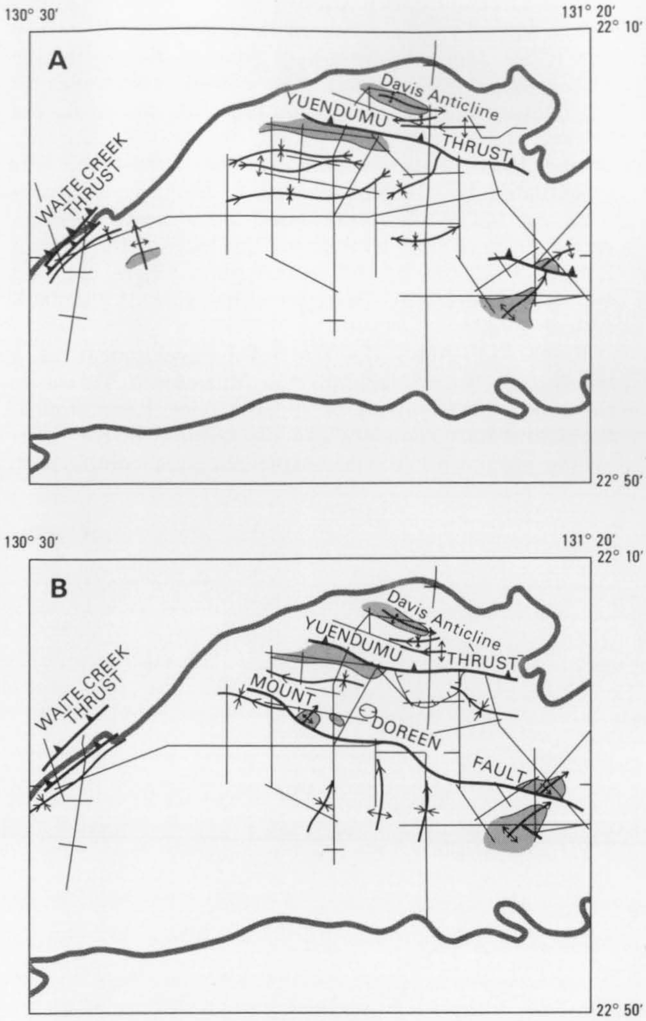
of thrusting and reverse-faulting. Only the southern thrust fault is exposed; the Yuendumu Thrust is extrapolated into the section and the intermediate fault inferred. Overturned beds of the Yuendumu Sandstone, dipping 82° north, form the footwall of the quartz-filled southern thrust and Precambrian basement granite the hangingwall. In an adjacent area to the west, beds of the Mount Eclipse Sandstone are overturned by movement along the continuation of the same thrust zone, suggesting that the principal movements occurred during the Mount Eclipse Orogeny.

At the eastern outcrop termination of the Yuendumu Thrust (Fig. 44) the Vaughan Springs Quartzite, which is faulted against basement rocks, shows the effects of intense tectonic stress. It is intensely silicified and cut by quartz veins up to 10 cm wide next to the thrust, and in other places has been brecciated and recemented by quartz. Tectonically impressed features include slickensides, kink folds (plunging about 20° west), boudins, incipient cleavage, and small recumbent folds. A prominent north-to-south movement is indicated, but in addition some slickensides imply a sinistral shearing component, suggesting later, possibly Cainozoic, reactivation of the fault. The silicification and quartz-veining, suggestive of a tensional regime, may have been generated during the phase of reactivation.

Mount Doreen Fault. Displacement along the Mount Doreen Fault is small compared with that of the Yuendumu Thrust. The fault has no surface expression, and it dies out to the west at about longitude 130°50′ at the western end of the Naburula Fault Trough. The eastern end of the fault, which apparently was the only part of the fault to experience rejuvenated movements during the Mount Eclipse Orogeny, either coalesces with or terminates against the Newhaven Fault Blocks.

Stanley Platform

The Stanley Platform encompasses a gently north-inclined basin floor and sedimentary cover lying south of the Naburula Fault Trough. It is bounded in the north and northeast by the Mount Doreen Fault and in the west-northwest by the Waite Creek Thrust. Towards the central zone of the basin the platform is bounded by the Newhaven Fault Blocks, and its southern limit is the southern margin of the basin; gravity anomalies indicate that the southern part of the platform is faulted.



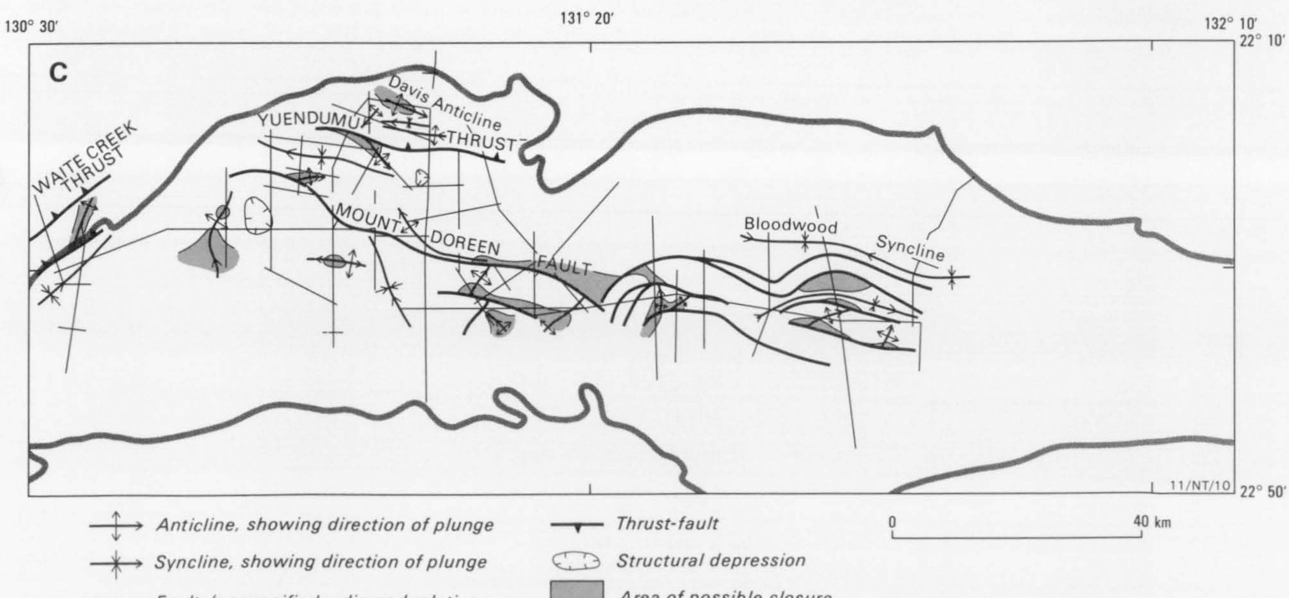


Fig. 45. Indicated closures and structure at seismic horizons A (top), B (middle), and C (bottom).

Fig. 46. Napperby Thrust truncating the northern margin of the Patty Hill Anticline to form the northern margin of the basin near Napperby. (GA2078)

There is no clear separation of the Naburula Fault Trough and the Stanley Platform (Plate 2, Fig. 45) at the Horizon A level, mainly because the Mount Doreen Fault is no longer evident. The platform dips at about 6° to 8° to the north and reaches its maximum depth of about 4100 m in a syncline in the Waite Creek area in the west, which probably corresponds to the Mount Carey Syncline in outcrop. The syncline is also evident at the Horizon A and B levels. The axial traces of minor folds are parallel to the platform slope in the eastern and central parts of the province at the Horizon C level, but the folds were apparently formed before the Horizon A and B levels, with the exception of the northeast-plunging faulted folds in the east.

Newhaven Fault Blocks

The Newhaven Fault Blocks can be considered as part of the Naburula Fault Trough which has been dissected by block-faulting (line 3 in Plate 3). The province comprises easterly trending horsts and grabens and minor cross-cutting folds. Several small isolated outcrops of the Vaughan Springs Quartzite occur in the province in the central zone; they correspond to the extension of horsts shown in Figure 45, and substantiate the interpretation of a series of fault blocks from seismic and gravity surveys.

The main structure along the northern part of the Newhaven Fault Blocks has been interpreted as a continuous, sinusoidal horst which narrows westwards and eventually merges into a single fault. As the trend of this horst and other horst blocks to the south is not certain, the structure here could equally well be interpreted as several discrete fault blocks. The slope of the basement surface forming the basin floor south of the Newhaven Fault Blocks is indicated by the seismic structure contours. This slope is probably about the same as the dip of the basement indicated by the basinward dipping outcrops of Vaughan Springs Quartzite at the basin's southern margin. However, there is a zone between the southern margin and the area of seismic coverage farther north in which there is no outcrop, but gravity profiles across this zone suggest the presence of some faults.

Structure in the eastern zone

The structure of the eastern zone of the basin is poorly defined because there is only one seismic cross-section and outcrops are sparse. A cross-section at Napperby Creek (Plate 1) shows a poorly defined northward-thickening sedimentary wedge up to about 4000 m thick cut by several small faults in its southern part. To the north, the Patty Hill Anticline, in which the Vaughan Springs Quartzite is in contact with granite on its faulted southern flank, is truncated on its northern flank by the Napperby Thrust at the northern margin of the basin (Fig. 46). The structure is interpreted as a thrusted anticline, or thrust nappe, bounded by the Napperby and Patty Hill Thrusts, and displaced several kilometres southwards over a wedge of sediments in the Ngalia Basin (section K-K3, Plate 1).

The Napperby Thrust possibly continues eastwards as far as the Hann Range Thrust, which intersects the quartzite of the southern basin margin. The thrust appears to eventually truncate this quartzite ridge and thus form the eastern closure of the basin (Fig. 33).

GEOLOGICAL HISTORY

The Ngalia Basin records nine alternate periods of sedimentation and diastrophism between Adelaidean and late Palaeozoic time. Until Devonian time the basin was part of a much larger sedimentary or structural province. The unconformities which record these periods of diastrophism divide the succession into four early tectosomes of continental and marine sedimentation and two later tectosomes of only continental sedimentation (Fig. 37).

Several periods of sedimentation interrupted by diastrophic events, of which some included plutonic igneous activity, are recorded in the basement Precambrian Arunta Block (D1 in Fig. 37).

Sedimentation in the Ngalia Basin began in the Adelaidean with the deposition of a blanket-like accumulation of sand (Vaughan Springs Quartzite) as a westward-thickening tabular body over the planated Arunta Block. The environment may have been largely continental but there was at least one marine incursion (Treuer Member). Sedimentation was continuous over wide areas and extended at least as far as the Amadeus and Officer Basins to the south and southwest, the Birrindudu Basin to the northwest, and the southern Georgina Basin to the east. Local uplift and a short period of erosion preceded a marine transgression (Albinia Formation).

Uplift and block-faulting later in the Adelaidean (Vaughan Springs Movement—D2) caused the sea to regress, and initiated the major structural divisions of the basin. A large tilted horst block formed in the western zone (Fig. 47), roughly in the present position of the Naburula Fault Trough, and probably several smaller horsts and grabens formed in the central (Newhaven Fault Blocks) and southern parts of both the western and central zones. Erosion of them removed a considerable part, and in a few areas probably all, of the Vaughan Springs Quartzite and Albinia Formation from the crests of uplifted blocks and from other structural highs such as the area around the eastern nose of the Patmungala Syncline, and possibly also from the top of the horst block in the central part of the basin (traverse A in Plate 3).

Late Adelaidean continental glaciation (Naburula Formation) was followed by a marine transgression (Rinkabeena Shale) that was terminated by minor differential uplifts (Rinkabeena Movement—D3), after which additional parts of the Adelaidean section were removed from structural highs.

A second glacial period (Mount Davenport Diamictite Member of the Mount Doreen Formation) was also succeeded by a marine incursion (Wanapi Dolomite and Newhaven Shale Members) in late Adelaidean times. There followed further tectonic movements (D4), possibly related to the Petermann Ranges Orogeny, which severely affected the Amadeus Basin.

A later phase of these movements may have been responsible for the possible unconformity within the Yuendumu Sandstone. Subsequent minor uplift (Yuendumu Movement—D5) resulted in the removal of part of the Yuendumu Sandstone in the central zone before the main marine transgression (Walbiri Dolomite) in early Palaeozoic time.

The Naburula Fault Trough began forming early in the Palaeozoic by reactivation and reverse movements on the Mount Doreen Fault and Yuendumu Thrust. The renewed faulting probably commenced during the Petermann Ranges Orogeny and continued during the Yuendumu, Bloodwood and Djagamara Movements.

A thick clastic and carbonate sequence was deposited during Cambrian (Walbiri Dolomite and Bloodwood Formation) and probably Ordovician (Djagamara Formation) marine transgressions. In the western zone of the basin a northerly provenance is suggested by southward thinning and downlap of units, and only thin equivalents are present on the Stanley Platform.

Local movements, probably in Late Cambrian time (Bloodwood Movement—D6), interrupted sedimentation. They generated uplift in the area of the present

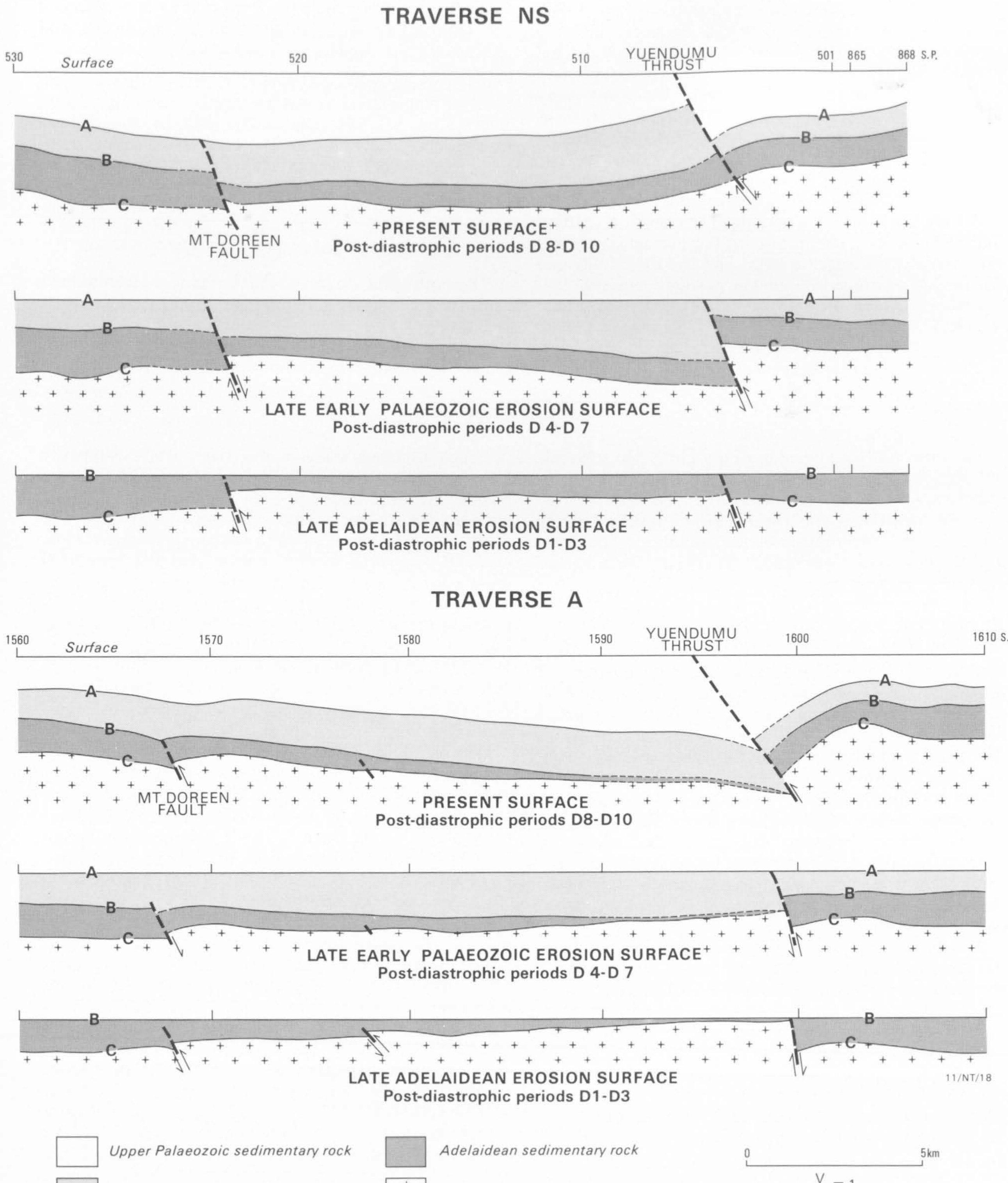


Fig. 47. Palinspastic reconstructions along traverses A and NS. The surface (annotated) is the same as the datum of the seismic sections—that is, 600 m above MSL.

northern margin of the central zone, resulting in the local removal of the Cambrian sequence, and displacement along the Treuer Fault accompanied by removal of the lower Palaeozoic section. The thick Palaeozoic sequence of the Naburula Fault Trough (interpreted from the isopachs in Plate 2) was apparently not affected by this movement.

The sea retreated from the region for the last time as a result of the Late Ordovician Djagamara Movement (D7); the resulting uplift, folding, and erosion were most intense in the west. Continental sands (Kerridy Sandstone) accumulated on the eroded surface and were probably partly derived from the older lower Palaeozoic rocks.

In the ?Middle Devonian, major latitudinal uplifts (Kerridy Movement—D8) of the basement and the overlying sediments occurred north and south of the present basin margins. Erosion of the sedimentary sequence resulted in the exposure of basement rocks along the crests of the uplifts, and the formation of a primitive basin outline. Further continental sedimentation (Mount Eclipse Sandstone) was primarily concentrated in the area of the present Ngalia Basin, the depocentre being close to the northern margin.

A Late Carboniferous period of deformation (Mount Eclipse Orogeny—D9) produced the present-day broad synclinal structure of the basin and the tight folds and the thrusts characteristic of the northern margin. Displacement by thrusting (Waite Creek and Yuendumu Thrusts) was as much as 10 km in places (Waite Creek and Davis Thrust Nappes; traverses H-O and K in Plate 3). In the central zone of the basin, renewed fault movements accompanied by folding and tilting of the sedimentary sequence accentuated the horsts and grabens of the Newhaven Fault Blocks.

The ensuing prolonged period of erosion that spanned the late Palaeozoic to the Holocene was only briefly interrupted by differential uplift and by the deposition of thin Cainozoic fluvial and lacustrine sediments in widespread interconnected continental basins. Evidence for a variety of climatic regimes is preserved at various levels in the Cainozoic sequence, which contains deep-weathering profiles, pisolitic ironstone, silcrete, aeolian red sands, playa deposits, and sand dunes.

The prominent ridges, hogbacks, and small mountain ranges of the present landscape probably owe their existence to rejuvenation brought about by Tertiary tilting and faulting (D10). Uplifts probably took place largely by reactivation of pre-existing faults.

MINERALS

The potentially and economically important minerals are petroleum, uranium, and water; the water resources impose a constraint on the future expansion of the pastoral industry in the region. Minor mineral occurrences include aggregate, barite, building stone, coal and lignite, copper, dolomite, evaporites, fluorite, and galena.

Petroleum potential

No exploratory drilling for petroleum has been carried out in the Ngalia Basin*; consequently an assessment of its potential is hampered by the general lack of information on the extent of the potential source, reservoir, and cap rocks, particularly those in the lower Palaeozoic sequence, which are likely to be the most important. There are few data on the petrophysical characteristics of the sediments, except for the sparse information available from shallow stratigraphic drilling, uranium exploration drillholes, and water-bores; the data are mostly based on the characteristics of the sediments from outcrops, which are deeply weathered, so interpretations based on them can be misleading.

The maximum preserved thickness of sediments in the Ngalia Basin is about 5 km. About 60 percent of the sedimentary column comprises Adelaidean rocks, and ?Ordovician and Devono-Carboniferous continental deposits, which at best can be considered as marginally prospective for petroleum source rocks. The most likely hydrocarbon-bearing beds are contained in the Cambrian and Ordovician marine formations, which on the average constitute the remaining 40 percent of the sedimentary sequence.

Source rocks

In the Adelaidean sequence, possible source rocks are present in the Albinia Formation, Naburula Formation, and Rinkabeena Shale. The Albinia Formation contains dark grey stromatolitic dolomite; similar dolomite in the Bitter Springs Formation, with which it is correlated, is a fair source rock (D. McKirdy, formerly BMR, personal communication). The Naburula Formation contains a thin sequence (8 m in outcrop) of black shale. Cores from BMR Napperby No. 5, which are considered to be equivalent to the Naburula Formation or possibly the Rinkabeena Shale, have a lean to fair source rock potential (Table 4): a vitrinite reflectance of 0.74 percent for one sample in BMR Napperby No. 5 implies that the sample is mature for oil generation; the total organic carbon and extract data indicate a lean to fair source rock, particularly for the sample from a depth of 153 m (K. Jackson, formerly BMR, personal communication 1981). The Rinkabeena Shale attains a thickness of 100 m, but its source rock potential is unknown. A conservative estimate of the total thickness of Adelaidean source rocks is about 260 m.

Possible lower Palaeozoic source rocks occur in the Djagamara Formation and in fossiliferous marine shales and dolomite of the Walbiri Dolomite. The combined thickness of these formations in the central zone of the Ngalia Basin is about 570 m and although they have limited distribution in outcrop they may be more continuous in the subsurface. The siltstone of the Djagamara Formation reaches a maximum thickness of about 250 m, but only 40 m of shale and siltstone are exposed in the Walbiri Dolomite.

The results of source rock analyses on cuttings of samples of dark grey shale from the Djagamara Formation are given in Table 5. It is difficult to interpret maturation based on the vitrinite reflectance data. The wide range of values for vitrinite reflectance in samples of the Djagamara Formation from Mount Doreen (Afmeco) No. 1 (from 0.39 percent at 206 m to 0.74 percent at 275 m), and the probable difficulty in recognising true vitrinite macerals, preclude an interpretation of the maturation. The total organic carbon and extract data indicate lean to barren source rocks (K. Jackson, formerly BMR, personal communication 1981).

The Bloodwood Formation is marine in origin and may contain thin source beds. The deeply oxidised red-brown sandstone and siltstone persist to depths of over 100 m (Grainger, 1969), suggesting they have negligible petroleum source rock potential.

The thick sequences of continental arenaceous sediments in the Mount Eclipse and Kerridy Sandstones are considered to have negligible petroleum potential. The sediments are partly oxidised at depth and generally coarse-grained, and the organic content is

* Since this text was written, the first petroleum exploration well in the Ngalia Basin—Davis No. 1—has been drilled, in 1981, on the Davis Anticline (Appendix 7).

TABLE 4. SOURCE ROCK DATA, NABURULA FORMATION OR ?RINKABEENA SHALE

All the samples are from BMR Napperby No. 5 well.

Core	*Depth (m)*	*Total organic carbon (%)*	*Total extractable hydrocarbons (ppm)*	*Vitrinite reflectance (%)*	*Remarks*
5	152.40–153.31	1.25	221	0.74	unreliable
7	182.88–184.40	0.65	63	—	
8	213.36–216.41	0.30	61	—	
9	230.12–233.17	0.65	53	(0.88)	less than 10 readings

Source: CSIRO/BMR source rock investigations (Saxby, 1977).

TABLE 5. SOURCE ROCK DATA, DJAGAMARA FORMATION

All the samples are from Mount Doreen Afmeco No. 1 well.

Lab. no.	*Cuttings*	*Depth (m)*	*Lithology*	*Total extract (ppm)*	*Aliphatic fraction (ppm)*	*Aromatic fraction (ppm)*	*Polar fraction (ppm)*	*Organic carbon (%)*	*Reflectance (%)*
78499	C1	206	Shale (grey, slightly micaceous and carbonaceous)	173	13	7	70	0.25	(0.39)
78500	C2	245	Siltstone (grey, slightly micaceous and carbonaceous)	91	12	3	30	0.25	—
78501	C3	275	Siltstone (grey, slightly micaceous and carbonaceous)	114	16	74	37	0.20	(0.74)
78502	C4	337	Sand (fine-medium, some carbonaceous material)	69	12	5	18	0.15	0.47

Values in parentheses are unreliable because insufficient vitrinite was present for measurement.
Source: CSIRO/BMR source rock investigations (Raphael & Saxby, 1979).

small. However, analyses of carbonaceous sandstone and shale from cores in the Mount Eclipse Sandstone (Table 6) from the Walbiri Prospect (Fig. 48) were classed as fair source rocks (D. McKirdy, formerly BMR, personal communication). The organic matter in the sediments is thermally immature, and the carbonaceous intervals in the formations could have generated petroleum hydrocarbons if and where they have been more deeply buried; the maximum preserved thickness of the upper Palaeozoic rocks which contain these source rocks is about 2400 m. The carbonaceous sandstone and shale of the Mount Eclipse Sandstone contain a great deal of inertinite, commonly in a massive featureless form readily confused with vitrinite and hence not considered reliable for reflectance studies (A. J. Kantsler, formerly University of Wollongong, personal communication). The variable reflectance, the internal textures in the inertinite, and the presence of large grains and framboids of pyrite replacing vitrinite suggest predepositional oxidation, fusinisation, and derivation of the coaly material from eroded peat. Kantsler considered that the results imply a coalification history of deep burial (2-3 km) in a high thermal gradient (about 40°C/km) before major uplift and erosion. The potential source rocks at this maturation stage are still within the oil window, but present burial temperatures are unlikely to provide sufficient thermal drive for the generation of hydrocarbons.

Carbonaceous material in the Pertnjara Group, an equivalent tectosome in the Amadeus Basin, has a mean reflectivity of 0.66 percent (Kurylowicz & others, 1976). Assuming an available time for coalification of about 60 m.y. (the time between deposition of the formation and pre-Permian unloading), a temperature of 75° C, and a geothermal gradient of 3.4°C/100 m (derived from Mereenie No. 1 well in the Amadeus Basin), Playford & others (1976) calculated that the cover must have been about 2 km thick in order to account for this reflectivity value. Not all the unloading necessarily took place before the Permian, and less cover over a longer period of time could account for the same reflectivity value.

The samples from the Mount Eclipse Sandstone occur about 1.4 km from the preserved top of the formation, so that the original depth of burial could be of the same order as that estimated by A. J. Kantsler (personal communication) and by Playford & others for the Pertnjara Group.

Reservoir rocks

Proterozoic rocks are considered to have negligible reservoir potential mainly because silicification of many of the arenaceous rocks probably persists at depth. They may be important in areas where they are situated structurally updip from Palaeozoic source rocks.

The Yuendumu Sandstone, about 700 m thick, probably has low porosity and permeability. Permeability reported from the Yuendumu Sandstone in water-bores is caused by fissuring, and the formation can be classified only as a poor reservoir.

Both the Walbiri Dolomite and Bloodwood Formation are probably poor reservoirs. Sandstone constitutes only a small part of the Walbiri Dolomite and has a secondary carbonate cement. In places the dolomite is brecciated, and secondary porosity may be developed in fractured zones. The Bloodwood Formation probably has similar reservoir characteristics to the Yuendumu Sandstone. The high percentage of silt in the matrix probably makes it a poor reservoir.

Outcrop characteristics suggest that the more friable porous massive sandstone intervals commonly interbedded with silicified tough thin-bedded sandstone of the Djagamara Formation in the east have good reservoir rock properties. However, the limited data on the

TABLE 6. SOURCE ROCK DATA, MOUNT ECLIPSE SANDSTONE

Sample *drill-hole*	*depth (m)*	*Organic carbon (%)*	*Total extract (ppm)*	*Total extract (mg/g C)*	*Sat. hydrocarbons (ppm)*	*Sat. hydrocarbons ÷ total extract*	*Sat. hydrocarbon pattern* range*	*Sat. hydrocarbon pattern* maximum*	*pristane/phytane*	*Kerogen rank (%C dmmf)*	*$\overline{R}o$ mean max. (%)*	*Vitrinite reflectance range $\overline{R}o$ max. (%)*	*N*
DD18	85.1– 85.4	1.11	121	10.9	28	0.23	C_{15}–C_{34}	C_{24}	1.3	76.5	?1.06		1
DD17	147.5–147.8	0.44	149	33.9	25	0.17	C_{15}–C_{32}	C_{17},C_{24}	1.4	76.1	0.97	0.68–1.12	12
DD13	94.4– 94.6	0.19	119	62.9	35	0.30	C_{13}–C_{28}	C_{15}	3.2		?1.05	0.86–1.14	5
YRD121	130.95–131.0										0.66	0.60–0.76[a]	
											0.01	0.94–1.06[b]	
YRD119	210.5–210.6										0.87	0.69–1.08[c]	
YRD119	151.95–152.0										1.04	0.96–1.20[c]	
ECD12	103.4–103.45										0.93	0.76–1.18[c]	
YRD51	130.0–132.0										0.23	0.18–0.30[d]	

* Carbon numbers refer to n-paraffins. dmmf—dry, mineral-matter free.

[a] bimodal, [b] ?semifusinite, [c] sandstone with thin carbonaceous laminae, [d] rotary cuttings.

Data from D. M. McKirdy (formerly BMR), except the vitrinite reflectance measurements, which were supplied by A. J. Kantsler (formerly University of Wollongong) for drillholes DD18, DD17, and DD13, and by A. C. Hutton (University of Wollongong) for drillholes YRD121, YRD 119, ECD12, and YRD51.

Drillholes DD18, DD17, and DD13 are located 4 km west-northwest of Mount Eclipse, YRD121 and YRD119 about 27 km east-northeast of Mount Wedge Homestead, YRD51 about 25 km west of Mount Wedge Homestead, and ECD12 at the northern edge of the Ngalia Basin about 16 km south of Djagamara Peak.

TABLE 7. POROSITY AND PERMEABILITY DETERMINATIONS ON CORES

Well	*Formation*	*Core no.*	*Sample depth (m)*	*Average effective porosity two plugs (% bulk vol.)*	*Absolute permeability (millidarcy) V*	*Absolute permeability (millidarcy) H*	*Average density (t.m³) Dry bulk*	*Average density (t.m³) Apparent grain*	*Fluid saturation (% pore space) Water*	*Fluid saturation (% pore space) Oil*
BMR Mt Doreen No. 9	Mount Doreen Formation	1	205.64–205.82	33.9	1.9*	12*	1.72	2.63	ND	
		2	241.40–241.94	6.9	0.16	<0.1	2.62	2.82		
		2	242.87–243.18	7.0	<0.1	<0.1	2.64	2.84		
		2	243.18–243.38	9.2	<0.1	0.12	2.42	2.66		
BMR Mt Doreen No. 10	Mount Eclipse Sandstone	1	94.79– 95.28	12.4	3.2	4.3	2.30	2.63	ND	
		1	95.81– 96.39	12.4	14	23	2.29	2.62		
		2	113.54–113.64	13.7	0.1	0.1	2.37	2.74		
		2	113.74–113.82	10.1	0.1	0.14	2.47	2.74		
		2	115.27–115.42	8.1	0.41	1.2	2.41	2.62		
		3	160.02–160.63	9.0	0.88	1.1	2.39	2.63		
BMR Mt Doreen No. 12	Cainozoic	1	65.15– 65.33	34.3	495	810	1.82	2.76	ND	
	Mount Eclipse Sandstone	2	182.88–183.29	8.8	1.5	1.5	2.40	2.63		
		2	184.48–184.71	9.1	0.95	1.5	2.40	2.63		
BMR Mt Doreen No. 13	Vaughan Springs Quartzite?	2	179.83–181.05	5.3	0.24	0.14	2.50	2.63	ND	
BMR Mt Doreen No. 14	Walbiri Dolomite	1	16.76– 17.45	4.0	<0.1	<0.1	2.58	2.69	ND	
BMR Napperby No. 5	Naburula Formation/ Rinkabeena Shale?	8	214.73–214.83	11	NIL	NIL	2.56	2.68	77	Nil
		10	243.79–243.87	12	ND	NIL	2.51	2.61	99	Nil
BMR Napperby No. 7	Mount Eclipse Sandstone?	4	122.10–122.17	4.8	ND	0.86	2.43	2.74	10	Nil
		5	130.23–130.33	3.9	2.9*	0.97	2.34	2.64	7.6	Nil
DD 13	Mount Eclipse Sandstone		94.4 – 94.6	4.9	<0.1	<0.1	ND	ND	ND	
DD 17	Mount Eclipse Sandstone		147.5 –147.8	8.2	<0.1	<0.1	ND	ND	ND	
CPM 1	Mount Eclipse Sandstone			13.3	<0.1	<0.1	2.34	2.70	ND	
CPM 2	Djagamara Formation			3.7	<0.1	<0.1	2.53	2.63	ND	

* Fractured.
Samples from DD 13 and DD 17 are from Walbiri prospect, Walbiri Ranges, and CPM 1 and CPM 2 are from Dingos Rest prospect, west Wanapi Escarpment.
ND—not determined.

Additional notes

1. Unless otherwise stated, porosities and permeabilities were determined on two plugs (V and H) cut vertically and horizontally to the axis of the core. Ruska porosimeter and permeameter were used with air and dry nitrogen as the saturating and flowing media respectively.
2. Oil and water saturations were determined using Soxhlet-type apparatus.
3. Acetone test precipitates and fluorescence of freshly broken core carried out for BMR Napperby Nos. 5 and 7 were negative.

Determinations by Petroleum Technology Laboratory, BMR, Canberra.

subsurface characteristics of the formation are not encouraging. A single sample from a mineral exploration drillhole has a porosity of 3.7 percent and permeability of 0.1 md (vertically and horizontally). Water-bores have failed to penetrate it because of its extreme toughness. Even so, its reservoir potential is marginally enhanced because of its similar lithology and age to the Pacoota Sandstone, the major petroleum reservoir rock in the Amadeus Basin.

The Kerridy Sandstone is too silty to possess much interstitial porosity or permeability and is probably a poor reservoir. Any permeability in the formation is probably due to jointing and possible fissuring associated with faulting.

The Mount Eclipse Sandstone contains beds which have fair porosity and permeability (Table 7). Some shallow water-bores in the formation suggest that it has some interstitial porosity; but it is unlikely to have widespread secondary porosity, although fracture porosity is evident in one drill core.

The thickness and extent of cap rocks in the basin are difficult to assess, mainly because the siltstones and shales generally weather recessively and are covered by superficial deposits. Possible cap rocks are known in many of the formations, but the thickest occur in the Treuer Member of the Vaughan Springs Quartzite and in the Djagamara Formation. The latter is probably the most important cap rock, as it is probably also a source rock and is interbedded with sandstone reservoirs.

Siltstone and shale in the upper Palaeozoic sequence are probably of sufficient thickness and extent to form cap rocks for any petroleum generated in lower Palaeozoic rocks.

Structures

The Davis Anticline is the only known fold in the Ngalia Basin showing closure in the Mount Eclipse Sandstone (Fig. 45). It is probably the most prospective drilling target in the basin, because it occurs in an area where a thick Palaeozoic sequence has been suggested, and a small gas show was reported from a mineral exploration drillhole near the crest of the fold.

Most other folds, such as those exposed in the eastern Walbiri Ranges, are breached below the top of the Djagamara Formation. Poor exposure of some, however—for example, the Beantree Anticline, on the south flank of the Walbiri Ranges—precludes any qualitative assessment of their value as petroleum traps.

Interpretations of seismic surveys and surface geology have outlined possible fault traps. The prospectiveness of the fault traps depends not only on the presence of a seal on the fault-plane closure, and presence of Palaeozoic source rocks, but largely on whether structures mapped near the base of the sedimentary sequence in the central zone persist into the shallower, more prospective Palaeozoic rocks. Fault closures with the most potential are those towards the northern margin of the basin in the western zone, where a lower Palaeozoic sequence with possible source rocks is indicated and the thrusts have large displacements. Fault closures towards the southern margin of the basin are less prospective because the Palaeozoic sediments are practically flat-lying and appear to thin perceptibly to the south and in places may be truncated by younger formations; in addition, displacements on the faults are less, and the depth of burial may not have been sufficient to mature hydrocarbons. Although fault closures have been mapped near the base of the Proterozoic sequence in the Newhaven Fault Blocks, very little is known about the thickness and distribution of the Palaeozoic rocks there, and persistence of the deep structures into Palaeozoic levels cannot be demonstrated.

Seismic profiles across the Naburula Fault Trough indicate that the Palaeozoic formations pinch out towards the southern margin of the basin. The change in general character of the seismic reflections suggests that there are also lithological changes present in this sequence. These changes of lithology and suggested pinchout are particularly significant as they may indicate the presence of stratigraphic traps in the thick Palaeozoic sequence.

Summary

Most of the structure mapped in the basin sediments was generated during the Late Carboniferous Mount Eclipse Orogeny, which followed at least eight other periods of diastrophism. The resulting unconformities evident in the sequence around the margins of the basin indicate long periods of non-deposition and possible fluid escape, and seriously reduce the petroleum potential. Nevertheless, the probably thick and more complete Palaeozoic sequence in the Naburula Fault Trough may not have been as severely affected by the movements, and as a consequence large hiatuses could be absent.

The depth of burial of the sediments was probably never very great until the Mount Eclipse Sandstone was deposited. Hence, hydrocarbons may not have matured and migrated until the Carboniferous.

The thick sequence in the Naburula Fault Trough is the most prospective area for petroleum exploration. The Davis Anticline occurs close to the fault trough, and is the only known anticline in the basin showing closure in the Mount Eclipse Sandstone. The Djagamara Formation, which probably underlies the Mount Eclipse Sandstone in the fold, is considered to contain the most prospective source beds in the succession.

URANIUM*

Carnotite occurs in the Devono-Carboniferous Mount Eclipse Sandstone at the Bigrlyi, Walbiri, Dingos Rest, and other prospects (Fig. 48; Ivanac & Spark, 1976). The host rocks are mostly in the lowermost part of the formation, and comprise friable to tough kaolinised white, grey, and reddish brown subarkosic or feldspathic sandstone with minor shale, siltstone, conglomerate, and dolarenite interbeds. Carbonaceous material and plant remains are common. In the primary zone the host rocks are compact grey to greyish white and pink medium to coarse-grained feldspathic sandstone with green shale and siltstone. Carnotite grades at shallow depth to sooty and lustrous black uraninite which fills the interstices between sand grains, replaces clayey particles, and fills fractures.

Radioactive opal and ochres occur in quartz veins and gossans filling fractures in granites and gneisses of the Arunta Block, and carnotite occurs in Quaternary calcrete near the southern margin of the basin.

Bigrlyi (F in, Fig. 48; Fig. 49) comprises a series of disconnected uraniferous lenses in the lower part of the Mount Eclipse Sandstone which crop out over a strike

* Contributed by Central Pacific Minerals NL.

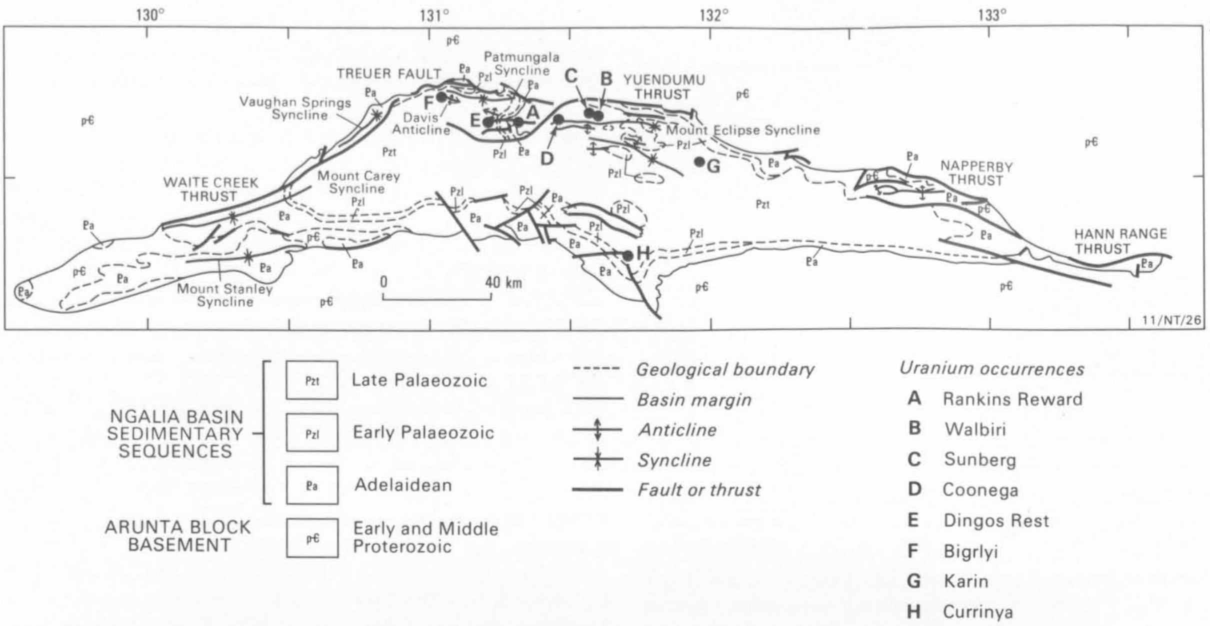


Fig. 48. Uranium occurrences in the Ngalia Basin.

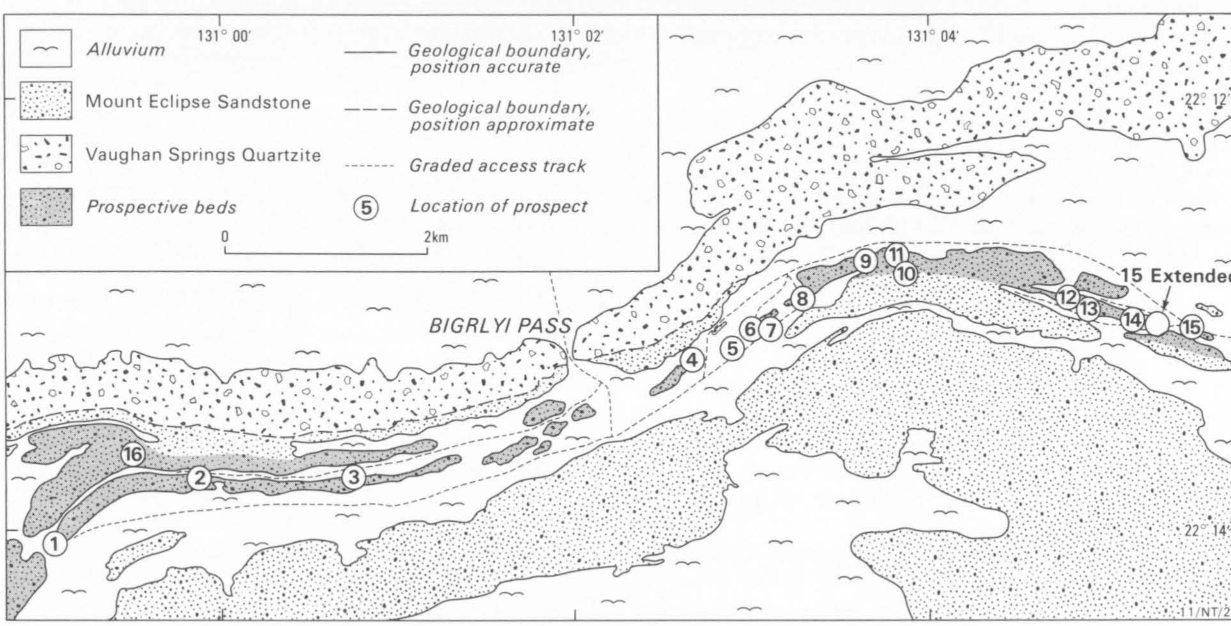


Fig. 49. Bigrlyi uranium prospects (from Central Pacific Minerals NL).

length of 12.5 km at the northwestern margin of the Ngalia Basin from Dingos Rest (E in Fig. 48) to Mount Doreen homestead. Sixteen surface and near-surface carnotite prospects have been located. In one place the cavities of a termite mound were found to be lined with carnotite.

The deposits at Bigrlyi occur in razorback ridges and beneath the intervening valley floors. They occupy a west-trending belt flanked to the north by the Vaughan Springs Quartzite, and to the south by a uniform sequence of tightly folded red, grey, and pink interbedded tough sandstone, ferruginous feldspathic sandstone, and claystone beds in the Mount Eclipse Sandstone. The mineralised host rock is a tough light grey-cream to pale greenish-grey medium to coarse-grained arkosic sandstone with minor red and green interbedded shale and siltstone. Red ferruginous beds are common towards the base, and dolarenite and claystone in lenses and beds are common in places. The mineralised host rocks are commonly kaolinised, white, and friable, and contain carbonaceous material and plant remains. Carbon, uranium, and vanadium are usually closely associated in them, and up to 8.05 kg/t of vanadium has occurred in some intersections. The tightly folded host sequence is about 450 m thick, and dips from 75° south to 80° overturned northwards.

Thirty thousand metres of drilling has helped to define the reserves at Bigrlyi (Table 8). Prospect 15 (Fig. 49) is the largest deposit discovered to date. It occurs in a roughly tabular body pitching subhorizontally to the west and dipping 70-80° south. It is at least 500 m long along strike and extends to a depth of 300 m. At the surface, carnotite forms flakes, grains, and veinlets in medium to coarse-grained light arkosic sandstone interbedded with purple and red hematitic sandstone and dolarenite. It grades to sooty uraninite

TABLE 8. URANIUM RESERVES—BIGRLYI PROSPECTS

Prospect		Classification	Tonnes of ore	Grade (kg U_3O_8/tonne)	Kg U_3O_8	Average width (m)
Treuer	15	Probable	83 179	3.59	299 014	3.95
Treuer	15 Ext.	Probable	187 867	3.42	643 278	3.77
Treuer	15 Ext.	Inferred	62 218	3.25	202 267	3.77
	8	Probable	23 447	1.36	31 820	3.90
SW of	8	Probable	18 413	3.80	70 035	1.53
Between 4 and 5		Probable	15 922	5.17	82 380	2.0
	4	Probable	35 125	3.88	136 426	2.23
SW of	4	Inferred	18 087	3.11	56 259	1.53
	2	Probable	91 570	2.14	195 698	2.38

Source: Central Pacific Minerals NL (1978).

at shallow depth. Prospect 2, at the western end of the prospect area, crops out as a narrow carnotite lens in medium to coarse-grained pale yellow ochreous to creamy-white arkosic sandstone. In contrast to prospect 15, the carnotite at prospect 2 forms a ribbon below the surface broadly related to the present or a former water-table; there is no significant uraninite. Other uraniferous deposits are either variations of the two described above or are pipelike, but all are conformable to the bedding.

Dingos Rest (E in Fig. 48) comprises two prospects: Dingos Rest South and, 2.5 km farther north, Dingos Rest North. Dingos Rest South prospect occurs in north-striking beds of medium to coarse-grained white, cream, and mottled purple and cream arkosic sandstone. It comprises two parallel irregular layers of mineralised sandstone about 20 m long: the upper one has a maximum width of 1.37 m; the other is narrower. At Dingos Rest North, minor carnotite deposits occur in beds with dips from 14° to 40° on the south limb of the Patmungala Syncline; the host rocks are a continuation of those from Dingos Rest South. Carnotite at both prospects is closely associated with clay pellets and purple hematite, and occurs as disseminations, as fracture and pore fillings, as coatings to sand grains, in pockets, in irregular segregations, and in golf-ball-size accretions. The deposits are secondary, are discontinuous with depth, and may be related to the mottled zone of lateritisation.

At *Walbiri* (B in Fig. 48), discontinuous carnotite deposits occur over a strike length of about 3 km in outcrops of white to pink-white quartz-feldspar sandstone and arkose which at depth grade to light grey to grey-green and contain minor pyrite and carbonaceous matter, including fossil logs; the beds dip 14° south-southwest. Carnotite occurs as needles; it forms disseminations and fracture-fillings, and is also found with clay pellets. Two lenticular bodies of sooty uraninite are irregularly dispersed through the host sandstone at depth, although at one location it occurs with black shale; the easternmost lens is the most important.

The mineral deposit at Walbiri pitches southeasterly from the surface radiometric anomalies at a low angle in a sinuous conformable lens 740 m long with an average width of 113 m and average thickness of 2.1 m. It was estimated in 1976 to contain 423 519 tonnes of ore with 686.1 resource tonnes of U_3O_8. The average grade is 1.63 kg U_3O_8/t, and the uranium is expected to be irregularly distributed within the lens.

Minor carnotite associated with carbonaceous matter was discovered in arkosic sandstone at *Sunberg* (C in Fig. 48), 3 km west along strike from Walbiri.

At *Coonega* (D in Fig. 48), small blebs of carnotite occur in white feldspathic quartz sandstone which is probably the same as the mineralised stratigraphic sequence at Walbiri.

At *Karin* (G in Fig. 48), carnotite occurs in white to grey medium to coarse-grained feldspathic sandstone with minor claystone beds which dip 16° south-southwest. Uraninite in the primary zone coats grain boundaries, fills pore spaces, and occurs as disseminations and blebs.

Patches of mineralised rock have been found along strike for 9000 m from the Karin anomaly. The largest deposit is a 1-m line-of-hole intersection which assayed 4.8 kg U_3O_8/t.

Currinya (H in Fig. 48), located near the central southern edge of the basin, comprises two weak radiometric anomalies, each measuring roughly 2.4 x 1.2 km. Traces of carnotite occur in calcrete and sandy clay of Quaternary age. In this part of the basin, calcrete is common in an area of widespread lagoons, salt pans, meanders, and cut-off meanders where modern streams trending across the basin debouch through a gap in the Vaughan Springs Quartzite. Pale yellow carnotite, distinct from the bright yellow variety at Dingos Rest, forms a thin film on very irregular surfaces in the calcrete. At shallow depth, the carnotite occurs as pea-size fragments and minor irregularly shaped grains, but the deposit is patchy and discontinuous. The maximum grade is 0.64 kg/t over a 2-m thickness between the depths of 4 and 6 m.

At *Rankins Reward* (A in Fig. 48), weak radiometric anomalies up to 600 m long and averaging 2 m wide occur in vertical or steeply, southwesterly dipping lenticular hematite/limonite gossans and quartz-hematite breccia. The gossans and breccia zones are weathered to depths of over 200 m, but no mineral deposits of economic significance were discovered.

In the *Arunta Block* several gossans and quartz-hematite breccia lenses and some of the granites and granite-gneisses show anomalously high radioactivity, and together have probably contributed uranium to sediments within the Ngalia Basin. Radiometric data recorded in the region (Fig. 50) show several major zones of anomalously high radioactivity in outcrops of the Arunta Block north of the basin.

Water supply

Surface water

Surface water is scarce, as the area lies within the 250 mm annual-rainfall isohyet and long droughts are common. Streams flow intermittently and mostly flood out into the surrounding sand plains and salt flats. The larger waterholes—Keridi, Oodnapinna, Pulca Currinya, and 20 Mile—and some of the unnamed soakages and waterholes in the larger creeks and rivers often retain water all year round and supplement bore-water for the pastoral industry. Native wells that are marked on the map are usually small depressions 1-2 m deep in impermeable rocks, commonly granite and ferricrete, and small soakages in creeks; they yield little water.

Natural springs are known from several areas; the largest occur around the periphery of the Vaughan Springs Syncline. Yields of 7000 l/h have been recorded from Vaughan Springs, at the northeast end of the syncline; the water is suitable for domestic use and is used at Mount Doreen homestead.

Groundwater

The following brief assessment of the potential of some of the formations most likely to yield groundwater was provided by R. E. Read (formerly Water Resources Branch, Northern Territory Administration, Alice Springs, personal communication 1979).

The Yuendumu Sandstone yields water in Penhalls Bore, which for a long time was the sole source of supply for Yuendumu Native Settlement (Appendix 3). Water quality is marginally over the World Health Standard of 1500 ppm total dissolved salts. Permeability is due to fissuring, and drilling in the formation has shown that the area of even marginally potable water is limited.

The Walbiri Dolomite has the potential to yield large supplies from solution joints. However, at present it yields water suitable only for stock, and it is unlikely to yield potable water in the future.

The Djagamara Formation might be expected to yield small to moderate supplies of potable water, but attempts to drill it have failed because of its extreme toughness.

The Kerridy Sandstone has assumed importance as an aquifer, as it is being tested by several bores for its suitability for long-term supply to Yuendumu Native Settlement. No interstitial permeability is evident in cuttings, and permeability must be due chiefly to joints and possibly to fissures associated with faulting. The well-developed joints in the test area may be due to the relatively tight folds here. Drilling logs show that water commonly flows from intervals with low penetration rates, suggesting that joints may be best developed in hard brittle sandstone beds.

The Mount Eclipse Sandstone probably has similar aquifer properties to the Kerridy Sandstone, and may need to be developed in the future to augment supplies from this formation. The formation may have some interstitial permeability, but joints may not be as well developed as in the Kerridy Sandstone. A bore in the Mount Eclipse Sandstone in an area near Bigrlyi Pass supplies adequate potable water for a small mining camp.

Of the eleven sedimentary formations in the basin, only the Mount Eclipse, Yuendumu, and Kerridy Sandstones have yielded potable water; the Mount Eclipse and Kerridy Sandstones, and aquifers in Cainozoic sediments, will probably be the main targets for exploration.

Aggregate

Cainozoic gravel has been excavated from several areas adjacent to the Alice Springs/Yuendumu road, and, after screening, has been used for road construction. Sites where gravel has been excavated for this purpose occur south of Yuendumu Native Settlement on scree slopes on the northern side of steep low ridges, and on the southern slopes of the Stuart Bluff Range near Mount Hammond. At both sites the scree is from the Vaughan Springs Quartzite.

Barite and galena

Barite and disseminated galena occupy irregular veins up to 60 cm wide along joints, and constitute replacement bodies, in an outcrop of the Walbiri Dolomite about

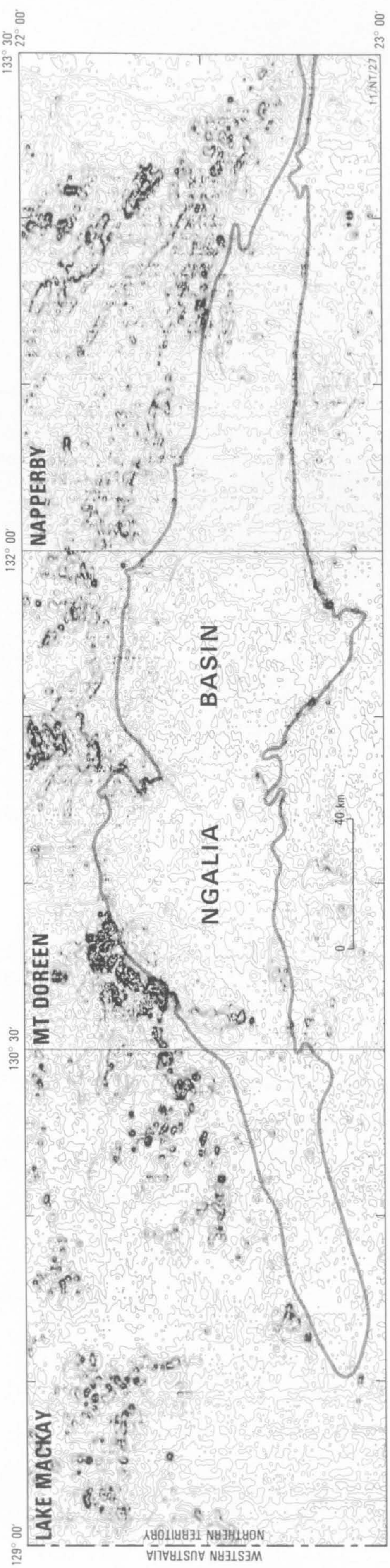


Fig. 50. Radiometric anomalies in the Ngalia Basin and surrounding parts of the Arunta Block.

0.5 km northwest of White Point, on the north flank of the Walbiri Ranges. Two diamond-drillholes about one kilometre north-northwest of the deposit encountered similar veinlets and small irregular masses of barite with small amounts of galena and pyrite in the dolomite (Grainger, 1969).

Building stone

The flaggy salmon-coloured micaceous sandstone from the upper part of the Yuendumu Sandstone is used as a facing and paving stone for buildings, retaining walls, and paths at the Yuendumu Native Settlement. The sandstone is hand-picked from a quarry about 5 km south of the settlement.

Coal and lignite

Tertiary sediments and the Devonian-Carboniferous Mount Eclipse Sandstone, both continental in origin, are the only deposits in the basin that contain significant quantities of carbonaceous material.

About 15 cm of lignite occurs in middle Eocene clay in the lower part of the bottom hole core (138.8-139.0 m) in BMR Napperby No. 1 stratigraphic borehole.

Carbonaceous clay, lignite, and some coal of possible middle Miocene age have been recorded in cores and cuttings from water-bores in the Tertiary Tea Tree Basin. The carbonaceous beds and clastic intercalations occur at depths from about 90 m down to about 200 m, over intervals ranging from about 10 m up to 40 m; the thickest lignite seams are 4 m thick.

Laminae and thin lenses of coal have been recorded from cores and cuttings in the Mount Eclipse Sandstone. The coal occurs mostly in fine-grained sandstone and in siltstone.

Copper

Small secondary copper concentrations occur in the lower part of the Walbiri Dolomite 6.5 km southwest of Yuendumu Native Settlement. The copper occurs as malachite and chalcocite in veinlets, in fissures, and as encrustations in breccia zones in the massive dolomite of the formation. Azurite and malachite are common along laminae and occur in veinlets in the siltstone and shale in the basal part of the formation. The copper deposits have been explored by small costeans, but there is no evidence of extensive mineral deposits.

Small secondary copper deposits have also been reported in the Djagamara Formation near White Point.

Dolomite

Large deposits of dolomite occur in the Walbiri Dolomite, but in many places it is sandy and silty, and would have to be selectively mined to recover dolomite of high purity. An analysis of dolomite from the formation at MD7* (about 0.5 km north of White Point) gave 52.5 percent $CaCO_3$, 43.1 percent $MgCO_3$, and 3.4 percent acid insoluble residue. Two samples from the formation analysed for phosphate gave 1.03 percent P_2O_5 (MD1, about 0.5 km southwest of Penhalls Bore) and 1.27 percent P_2O_5 (MD31F, about 1.5 km north of White Point Bore).

A thin sequence of dolomite occurs at the top of the Mount Doreen Formation in most outcrops, and dolomite from the Albinia Formation is known in the southwestern part of the Vaughan Springs Syncline. The deposits in the Walbiri Dolomite are more extensive, thicker, and more accessible than those of the other two formations.

* MD refers to samples located on the MOUNT DOREEN geological map (Wells, 1972).

TABLE 9. ANALYSES OF SAMPLES FROM PLAYA LAKES

	LM194A	*LM194B*	*MD449A*	*MD449B*	*LM56*	*(Terry 1934)*
Water soluble						
Calcium (%)	0.19	3.8	5.5	0.05	2.15	5.91
Magnesium (%)	0.54	0.09	0.035	0.155	0.08	
Sodium (%)	35.3	2.85	2.1	9.685	14.0	1.64
Potassium (%)	0.59	0.16	0.089	0.32	0.32	0.49
Carbonate (%)	Nil	Nil	Nil	Nil		
Bicarbonate (%)	Nil	Nil	Nil	0.0055		
Chloride (%)	53.6	3.6	2.55	14.31	0.74	2.97
Sulphate (%)	4.35	10.7	14.4	2.01	34.1	14.17
TDS (%) at 180°C	80.8	19.2	23.6	26.52		
Water insoluble residue (%)	1.88	72.0	65.2	0.526	43.8	
Calcium carbonate (% of residue)	Nil	Nil	Nil			
Calcium sulphate (% of residue)	0.48	4.5	19.0			
Nitrate (%)				0.00016	<0.05	
ph				7.0		
Spec. Cond. (μmhos/cm)				192 000		

Samples LM194A and B were taken on the western edge of Lake Mackay; LM194A was taken from the surface crust about 3 mm thick, and LM194B to a depth of 7.6 cm beneath the crust.

Samples MD449A and B were taken from Lake Bennett. MD449A was taken at a depth of 10.2 cm and MD449B is a water sample from about 0.3 m.

Sample LM56 was taken from the thin crust of a small salt pan in the southern part of LAKE MACKAY.

Analysis quoted from Terry (1934) has been recalculated from his figures which were given as 20.08% $CaSO_4$, 4.17% NaCl, 0.93% KCl, and total saline material 26.17%. The sample was taken to a depth of 1.09 m.

With the exception of the sample collected by Terry (1934) all samples were analysed by AMDEL (AMDEL Reports AN571/69 and AN1080/69).

EVAPORITES

Evaporites occur as thin crusts covering hundreds of square kilometres in playa lakes, and possibly as interbeds in the Treuer Member of the Vaughan Springs Quartzite. The compositions of several samples collected from playa lakes are listed in Table 9, and analyses of evaporite crusts and efflorescences that occur in the siltstone of the Treuer Member are recorded in Table 10.

Salt for local consumption is harvested infrequently from several small playas about 225 km northwest of Alice Springs. The playas are part of a large system of salinas, including Lake Lewis, south of the Stuart Bluff Range.

FLUORITE

Purple fluorite occurs in a small quartz vein 1.5 km north of Djagamara Peak, where the country rock is the Mount Doreen Formation.

TABLE 10. ANALYSES OF EVAPORITE CRUSTS ON THE TREUER MEMBER OF THE VAUGHAN SPRINGS QUARTZITE

	N206	*N223A*	*N223B*	*N224*
Sodium (%)	0.53	0.65	0.27	1.64
Potassium (%)	0.13	0.03	0.02	0.01
Calcium (%)	0.10	0.55	2.90	0.07
Magnesium (%)	0.25	0.07	0.15	0.40
Sulphate (%)	1.80	2.55	8.1	1.50
Nitrate (%)	Nil	Nil	Nil	Nil
Chloride (%)	0.55	0.36	0.76	2.8
Fluoride (ppm)	30	5	12	3
Water insoluble (%)	92.6	92.5	66.4	87.5

Analyst C. R. Trigg, AMDEL.

N223A, B, and N224 from north side of Hann Range.

N206 from 6.5 km west-southwest of Napperby homestead.

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APPENDIX 1

Summary of the results of shallow stratigraphic drilling in the Ngalia Basin

A. T. Wells

All samples recovered from these drillholes are available for inspection at the BMR Core & Cuttings Laboratory, Fyshwick, ACT. Grid references tabulated below refer, to the nearest 100 m, to the 10 000 m grid on the MOUNT DOREEN and NAPPERBY geological maps (Wells, 1972; Evans, 1972). In the following tabulation, SP is the abbreviation for seismic shot-point.

Well	*Location/ grid ref.*	*Elevation GL (m)*	*Depth water encountered (m)*	*Water quality*	*Core* no.	*Core* intervals (m)	*Core* % recovery	*Intervals of cuttings (m)*	*Total depth (m)*	*Bottom-hole formation*
BMR Mount Doreen No. 1	BMR seismic line A SP 1622 7206 5421	605.3			2	21.34–23.62 38.96–41.60	100% 47%	4.6 between 4.6 and 18.3 m (3 samples)	41.8	Rinkabeena Shale
BMR Mount Doreen No. 2	BMR seismic line A SP 1545 7185 4999	577.9			3	25.9–28.8 35.0–37.6 37.7–43.0	100% 100% 100%	nil	42.98	Mount Eclipse Sandstone
BMR Mount Doreen No. 3	BMR seismic line A SP 1539 7184 4968	569.4			2	80.8–82.7 99.1–101.5	100% 100%	nil	124.36	Cainozoic sandstone
BMR Mount Doreen No. 4	BMR seismic line G SP 102 7193 5417	612.6			0			One sample 0.6–36.6	36.6	Wanapi Dolomite Member of the Mount Doreen Formation
BMR Mount Doreen No. 5	BMR seismic line H SP 3023 7336 5314	673.0			0			One sample 0.6–36.6	36.6	Rinkabeena Shale
BMR Mount Doreen No. 6	BMR seismic line H SP 3026 7348 5314	680.0			0			One sample 22.9–36.6	36.6	Rinkabeena Shale
BMR Mount Doreen No. 7	N. end BMR seismic line A near SP 1624 7204 5431	603.2	58	salt	1	61.6–64.6	10%	1.52	114.3	Rinkabeena Shale
BMR Mount Doreen No. 8	S. end BMR seismic line A near SP 1539 7184 4962	569.4	41	TDS ca 1990, non-potable; excess sulphate	0			1.52	41.4 1st attempt; 71.6 2nd attempt	Cainozoic sediments
BMR Mount Doreen No. 8B	BMR seismic line A near SP 1540 7184 4974	570.6		TDS ca 5850, non-potable	2	125.0–128.0 216.4–218.7	5% 52%	1.52	218.7	Mount Doreen Formation
BMR Mount Doreen No. 9	BMR seismic line J near SP 3485 6619 4952	524.3	17	TDS 705, potable	2	204.2–206.2 241.4–243.8	96% 100%	1.52	243.8	Mount Doreen Formation

BMR Mount Doreen No. 10	7527 5098	615		TDS 1054, non-potable; excess fluoride	3	94.5–97.5 112.8–115.8 160.9–161.5	93% 87% 100%	1.52	161.5	Mount Eclipse Sandstone
BMR Mount Doreen No. 11	7720 4898	580		TDS 1152, potable by adults	1	146.3–149.3 176.8–179.8	83% 0	1.52	179.8	Cainozoic sediments
BMR Mount Doreen No. 12	7834 5060	605	23	TDS 2625 non-potable; excess sulphate	2	62.5–65.5 182.9–185.9	76% 76%	1.52	185.9	Mount Eclipse Sandstone
BMR Mount Doreen No. 13	8058 5236	635	35	TDS ca 5030, non-potable	2	121.9–125.0 179.8–181.1	15% 82%	1.52	181.1	Naburula Formation? overlying Vaughan Springs Quartzite?
BMR Mount Doreen No. 14	7828 5322	665	55	Small supply	2	16.8–17.5 54.9–55.1	50% 87%	1.52	54.9	Walbiri Dolomite
BMR Mount Doreen No. 15	7716 4912	580	18 (SWL)	TDS 1470, stock water	2	158.5–160.0 164.3–164.9	41% 100%	1.52	164.9	Vaughan Springs Quartzite
BMR Napperby No. 1	2602 4981	ca 620			2	128.93–131.98 135.94–138.99	30% 30%	nil	138.99	Tertiary clay (mid-Eocene lignite)
BMR Napperby No. 2	2398 4862	ca 560			1	56.39–59.28	42%	Mostly 3.2	112.17	Tertiary conglomerate
BMR Napperby No. 3	2105 5118	ca 620			1	153.62–156.36	33%	3.2	156.36	Treuer Member of the Vaughan Springs Quartzite?
BMR Napperby No. 4	BMR seismic line C SP 486 2587 4840	ca 580			2	65.53–72.09 94.49–97.54	84% 78%	0.6 between 13.1 and 59.4 m; one sample 33.8–38.4; one sample 61.0–64.0; 4.6 between 73.2 and 91.4 m; one sample 91.4–94.5	97.54	Cainozoic clay
BMR Napperby No. 5	2067 5116	ca 620	30		11	30.48–32.31 60.96–64.01 91.44–94.49 121.92–124.36 152.40–153.31 153.31–154.23 182.88–184.40 213.36–216.41 230.12–233.17 243.54–244.15 244.15–244.75	100% 50% 50% 50% 66% 66% 80% 100% 98% 100% 100%	1.52 between 0 and 59.44 m; 4.57 between 59.44 m and TD	244.8	Naburula Formation/ Rinkabeena Shale?
BMR Napperby No. 6	2190 4845	ca 560	45 (3.7 SWL)	TDS 6940, non-potable	2	106.38–108.20 111.56–111.64	100% 100%	1.52	112.47	Mount Eclipse Sandstone
BMR Napperby No. 7	2806 4922	ca 620	44		8	30.48–33.53 60.96–64.01 91.44–94.49 121.92–122.53 129.54–132.59 152.40–155.45 220.98–224.03 243.84–245.97	98% 40% 50% 100% 73% 33% 33% 38%	1.52	245.97	Mount Eclipse Sandstone?

APPENDIX 2

The Patmungala beds of the Arunta Block

A. T. Wells

Definition

The Patmungala beds are here defined as a sequence of slightly metamorphosed silty sandstone, quartzite, siltstone, recrystallised tuff, and minor interbedded conglomerate, commonly with chert pebbles that show pronounced stretching caused by later tectonism. The precise order of the rock types in the sequence is not known.

The name of the beds is derived from Patmungala Creek, which flows along the north flank of the main outcrop of the beds.

History of investigations

Descriptions of outcrops of the Patmungala beds are given in the field record of Wells, Evans, & Nicholas (1968).

Type area

The type area includes the outcrops between Patmungala Creek and the Naburula Hills about 6 km west-northwest of Djagamara Peak.

Contacts

The Patmungala beds are overlain with angular unconformity by glacigene sediments tentatively identified with the Adelaidean Naburula Formation. They are intruded by Middle Proterozoic granite, but their relationship with nearby outcrops of basement metamorphic rocks is not certain.

Distribution

The Patmungala beds crop out in several large, closely spaced outcrops to the north of and adjacent to the margin of the Ngalia Basin north of the Patmungala Syncline (Plate 1); the total length of known outcrop is about 16 km. The beds form low strike ridges and irregular groups of hills.

Thickness

The maximum exposed thickness, estimated from measurements on airphotographs, is about 1100 m.

Lithofacies

Poorly sorted medium-grained tough thin-bedded grey silty sandstone forms the prominent ridges in outcrops of the beds. It is closely jointed, and in places is well sorted, friable and silicified. Cross-bedding and small ripple marks are rare. The sandstone is interbedded with thin-bedded and laminated siltstone, and in some places small cross-lamination is evident. The siltstone is deeply weathered and poorly exposed, and commonly the weathered surface has thin white efflorescences. Interbeds of pebble conglomerate (with stretched chert clasts), quartz and quartzite-pebble conglomeratic sandstone, and spotted recrystallised vitric crystal tuff occur at several localities. The tuff consists of about 10 percent angular quartz and feldspar grains up to 0.2 mm across in a mostly very fine-grained matrix with minor sericitic material. The stretched-pebble conglomerate consists of elongated fragments of chert—some with laminations of heavy minerals and others with small quartz veins—quartzite with squeezed and flattened grains, and a matrix mainly of crushed quartz grains.

Metamorphism

The beds are invariably tightly folded along easterly trending axes. Small quartz-muscovite veinlets cut the beds, and in other areas quartz veins from a fraction of a centimetre up to 10 metres wide intrude the Patmungala beds; the larger veins occur along major faults, and the largest forms the northern boundary to the main outcrop area.

Low-grade metamorphic effects are shown by stretching of chert clasts in the conglomerate, and quartz grains in the sandstone show irregular or subaligned cracks and wavy extinction probably caused by the low-grade metamorphism.

Age

The Patmungala beds are Precambrian in age. They lie unconformably beneath the Adelaidean Naburula Formation, and are undoubtedly older than the Adelaidean Vaughan Springs Quartzite because of their different structural style and setting. The base of the beds is not exposed, and they are intruded by Precambrian granite. There are no lithologically similar beds known in the Ngalia Basin succession.

Correlation

Beds of similar lithology occur in the Reynolds Range area to the north of the Ngalia Basin (Stewart & others, 1980).

Palaeogeography, environment, and history of deposition

The environment of deposition and provenance area are unknown. The high proportion of coarse-grained sediments suggests a shallow-water environment, and contemporaneous volcanism is indicated by the interbeds of lithic crystal tuff.

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APPENDIX 3

Groundwater

A. T. Wells

The main users of water are the Native Welfare Settlement at Yuendumu and the cattle industry; Yuendumu and several homesteads on pastoral leases in the eastern two-thirds of the region are the only permanent settlements. The main source of water is from bores and earth dams and from a few natural springs.

History

Jones & Quinlan (1962) described the water resources of the Alice Springs area, including the Ngalia Basin. Various other reports describing aspects of the water supply of local areas within the area of the geological map are cited by Quinlan (1958a, b), Jones & Quinlan (1958), Wiebenga, Goodchild, & Bamber (1959), Cook (1962, 1963), and Edworthy (1966, 1968). The reader is referred to these reports for details; only the broad results are given here.

Drilling data

A total of 767 bores had been drilled in the area shown on the 1:500 000 geological map up to the end of 1977. They include 443 in NAPPERBY, 301 in MOUNT DOREEN, 6 in LAKE MACKAY, and the remainder (17) in the western quarter of ALCOOTA; Kingdom & others (1967) have illustrated the locations of most of them. Bore data sheets providing information for each bore are available on file at the Resident Geologist's Office, Alice Springs; a duplicate set is held in the Technical Files of the Bureau of Mineral Resources in Canberra.

Yuendumu water supply

The water supply for Yuendumu Native Settlement was originally obtained from nearby bores in Quaternary sediments and from a few in Precambrian basement rocks; the supply and quality proved to be inadequate. Two bores subsequently drilled to the south of the settlement in sediments of the Ngalia Basin gave contrasting results. In the White Point Bore the aquifer is the Cambrian Walbiri Dolomite and the supply is 4500 l/h; it is used as a stock bore and the water is of marginal quality for human consumption. Penhalls Bore penetrated red sandstone and siltstone of the Yuendumu Sandstone; the supply is 8000 l/h, and most of this water is pumped into holding tanks nearby for domestic consumption at the settlement.

The Water Resources Branch of the former Northern Territory Administration carried out a water supply investigation south of Yuendumu Native Settlement, and four production bores have been completed in the Kerridy Sandstone in an area centred about 10 km southwest of Yuendumu. Permeability is due almost entirely to jointing (R. E. Read, formerly Water Resources Branch, personal communication). The aquifer is bounded to the north by the outcropping Djagamara Formation, and to the south in part by a fault; it is open to the east, and in connection with the Mount Eclipse Sandstone to the west.

Southern basin water supply

The large area of internal drainage along the southern margin of the basin commonly yields saline groundwater, and the homesteads in this area experience problems in providing sufficient stock water. As well as the quality, the quantity too is variable: several bores drilled in Quaternary calcrete and clay near Newhaven homestead yield up to about 5 kl/h, whereas other bores close by are dry.

Data from seismic shot-holes

Many of the shot-holes drilled along seismic lines tapped water. Most of these were drilled to a depth of 40 m; the water was encountered generally at depths between 25 and 30 m. Water in Cainozoic gravel occurs at 26 m in shot-holes 1561 and 1566, and at 24 m in shot-hole 1559, all on BMR line A. On BMR line L, water at 30 m in shot-hole 4515 from probable Cainozoic 'sandstone bands in clay' (driller's log), and water at 64 m in shot-hole 4501, probably came from the Mount Eclipse Sandstone.

Data from stratigraphic drillholes

Analyses of water samples from shallow stratigraphic drillholes (Evans & Nicholas, 1970; Wells, 1974) are listed in Table A1, and porosity and permeability of selected cores from these holes are listed in Table 7 (main text). A prolific supply of water was produced from Mount Doreen No. 8, in which flow rates were estimated at about 140 000 l/h. The aquifer in this hole is a Cainozoic cobble bed at 41 m. Mount Doreen No. 8B, 550 m away, failed to penetrate this bed.

References

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TABLE A1. WATER ANALYSES

Borehole/shot-point	*BMR Mt Doreen No. 8** *(mg/l)*	*BMR Mt Doreen No. 8B** *(mg/l)*	*BMR Mt Doreen No. 9** *(mg/l)*	*BMR Mt Doreen No. 10** *(mg/l)*	*BMR Mt Doreen No. 11** *(mg/l)*	*BMR Mt Doreen No. 12** *(mg/l)*	*BMR Mt Doreen No. 13** *(mg/l)*	*BMR Mt Doreen No. 15†* *(mg/l)*	*BMR Napperby No. 6†* *(mg/l)*	*BMR Napperby No. 6†* *(mg/l)*	*SP 1561** *(mg/l)*	*SP 4515‡* *(ppm)*	*SP 4501‡* *(ppm)*
Sample no.								71/0336	71/0334	71/0335			
Standing water-level								ca 18 m	ca 3.7 m	ca 3.7 m			
Conductivity at 25 °C (micromhos/cm^2)								2470	10340	58830			
Hardness (calculated as $CaCO_3$)													
Total	512	830	240	316	244	906	2532	252	1500	8000	130		
Carbonate	238	301	240	194	227	218	142	252	52	56	130		
Non-carbonate	274	529	Nil	122	17	688	2390	Nil	1448	7944	Nil		
Alkalinity in excess of total hardness	Nil	Nil	64	Nil	Nil	Nil	Nil	278	52	56	92 (RA93)		
Chloride	675	2680	80	300	305	885	1570	470	2460	22460	45	1890	575
Sulphate	314	723	37	151	169	608	1660	225	2050		ND	1670	310
Bicarbonate	290	370	371	237	277	265	174	339	63	68	271	270	180
Nitrate	ND	ND	22	22	22	ND	ND	42	14				
Fluoride	ND	ND	1.0	1.6	1.4	ND	ND	1.7	1.9				
Carbonate	ND	ND	Nil	Nil	Nil	ND	ND				ND	Nil	Nil
Sodium	490	1760	86	192	255	490	720	432	1820		97	1240	254
Potassium	67	52	31	54	34	92	60	48	158		35	115	49
Calcium	71	110	48	50	73	160	553	45	244		19	357	112
Magnesium	81	135	29	46	16	123	280	34	195		20	214	88
Iron								UD	27				
Silica								32	3				
Phosphate								<1	<1				
Total dissolved salts	ca 1990	ca 5850	705	1054	1152	2625	ca 5030	1470	6940			5650	1490
Residue on evaporation	3000	6500				3000	6000			46000	620		
Water insoluble residue												6	111
pH	ND	ND	8.3	8.1	8.1	ND	ND	7.6	6.5	6.5			
Remarks	Unsuitable for human consumption—excessive sulphate content	Unsuitable for human consumption—excessive dissolved salts	Suitable for adults but not infant children—excessive nitrate	Unsuitable for human consumption—excessive fluoride and nitrate	Suitable for adults but not infant children—excessive nitrate	Unsuitable for human consumption—excessive sulphate	Unsuitable for human consumption—excessive salts	Unsuitable for human consumption—excessive fluoride; suitable for stock	Unsuitable for human consumption—sample obtained several days after hole completed	Sample taken when bore at depth of 70 m			

* Analyses by former Northern Territory Administration—Animal Industry Branch (reference No. SN70/169 and specimen advice note 4465).
† Analyses by former Northern Territory Administration—Water Resources Branch.
‡ Analyses by C. R. Trigg, AMDEL.
ND—not determined; UD—unsuitable for determination; RA—residual alkali.

Additional notes

1. Sample from shot-point 1561, 37 km southeast of Vaughan Springs homestead, was from about 26 m.
2. Sample from SP 4515, next to the Alice Springs-Yuendumu road about 5 km south of Mount Allan, was from 29.9 m. Outcrops of Kerridy Sandstone occur close by.
3. Sample from SP 4501, about 13 km southwest of Mount Allan, was from a depth of 64.0 m. Nearby outcrops are the Devonian-Carboniferous Mount Eclipse Sandstone.

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APPENDIX 4

Microfossils from the Albinia Formation, Ngalia Basin

M. R. Walter & K. Cloud

During 1977, A. T. Wells collected black chert samples from the Albinia Formation in the Vaughan Springs Syncline. The chert occurs as lenses elongate parallel to the bedding in flat-bedded dolomite. Some of the collected samples occurred as float, but there is little doubt as to their origin. Samples from two localities (Fig. A1), both in the Mount Doreen 1:250 000 Sheet area, contain microfossils: 77807004 from the southeastern flank of the syncline (metric coordinates 68440E, 52780N); and 77807005 from the headwaters of Waite Creek (metric coordinates 68310E, 52820N).

The fossils are abundant but generally very poorly preserved. Two taxa are readily distinguishable; these are by far the most abundant components of the assemblage and are identified here as *Myxococcoides ?inornata* Schopf and *Eomycetopsis* sp. nov. Fossils not referable to these taxa are rare—for example, some cells resemble forms of *Caryosphaeroides* and *Globophycus* described by Hofmann (1976). This assemblage is similar to those found in present-day intertidal to supratidal cyanobacterial mats, and it is likely to have had such an origin. Very similar assemblages are known from sequences ranging in age from 1800 m.y. (Hofmann, 1976) to about 800 m.y. (Schopf, 1968). Therefore at this stage they cannot be considered to have any age significance.

DISTRIBUTION OF ALBINIA FORMATION

Fig. A1. Microfossil localities in the Albinia Formation.

Myxococcoides ?inornata Schopf

Plate A1, figs. 1–3

This consists of cells generally forming clusters with numerous individuals is up to several hundred per cluster); infrequently a small number of cells is loosely associated. In most cell clusters the çells are embedded in an unstructured organic matrix that in some examples has a fibrous appearance. The clusters are interpreted as remnants of microbial mats. The cells range in width from 5.6-22.4 μm, with an average near 17 μm. Most cells are empty, but some contain faint polygonal organic bodies of about one-third of the width of the cells; these cells also contain irregular membranous structures.

These fossils are similar to *M. inornata* Schopf, but differ in the frequent presence of cells smaller than those observed by Schopf (1968) and in the occurrence in clusters of many cells.

Eomycetopsis sp. nov.

Plate A1, figs. 4–6

This filamentous fossil occurs abundantly in intraclasts interpreted as fragments of microbial mats. It consists of intertwined, unsegmented, distinctly walled tubules 3.9-9.1 μm wide. The tubules have circular cross-sections with walls 0.8-1.3 μm thick. It differs from *E. robusta* Schopf in being slightly larger, gregarious, and in lacking evidence of brittle fracturing.

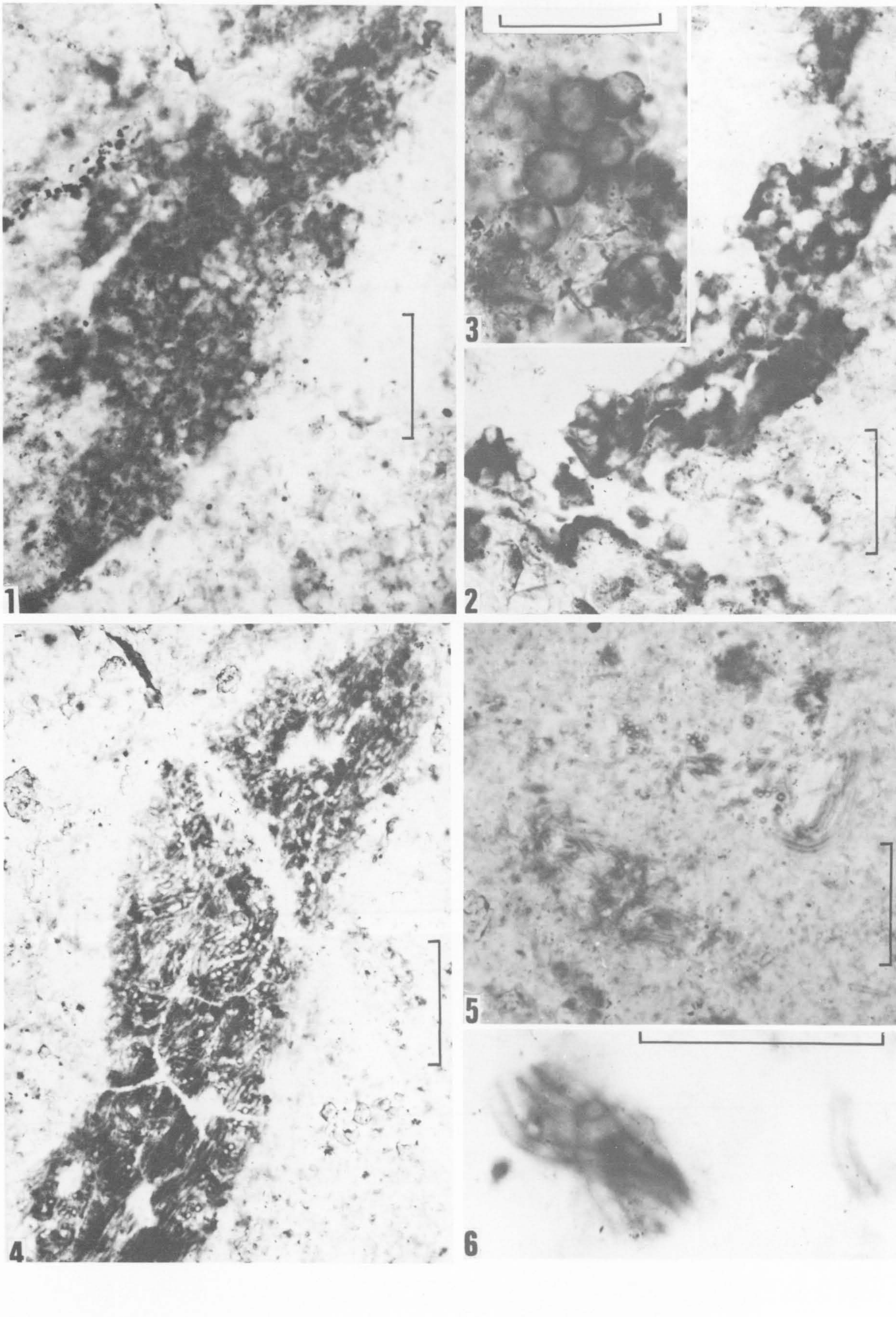
References

Hofmann, H. J., 1976—Precambrian microflora, Belcher Islands, Canada: significance and systematics. *Journal of Paleontology*, 50, 1040-1073.

Schopf, J. W., 1968—Microflora of the Bitter Springs Formation, late Precambrian, central Australia. *Journal of Paleontology*, 42, 651-688.

PLATE A1

Microfossils in thin sections of chert from the Albinia Formation. Figures 1-3, *Myxococcoides ?inornata* Schopf. Figures 4-6, *Eomycetopsis* sp. nov. Scale bars in 1, 2, 4, and 5 are equivalent to 100 μm; those in 3 and 6 are equivalent to 50 μm. 1, CPC 22412; 2, CPC 22413; 3, CPC 22414; 4, CPC 22415; 5, CPC 22416; 6, CPC 22417.


1
2
3
4
5
6

APPENDIX 5

Trace fossils from the Yuendumu Sandstone

M. R. Walter

Samples of red-brown flaggy micaceous siltstone and sandstone with trace fossils were collected by A. T. Wells from the Yuendumu Quarry (lat. 22°17′40″S, long. 131°48′05″E), about 4 km south of Yuendumu Native Settlement, MOUNT DOREEN. The samples come from about 60 m below the top of the 500 m of exposed beds.

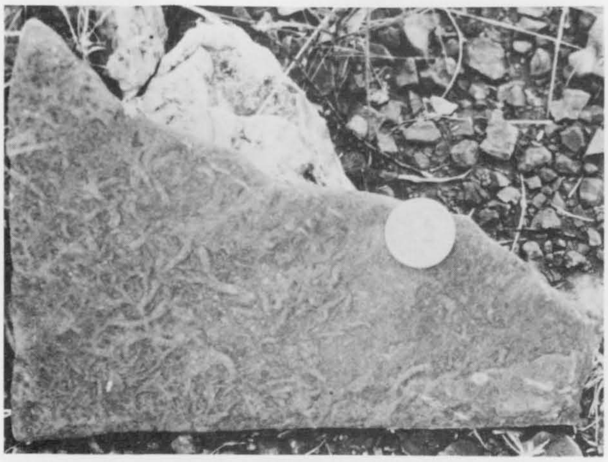


Fig. A2. ***Planolites ballandus*** **Webby from the Yuendumu Sandstone 4 km south of Yuendumu Native Settlement. (GB2007)**

Only one form of trace fossil is present (Fig. A2), but it is abundant. It is a sinuous burrow preserved as positive hyporeliefs, negative epireliefs, and longitudinal sections of the burrow-fill. The burrows are 1.5-4.0 mm wide; most are at the lower end of this size range. They vary from parallel to perpendicular to the bedding. The burrow-fill appears to be indistinctly laminated; the laminae are perpendicular to the long axis of the burrow and less than 0.5 mm thick.

The same trace fossil form is found in the uppermost Arumbera Sandstone (Arumbera Sandstone unit III of Wells & others, 1967, plates 11, 12, and 18) of the Amadeus Basin. A form from the Lintiss Vale beds (Torrowangee Group) of New South Wales is on the average slightly smaller, but is here considered conspecific. Thus the name *Planolites ballandus* Webby is applied to the Ngalia Basin and Amadeus Basin fossils.

A single trace fossil cannot be used for dating. Nonetheless, the only other occurrences of *P. ballandus* are Early Cambrian in age, and correlation of the Yuendumu Sandstone with unit III of the Arumbera Sandstone would be consistent with available data.

Reference

WELLS, A. T., RANFORD, L. C., STEWART, A. J., COOK, P. J., & SHAW, R. D., 1967—The geology of the north-eastern part of the Amadeus Basin, Northern Territory. *Bureau of Mineral Resources, Australia, Report* 113.

APPENDIX 6

Plant fossils from the Mount Eclipse Sandstone

Mary E. White

Fronds of a Carboniferous pteridosperm, and stems and a root buttress of a lycopod, are identified in samples collected from four localities in the Mount Eclipse Sandstone in MOUNT DOREEN. They represent the first substantial suite of late Palaeozoic plants from central Australia. The specimens are poorly preserved, but photographs taken by H. M. Doyle were of assistance in determining the plants.

Locality MD 43

Locality MD 43, in the western Naburula Hills 61 km west of Yuendumu Native Settlement and 10.5 km west-southwest of Djagamara Peak, yielded impressions of decorticated lycopod stems (reference F 22953; Fig. A3) on which leaf bases are crowded and arranged in ascending spirals. All the forms are of a general *Lepidodendron* sp. type, but are too poorly preserved for specific identification.

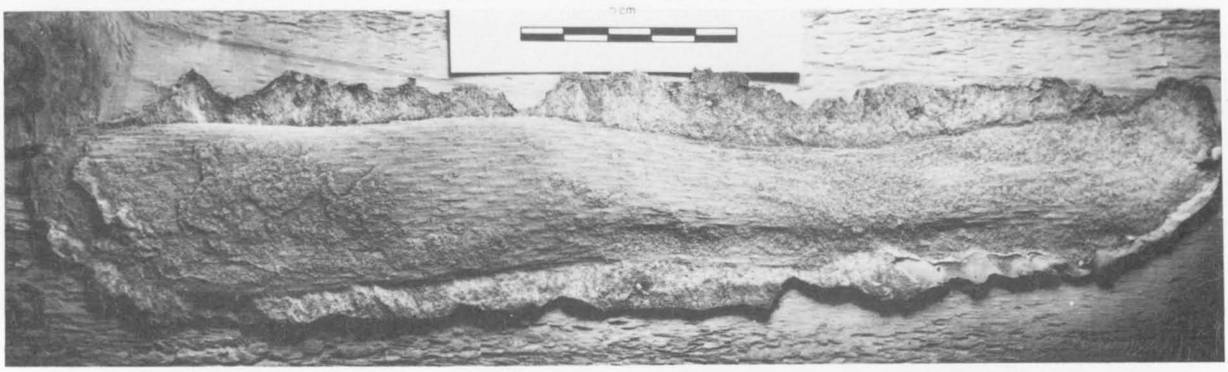


Fig. A3. Impression of a decorticated *Lepidodendron* sp. from the Mount Eclipse Sandstone 61 km west of Yuendumu Native Settlement. (GB2054)

Locality MD 135

At this locality, 6.5 km south-southeast of Djambidjimba Mesa, specimens (F 22954) are indeterminate stems and an indeterminate fern-like frond.

Locality MD 135A

This locality, also 6.5 km east-southeast of Djambidjimba Mesa, yielded specimens of two forms—F 22955 and F 22956. F 22955 is a poorly preserved frond of *'Triphyllopteris austrina'* Morris (unpublished name), which is illustrated in Figures A4 and A5. Controversy still remains in the naming of fronds of this sort: Rigby (1973) placed them in *Gondwanidium plantianum;* and Archangelsky & Arrondo (1966) determined probably identical South American specimens as *Botrychiopsis plantianum*—a determination that Gould (1975) has accepted. Morris (1977), in her revision of the Carboniferous flora of New South Wales, used the name *'Triphyllopteris austrina'* for Late Carboniferous fronds which show a great deal of pinnule variation—from much dissected to flabelliform —and derived the name *'Gondwanidium australe'*, which occurs with *Gangamopteris* and *Glossopteris* in uppermost Carboniferous and basal Permian beds, from *'Triphyllopteris austrina'*. Because of the confusion in identification, the presence of a *Botrychiopsis*-like frond alone would indicate a Late Carboniferous or Early Permian age, but, as the fronds in the Mount Eclipse Sandstone are associated with *Lepidodendron* stems, a Late Carboniferous age is more likely.

Specimens F 22956 show examples of decorticated *Lepidodendron* stems.

Fig. A4. *'Triphyllopteris austrina'* Morris from the Mount Eclipse Sandstone 13 km south-southeast of Mount Doreen homestead. (GB2055)

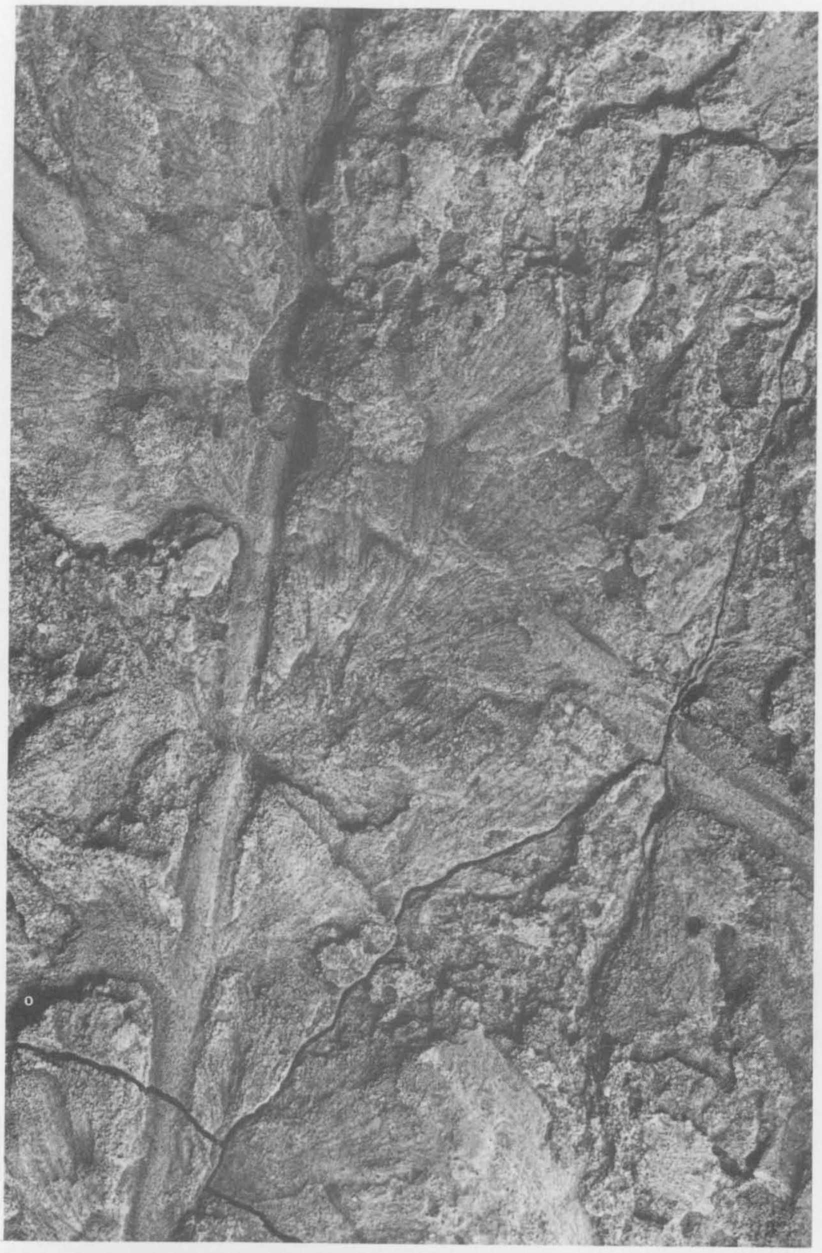


Fig. A5. Detail of part of the frond of *'Triphyllopteris austrina'* Morris (x 2.85) from the Mount Eclipse Sandstone 13 km south-southeast of Mount Doreen homestead. (GB2055)

Locality MD 145

This locality—on the southern flank of the Treuer Range 16 km northeast of Mount Doreen homestead—yielded indeterminate stem casts (F 22957).

Locality NT 28-131

The precise position of this locality, which has yielded a fossil specimen from the Mount Eclipse Sandstone, is not known. The specimen is a cast of part of a root buttress of an arborescent lycopod. It is referable to *Stigmaria ficoides* Brongniart, which is a form species used to accommodate the root systems of a number of related plants in which stigmarian rootlets were attached all over the surface of the organ. Attachment points for rootlets appear as small rings with central spots, which represent the single vascular trace.

References

Archangelsky, S., & Arrondo, O. G., 1966—Elementos Floristicos del Permico Argentino. *Museo de la Plata, Revista (N.S.), Palaeontologia,* 5, 1-16.

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APPENDIX 7

Davis No. 1 petroleum exploration well

compiled by A. T. Wells

Introduction

Davis No. 1 well, drilled in 1981, was the first petroleum exploration well in the Ngalia Basin. It was drilled by the Moonie Oil Company and others on the Davis Anticline at latitude 22°14′53″S and longitude 131°04′07″E, in the western half of Oil Permit 165, held by Magellan Petroleum Australia Limited. It reached a total depth of 1899 m in Precambrian granitic rocks intruding orthoquartzite. Kelly bushing elevation was 646.5 m above MSL, and ground-level elevation 640.4 m above MSL.

The following summary of the principal drilling results is abridged from the well completion report by Baarda & Buckingham (1982).

The primary objective of the well was to penetrate the Ordovician Djagamara Formation, which is considered to be a correlative of the Pacoota Sandstone—the producing reservoir in the Mereenie and Palm Valley Anticlines of the northern part of the Amadeus Basin. Other Palaeozoic formations, such as the Kerridy Sandstone, were regarded as secondary targets. A small gas show within the Mount Eclipse Sandstone in the Afmeco DDH-DAV 1 drillhole (French & others, 1978; Rippert & others, 1979), 1.85 km east of Davis No. 1, was regarded as encouraging, although this formation was not considered to have commercial potential. Except for the bottom-hole core, air drilling was used and water flows of up to 5500 l/h accompanied the air stream at depths between about 30 and 300 m.

Structure

The axis of the Davis Anticline trends about west and is doubly plunging. Surface closure is estimated to be about 20 km², and vertical closure about 200 m. Davis No. 1 well was sited to the south of the axis of the Davis Anticline. A dipmeter survey in the hole indicated a regional southwesterly dip in the Mount Eclipse and Kerridy Sandstones and the Djagamara Formation, as expected from the well location with respect to the anticlinal axis. The dipmeter results indicate that the beds of the Mount Doreen Formation dip northwards which suggests that the axis of the fold at this stratigraphic level is to the south of the well site. Dipmeter results in the Rinkabeena Shale indicate both north and south dips; these have a roughly equal density for low dips, but the northerly component exhibits a greater diversity of dip direction in the higher angles (up to about 35°). The more scattered population may be tensional fractures.

Stratigraphy

The lithological subdivision of the sequence penetrated in the well and the assignment of formations are necessarily tentative owing to the lack of definitive age determinations. The preliminary formation designations of Baarda & Buckingham (1982) are listed in Table A2.

TABLE A2. PRELIMINARY FORMATION DESIGNATIONS TO INTERVALS IN DAVIS No. 1

Formation	*Depth (KB, m)*	*Depth (MSL, m)*	*Thickness (m)*
Mount Eclipse Sandstone	surface	+ 647.0	996.7
Kerridy Sandstone	996.7	− 349.7	123.7
Djagamara Formation	1120.4	− 473.5	140.8
Mount Doreen Formation	1261.3	− 614.3	149.0
Rinkabeena Shale	1410.3	− 763.4	448.1
Patmungala beds	1858.4	−1211.4	40.2
Total depth	1898.6	−1251.6	

The Mount Eclipse Sandstone/Kerridy Sandstone contact is picked at the lithological change from predominantly poorly sorted sandstone to fine-grained micaceous sandstone and siltstone below. The change is gradational over a wide interval, and the wire-line logs for both formations are very similar. A change in bedding character is shown by Schmidt plots of the dipmeter surveys. Cross-bedding down to about 900 m is replaced by flat-lying laminations down the hole, together with a slight change in dip direction.

The lower Mount Eclipse Sandstone is significantly less sandy in Davis No. 1 than in DDH-DAV 1, but attempts to correlate units in the formation between the two wells are hampered by the lateral discontinuity of lithological units. The Mount Eclipse Sandstone comprises lenses of sandstone and shale, which vary laterally in thickness and pinch out over short distances. The formation exhibits cyclic sedimentation, though the cycles are commonly incomplete. In places, shale overlies coarse-grained sandstone; through the sequence, the shale as well as the sandstone intervals are virtually indistinguishable, and correlation even over short distances of the order of about 50 m is very diffiult.

A marine sequence of glauconitic and lithic sandstones, siltstone, shale, marl, and limestone (micrite) is assigned to the Djagamara Formation. The identification is based on the presence of glauconite, mainly in the upper part of the interval. The sequence comprises light brown, very calcareous, argillaceous shale between 1120 and 1131 m; glauconitic sandstone and limestone and grey-green shale between 1131 and 1180 m; and dark grey-brown siltstone grading downwards into brown and grey shale between 1180 and 1261 m, including minor thin beds of glauconitic sandstone and limestone between 1180 and 1195 m. A light brown marl in the interval 1120-1131 m is included in the Djagamara Formation, although its general appearance suggests that it is lithologically more similar to the Kerridy Sandstone sequence above.

Limestone (micrite) of the Mount Doreen Formation (Wanapi Dolomite Member) occurs from 1261-1341 m, and lithic calcareous sandstone (possibly glaciogenic) is predominant below 1341 m.

An alternative interpretation to that proposed by Baarda & Buckingham (1982; Table A2) is that the brown and grey shale sequence (1232 to 1261 m) above the limestone (marker bed of dolomite—Wanapi Dolomite Member of the Mount Doreen Formation) correlates with the Newhaven Shale Member of this formation. This interpretation recognises the presence of all three members of the Mount Doreen Formation (Newhaven Shale, Wanapi Dolomite, and Mount Davenport Diamictite Members) in the sequence.

The thick dark grey to black shale sequence from 1410 to 1858 m is identified at the Rinkabeena Shale, which is considerably thinner (about 100 m) at its type section—20 km east of Davis No. 1. The shale is fairly uniform, except for variations in the proportion of calcareous cement, calcite fracture fillings, and carbonaceous material. A change in the sonic log at 1611 m is probably caused by sandstone intervals.

Precambrian basement rocks penetrated from 1858 m to total depth of 1899 m comprise low-grade metamorphosed orthoquartzite intruded by granite. The quartzite may be part of the Patmungala beds.

Comparison with outcrop and geophysical interpretation

Although the basal Naburula Formation is missing, the sequence of lithological units of the Ngalia Basin penetrated in the well section is otherwise similar to that exposed in the eastern part of the Patmungala Syncline, where the beds have been described around the west-plunging nose of the fold. The thicknesses of some of the units vary considerably between the well section and the measured sections in outcrop. This may have been anticipated because the area around the eastern Patmungala Syncline was undoubtedly a topographic high during deposition of the Adelaidean formations.

The three major reflection horizons present on seismic record sections in the basin have been interpreted (see p. 54) as defining three major divisions of the basin sequence: upper Palaeozoic, lower Palaeozoic, and Adelaidean. The depths to these boundaries correspond reasonably well to the same boundaries interpreted in the well sequence; this correspondence of boundaries justifies th original seismic interpretation.

Reservoir and source rock results

Shallow water reservoirs are present in the Mount Eclipse Sandstone, but otherwise there are no indications of intergranular or other effective porosity in the sequence penetrated in Davis No. 1. A significant gas show occurred in the hole when converting from air to mud drilling for the bottom-hole core, and gas-saturated water was circulated out of the hole. The gas, mainly methane, was probably derived from the thick marine sediments, chiefly the Rinkabeena Shale, below the Mount Eclipse/Kerridy Sandstone interval. It probably originated from fracture porosity, which has been interpreted from the dipmeter survey.

No significant source rocks were found in a study of samples from the interval 945-1893 m, but below 1737 m the organic content increases slightly. A maceral analysis of a sample from 1836 m revealed common sapropelic organic matter which shows a high degree of organic metamorphism, or carbonisation, indicating a post-mature source rock for gas.

Source rock studies of samples from the interval 1789-1826 m indicate an oil-generative source rock. A cross-plot of total organic carbon (0.55%) and extractable organic matter (EOM, 1600 ppm), along with the high saturated value (70.3%) of the EOM, support this conclusion.

More favourable areas for petroleum accumulation may be present in the central and southern parts of the basin, away from the deeper sequences and overthrusts at the northern margin. Even though the attractive thick marine shale sequence is post-mature in Davis No. 1, it may not have been as deeply buried and subjected to excessively high temperatures away from the northern deformed margin. Traps for petroleum accumulation in the central and southern parts of the basin which antedate the Mount Eclipse Orogeny could present more favourable drilling targets.

Acknowledgement

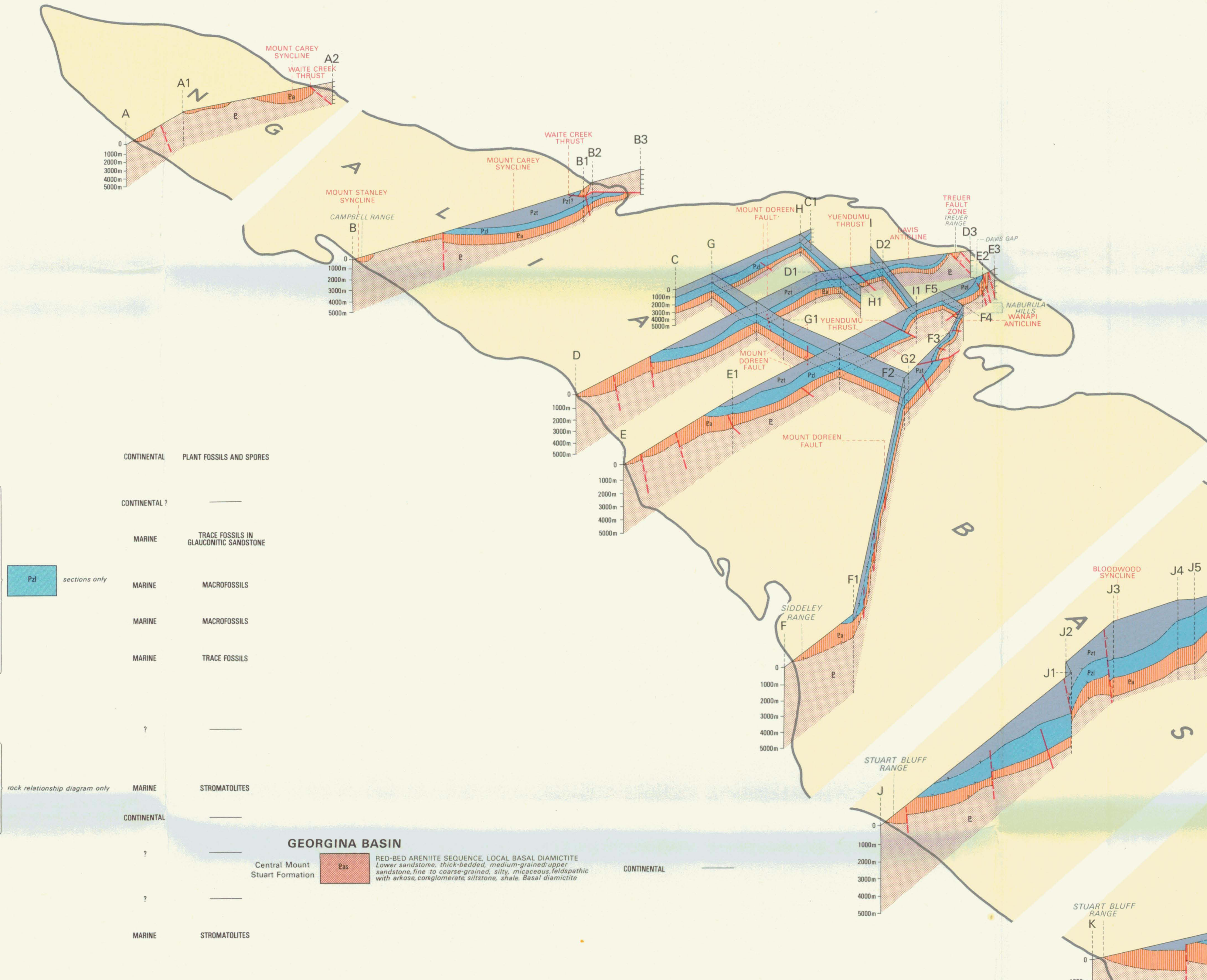
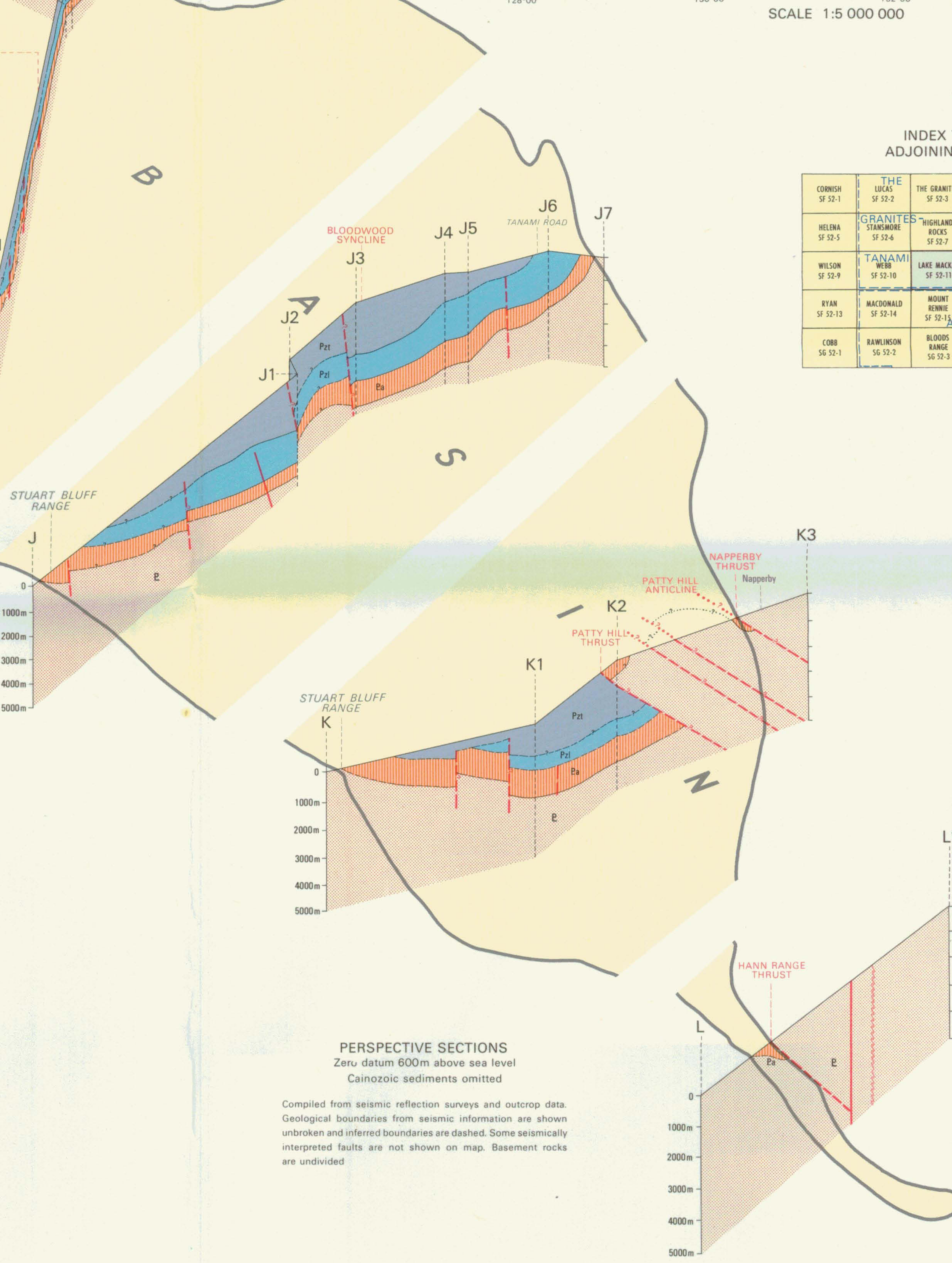
International Oil Proprietary kindly granted permission to publish data from the Davis No. 1 well completion report.

References

BAARDA, F. D., & BUCKINGHAM, I. D., 1982—Well completion report, Davis No. 1, Oil Permit 165, Northern Territory. *Moonie Oil Company Limited and others* (unpublished).

FRENCH, D. J., RIPPERT, J. C., BARRETT, F. M., & STYLES, G. R., 1978—Davis Dome, Ngalia Basin, E.L. 1321, annual report. *Afmeco Pty Limited, Report N.T. 292F* (unpublished).

RIPPERT, J. C., FRENCH, D. J., STYLES, G. R., & BARRETT, F. M., 1979—Ngalia Basin, E.L. 1662, DIN area, annual report. *Afmeco Pty Limited, Report N.T. 294F* (unpublished).

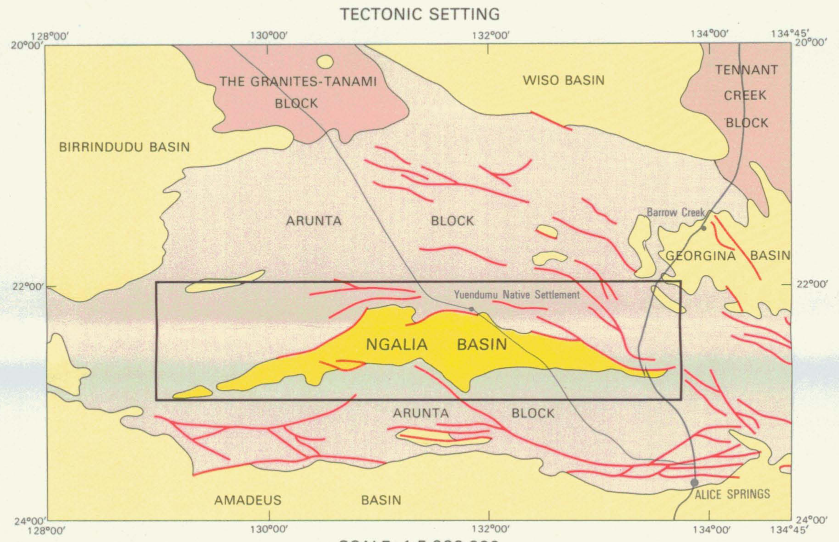



PERSPECTIVE SECTIONS

Zero datum 600m above sea level
Cainozoic sediments omitted

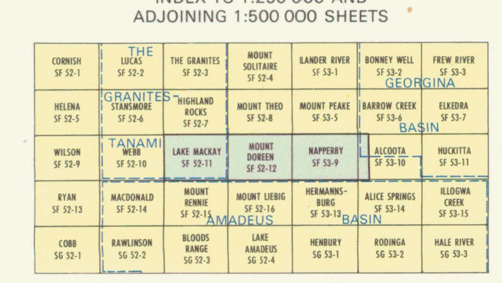
Compiled from seismic reflection surveys and outcrop data. Geological boundaries from seismic information are shown unbroken and inferred boundaries are dashed. Some seismically interpreted faults are not shown on map. Basement rocks are undivided

TECTONIC SETTING



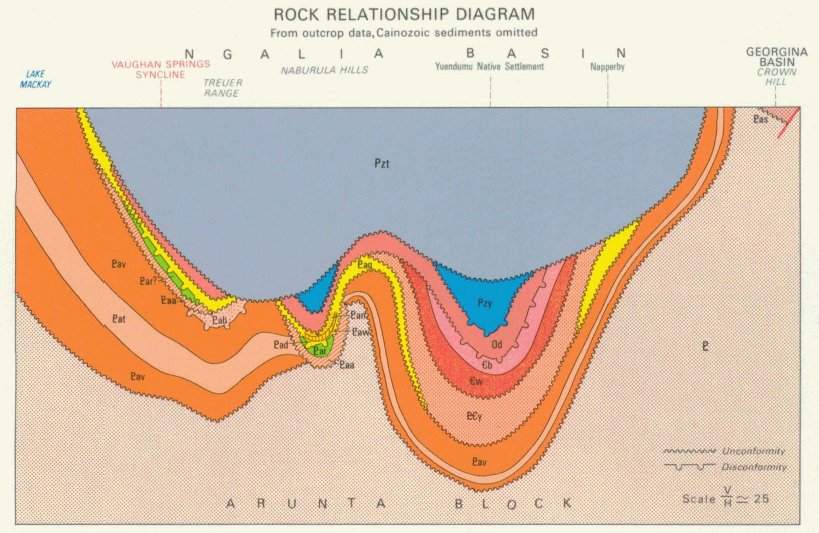
SCALE 1:5 000 000

INDEX TO 1:250 000 AND ADJOINING 1:500 000 SHEETS



ROCK RELATIONSHIP DIAGRAM

From outcrop data, Cainozoic sediments omitted



CAINOZOIC	QUATERNARY		Qa	Alluvium		
			Qs	Aeolian sand		
			Qr	Red soil, alluvium		
			Qe	Sand, evaporites, calcrete		
			Qt	Evaporites		
			Ql	Calcrete		
			Qc	Colluvium		
			Cz	Silcrete, ferricrete		
PALAEOZOIC			Pz	Sandstone		

PHANEROZOIC

NGALIA BASIN SEQUENCE

Age	Unit	Symbol	Description	Environment	Fossils
LATE PALAEOZOIC — DEVONIAN–CARBONIFEROUS	Mount Eclipse Sandstone	Pzt	PEBBLY, ARKOSIC SANDSTONE. *Arkosic, coarse, massive, red-brown sandstone; subgreywacke, cobble and boulder conglomerate; red and green, micaceous siltstone and shale. Plant fossils and spores*	CONTINENTAL	PLANT FOSSILS AND SPORES
ORDOVICIAN OR DEVONIAN	Kerridy Sandstone	Pzy	RED-BROWN, SILTY SANDSTONE. *Red-brown, medium to coarse, silty, arkosic sandstone and subgreywacke; siltstone*	CONTINENTAL ?	———
EARLY PALAEOZOIC — ORDOVICIAN	Djagamara Formation	Od	CLEAN, QUARTZ SANDSTONE. *Grey and white, medium, thick-bedded to laminated, siliceous, clay pellets, glauconitic sandstone; green siltstone. Trace fossils in sandstone*	MARINE	TRACE FOSSILS IN GLAUCONITIC SANDSTONE
CAMBRIAN	Bloodwood Formation	€b	RED-BROWN SILTSTONE. *Red-brown, micaceous siltstone; red sandstone. Marine macrofossils*	MARINE	MACROFOSSILS
CAMBRIAN	Walbiri Dolomite	€w	GREY DOLOMITE. *Grey, thick to massively bedded, pelletal, oolitic, stromatolitic dolomite. Red-brown and grey-green siltstone; pale grey and brown, medium and coarse sandstone. Marine fossils*	MARINE	MACROFOSSILS
	Yuendumu Sandstone	P€y	RED-BROWN SANDSTONE. *Red-brown, fine and coarse, thin to medium-bedded, fissile, silty, micaceous, slumped and cross-bedded sandstone; minor quartzwacke and arkose. Trace fossils*	MARINE	TRACE FOSSILS

Pzl — sections only (Kerridy Sandstone to Yuendumu Sandstone)

Age	Unit	Symbol	Description	Environment	Fossils
PRECAMBRIAN — PROTEROZOIC — ADELAIDEAN		Pa	UNDIVIDED ADELAIDEAN		
	Mount Doreen Formation	Paq	BASAL DIAMICTITE, PINK MARKER DOLOMITE. *Diamictite, dolomite and shale*	?	———
	Newhaven Shale Member	Pan	RED SHALE. *Red shale*		
	Wanapi Dolomite Member	Paw	PINK, LAMINATED DOLOMITE. *Pink, fine, laminated dolomite; pyrite holomorphs, manganese dendrites. Stromatolitic in places*	MARINE	STROMATOLITES
	Mount Davenport Diamictite Member	Pad	DIAMICTITE. *Polymictic diamictite; subrounded, faceted and striated erratics; green matrix, poorly sorted siltstone. Sandstone, sandy dolomite and pebbly sandstone near base*	CONTINENTAL	———
	Rinkabeena Shale	Par	GREEN SHALE. *Green shale; interbedded siltstone*	?	———
	Naburula Formation	Paa	BASAL DIAMICTITE, GREY SHALE AND DOLOMITIC MARKER BEDS. *Shale; dark grey to black, minor siltstone; diamictite, polymictic, subrounded, faceted and striated erratics; green-brown matrix, poorly sorted siltstone; green-grey and dark brown, fine, thin-bedded dolomite*	?	———
	Albinia Formation	Pab	SILTSTONE AND SHALE. *White, thin-bedded, dolomitic in part, siltstone and shale; pale grey, foetid, stromatolitic dolomite with black chert beds*	MARINE	STROMATOLITES
	Vaughan Springs Quartzite	Pav	WHITE AND PINK ORTHOQUARTZITE. *Pink to white, massive to thick-bedded orthoquartzite; white, friable, quartz arenite; pebble and boulder conglomerate; shale*	CONTINENTAL AND MARINE	GLAUCONITIC
	Treuer Member	Pat	WHITE SILTSTONE IN LOWER PART OF FORMATION. *White to grey, thin to poorly bedded siltstone, grey chert nodules and evaporite efflorescences; white to grey, laminated to thin-bedded sandstone, micaceous, glauconitic clay pellets*		

rock relationship diagram only (Newhaven Shale Member to Mount Davenport Diamictite Member)

GEORGINA BASIN

Central Mount Stuart Formation	Pas	RED-BED ARENITE SEQUENCE, LOCAL BASAL DIAMICTITE. *Lower sandstone, thick-bedded, medium-grained; upper sandstone, fine to coarse-grained, silty, micaceous, feldspathic with arkose, conglomerate, siltstone, shale. Basal diamictite*	CONTINENTAL	———

ARUNTA BLOCK

EARLY AND MIDDLE PROTEROZOIC — BASEMENT ROCKS		P	*Undivided*
		Pg	*Granite, granodiorite, orthogneiss*
	Patmungala beds	Pp	*Sandstone and quartzite; siltstone; chert, pebble conglomerate and recrystallised tuff, may be a correlative of Pq*
		Pq	*Moderately metamorphosed orthoquartzite, shale, siltstone, dolomite; minor arkose and conglomerate; acid igneous sills. Highly metamorphosed in east*
		Pm	*Moderately metamorphosed micaceous sandstone, shale, calc-silicate and basic rocks. Highly metamorphosed in east*
		Pr	*Mafic and felsic granulites; pelitic granulite and gneiss; subordinate amphibolite and charnockite*

Geological boundary
Anticline } showing trend of plunge
Syncline
Overturned syncline
Fault (q — indicates quartz filled)
Thrust fault (triangle, on upthrow side, indicates direction of dip)
Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries and folds are dotted, faults are shown by short dashes
Sheared zone
Strike and dip of strata
Strike and dip of strata, facing not known
Vertical strata
Horizontal strata
Strike and dip of overturned strata
Strike and dip of strata, dip less than 5° } airphoto interpretation
Strike and dip of strata, dip 5°–15°
Strike and dip of strata, dip 15°–45°
Strike and dip of strata, dip greater than 45°
Trend-line
Lineament
Joint pattern
Prevailing strike and dip of foliation
Vertical foliation
Strike of foliation, dip not determined
Macrofossil locality
Plant fossil locality
Dyke or vein; amph — amphibolite, apl — aplite, dl — dolerite, dr — diorite, peg — pegmatite, q — quartz

• Ky	Minor mineral or rock occurrence
	Prospect
	Mine not being worked
	Quarry or open cut
	Quarry or open cut, not being worked
Ag	Silver
Am	Amethyst
Au	Gold
Ba	Barite
Bs	Building stone
Cr	Chromium
Cu	Copper
Fe	Iron
Fl	Fluorite
He	Hematite
Korn	Kornerupine
Ky	Kyanite
Nb	Niobium
Ni	Nickel
Pb	Lead
Rc	Crushed rock aggregate
Rq	Rose quartz
Sa	Sapphirine
Sn	Tin
Staur	Staurolite
Ta	Tantalum
U	Uranium
W	Tungsten

DD	Diamond - drillhole
SH	Scout hole
St	Stratigraphic hole, BMR; MD — Mount Doreen, N — Napperby
	Bore
	Bore with windpump
	Well
	Well with windpump
E	Earth tank
WH	Waterhole
RH	Rockhole
	Spring
	Sand dunes
	Highway
	Secondary road
	Minor road
	Vehicle track
	Telephone line
Mount Doreen	Homestead
	Building
	Landing ground
	Trigonometrical station
943	Elevation in metres
abd	Abandoned
pd	Position doubtful

LOCALITY MAP

GEOLOGY OF THE NGALIA BASIN

NORTHERN TERRITORY

1981

SCALE 1:500 000

10 0 10 20 30 40 50 KILOMETRES

Transverse Mercator Projection

Geology of Ngalia Basin 1967-69 by A.T. Wells, T.G. Evans, T. Nicholas
Geology of Arunta Block 1967-69 by A.T. Wells, T.G. Evans, T. Nicholas
1971-76 by A.J. Stewart, L.A. Offe, A.Y. Glikson, R.G. Warren
Compiled 1978-79 by A.T. Wells, R.A. Chan
Sections compiled by F.J. Moss, A.T. Wells, R.A. Chan
Edited by G.W. D'Addario, A.S. Mikolajczak
Design and drafting by Cartography Section, BMR
Drawn by G.A. Young

Printed by Mercury-Walch, Hobart, Australia

Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development and Energy. Issued under the authority of the Minister for National Development and Energy. Base map compiled by BMR from 1:250 000 Planimetric Series of the Division of National Mapping, Department of National Development and Energy

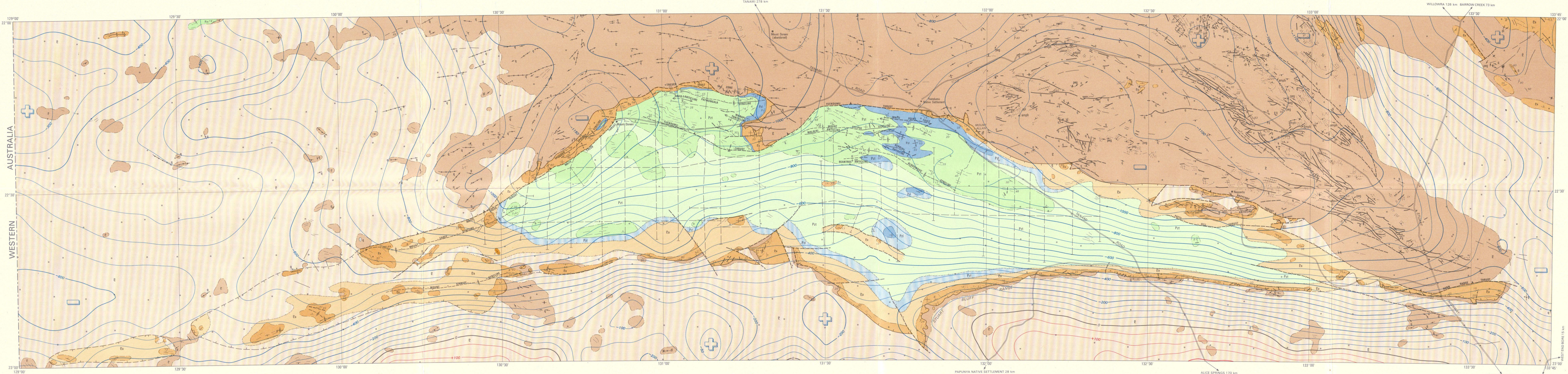
GEOLOGY OF THE NGALIA BASIN

1:500 000

PLATE 2

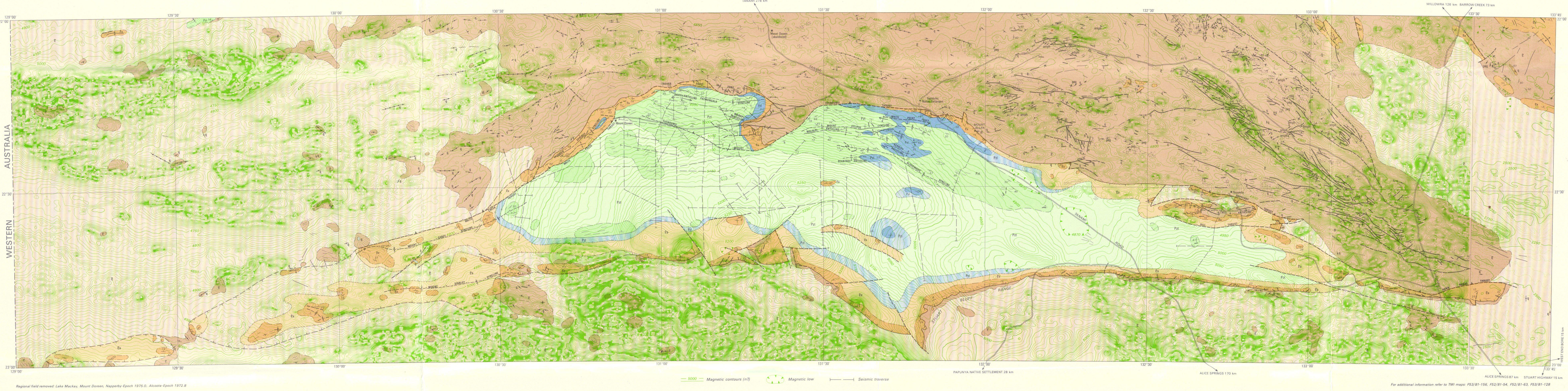
BOUGUER ANOMALY CONTOURS

Contour Interval: 50 μm s⁻² Bouguer Density: 2.67g cm⁻³



TOTAL MAGNETIC INTENSITY CONTOURS

Contour Interval: 10nT



SEISMIC STRUCTURE CONTOURS

Contour Interval: 100 m Datum: 600m above sea level

HORIZON A – NEAR BASE MOUNT ECLIPSE SANDSTONE

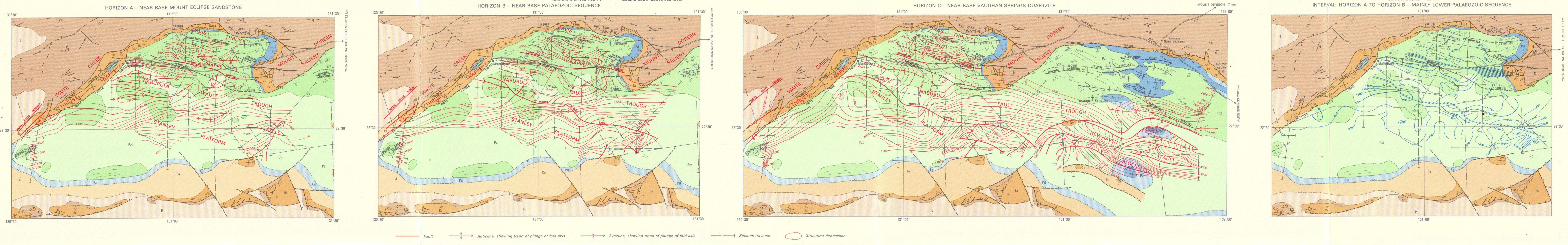
HORIZON B – NEAR BASE PALAEOZOIC SEQUENCE

HORIZON C – NEAR BASE VAUGHAN SPRINGS QUARTZITE

ISOPACHS (from seismic structure contours)

Contour Interval: 100 m

INTERVAL: HORIZON A TO HORIZON B – MAINLY LOWER PALAEOZOIC SEQUENCE



SEISMIC REFLECTION TIME CONTOURS

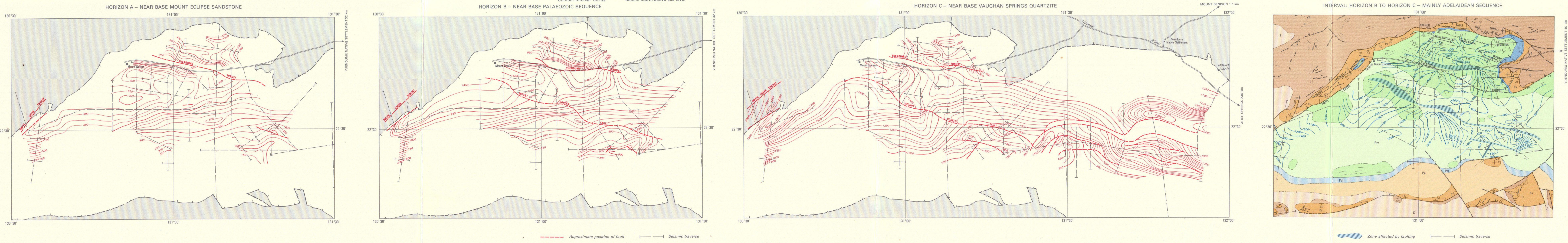
Contour Interval: 50 ms Datum: 600m above sea level

HORIZON A – NEAR BASE MOUNT ECLIPSE SANDSTONE

HORIZON B – NEAR BASE PALAEOZOIC SEQUENCE

HORIZON C – NEAR BASE VAUGHAN SPRINGS QUARTZITE

INTERVAL: HORIZON B TO HORIZON C – MAINLY ADELAIDEAN SEQUENCE



AUSTRALIA

STRUCTURE OF THE NGALIA BASIN

NORTHERN TERRITORY

1981

SCALE 1:500 000

Transverse Mercator Projection

Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development and Energy. Issued under the authority of the Minister for National Development and Energy

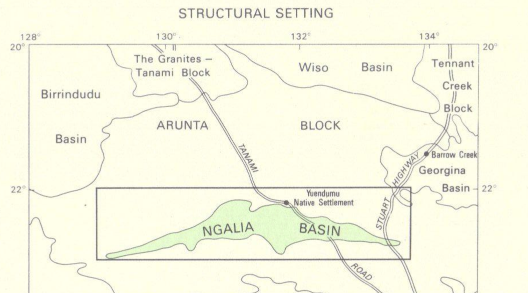
Ngalia Basin solid geology and structure by A.T. Wells
Bouguer Anomaly Contours and Total Magnetic Intensity Contours compiled by Geophysical Branch BMR, Canberra ACT
Structure Contours, Seismic Reflection Time Contours and Isopachs interpreted by F.J. Moss and A.T. Wells
Compiled 1979 by A.T. Wells, F.J. Moss, R.A. Chan
Edited by G.W. D'Addario, A.S. Mikolajczak
Design by Cartography Section, BMR
Drawn by R.L. Melsom
Printed by Mercury-Walch, Hobart, Australia

Bouguer anomaly contours and TMI contours scribed on a Calcomp 745 flat-bed plotter.

NGALIA BASIN SEDIMENTARY SEQUENCES

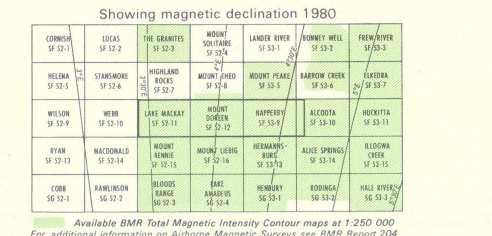
- Pzt Late Palaeozoic rocks: generalised outcrop
- Late Palaeozoic rocks: presumed extent
- Pzl Early Palaeozoic rocks: generalised outcrop
- Early Palaeozoic rocks: presumed extent

STRUCTURAL SETTING

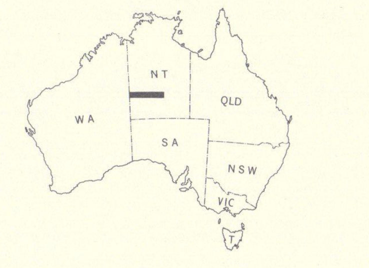


INDEX TO 1:250 000 SHEETS

Showing magnetic declination 1980

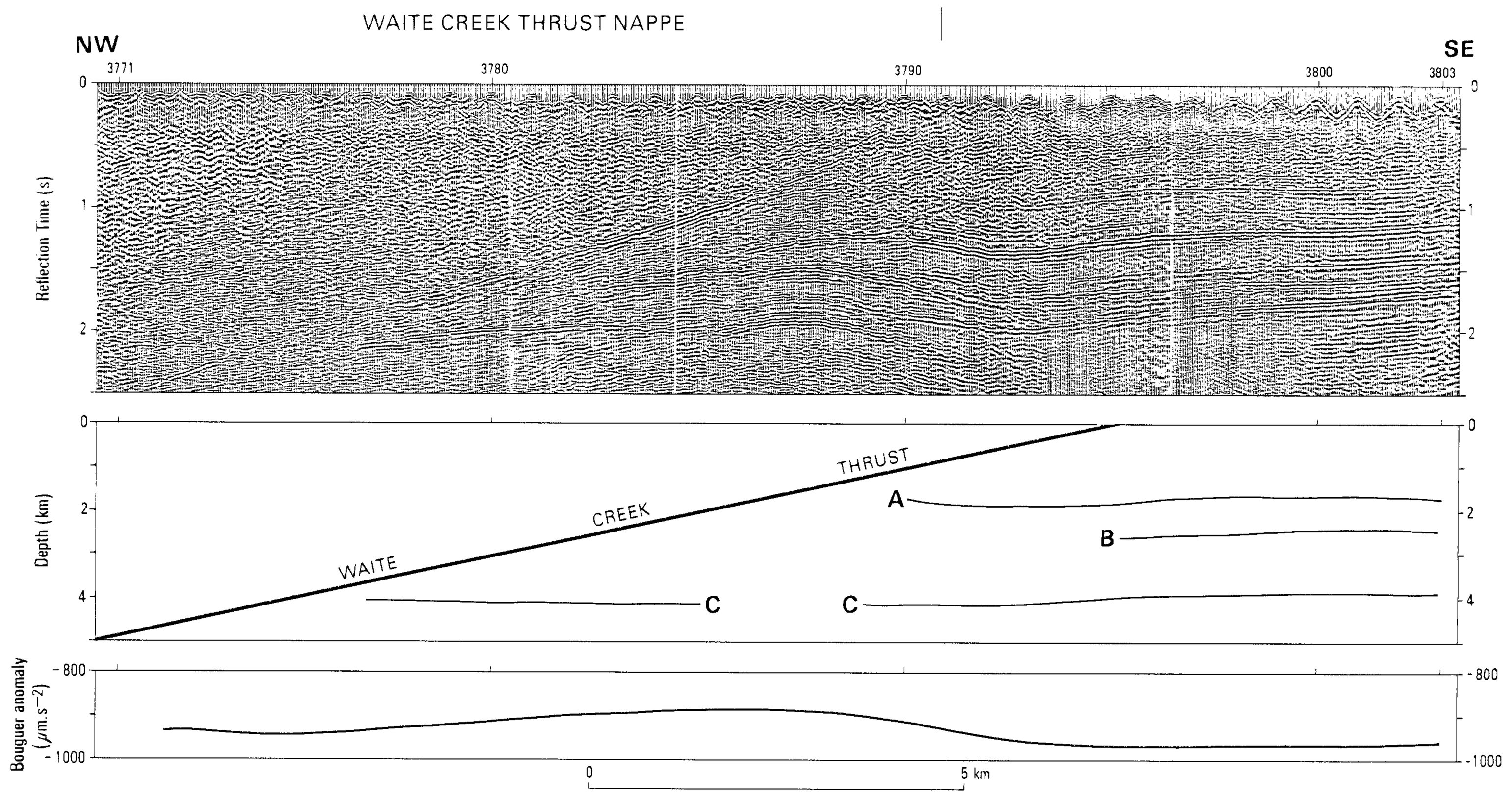


LOCALITY MAP



STRUCTURE OF THE NGALIA BASIN 1:500 000

TRAVERSE K



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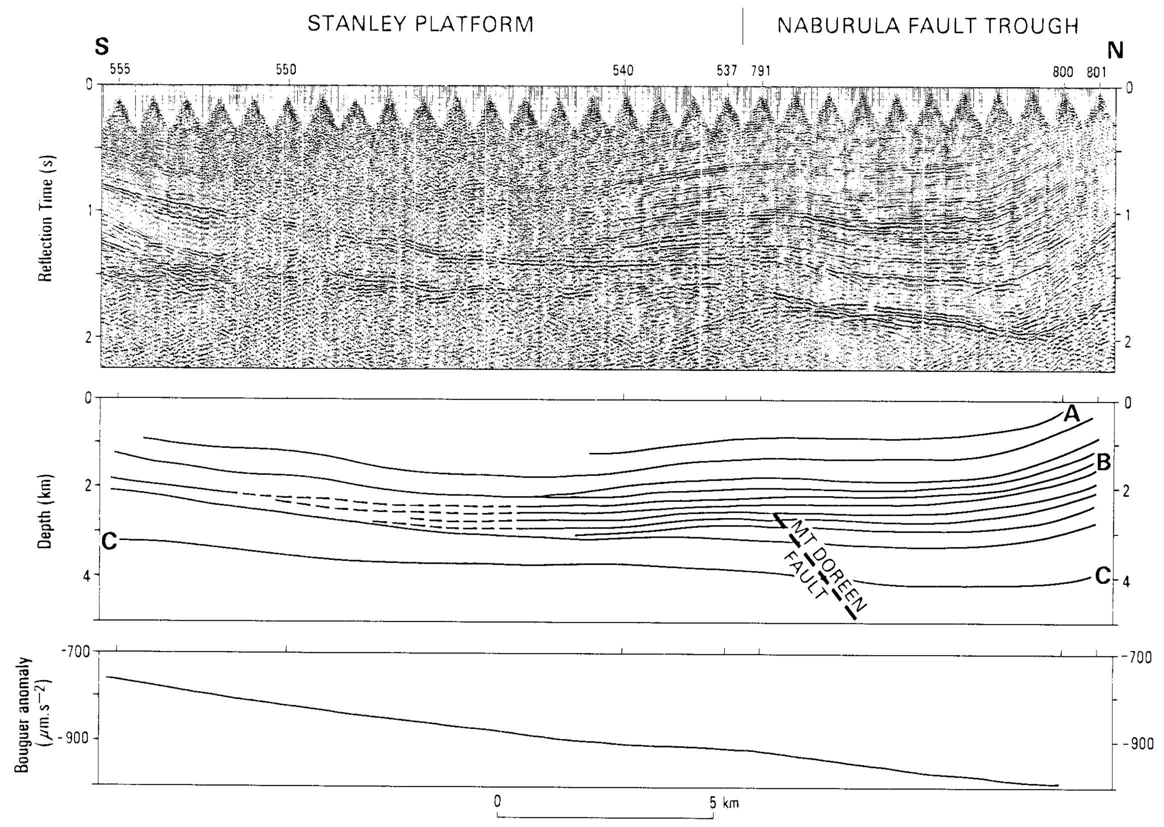

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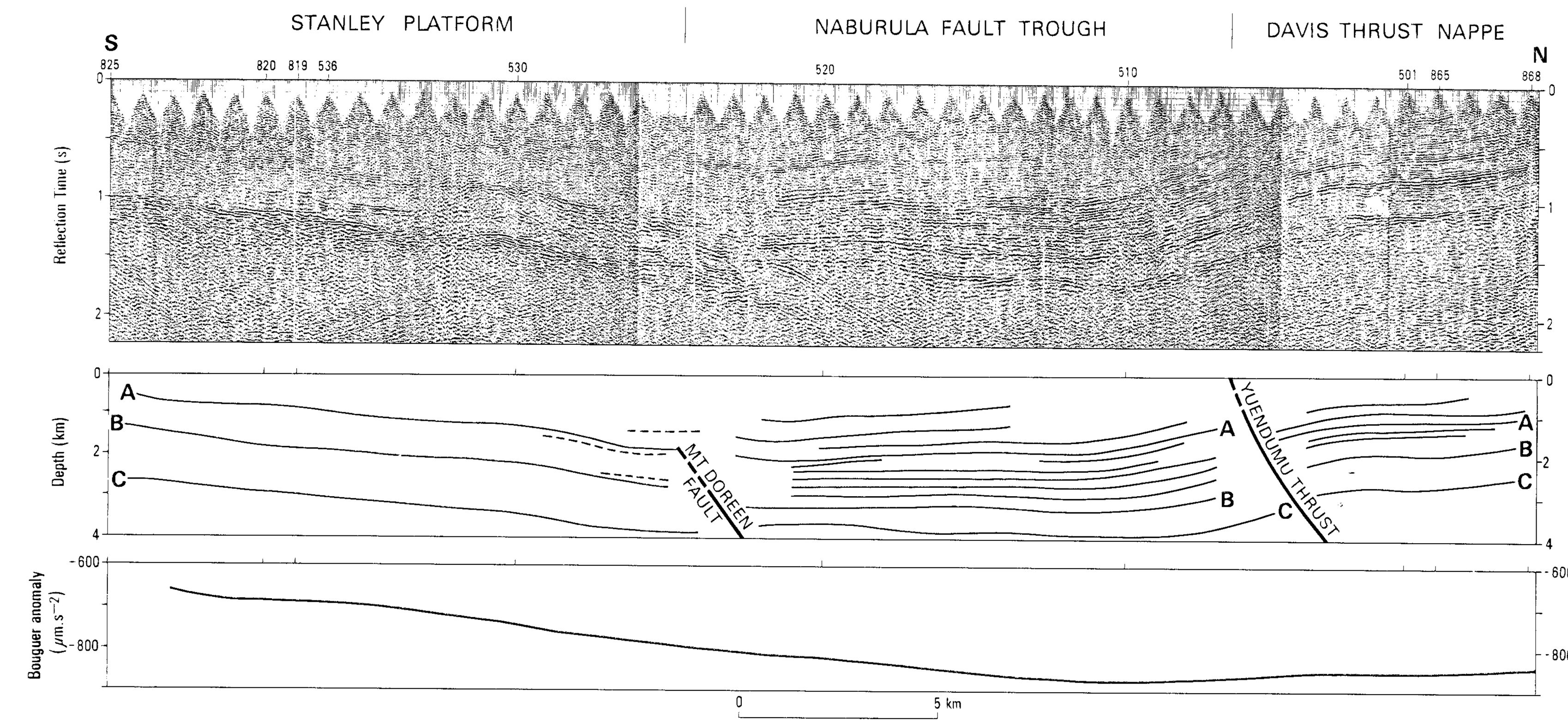

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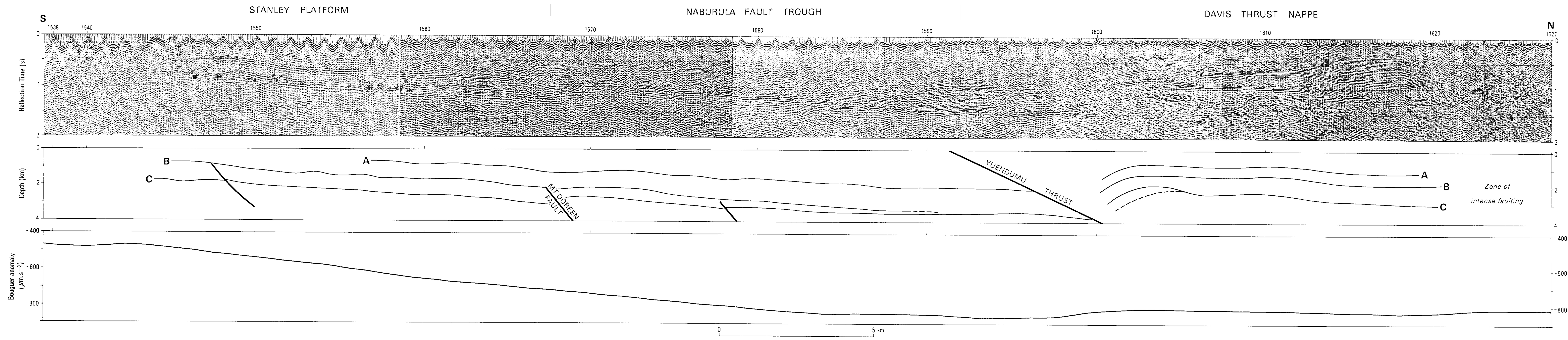

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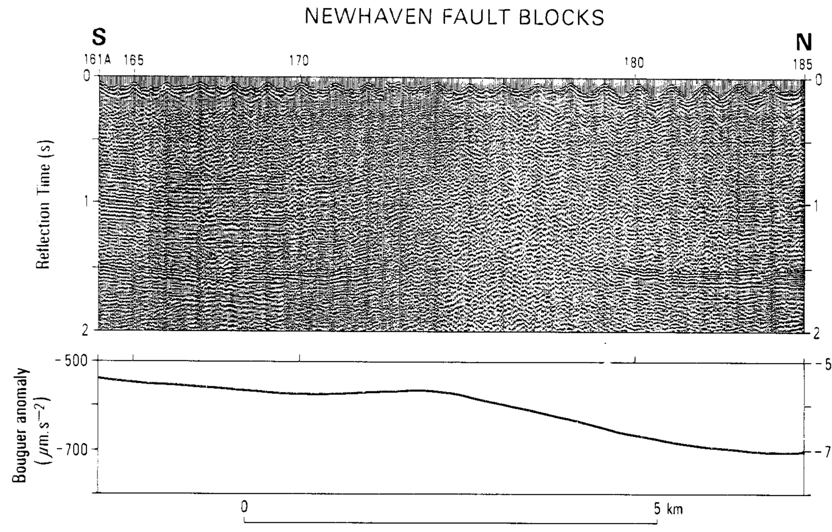
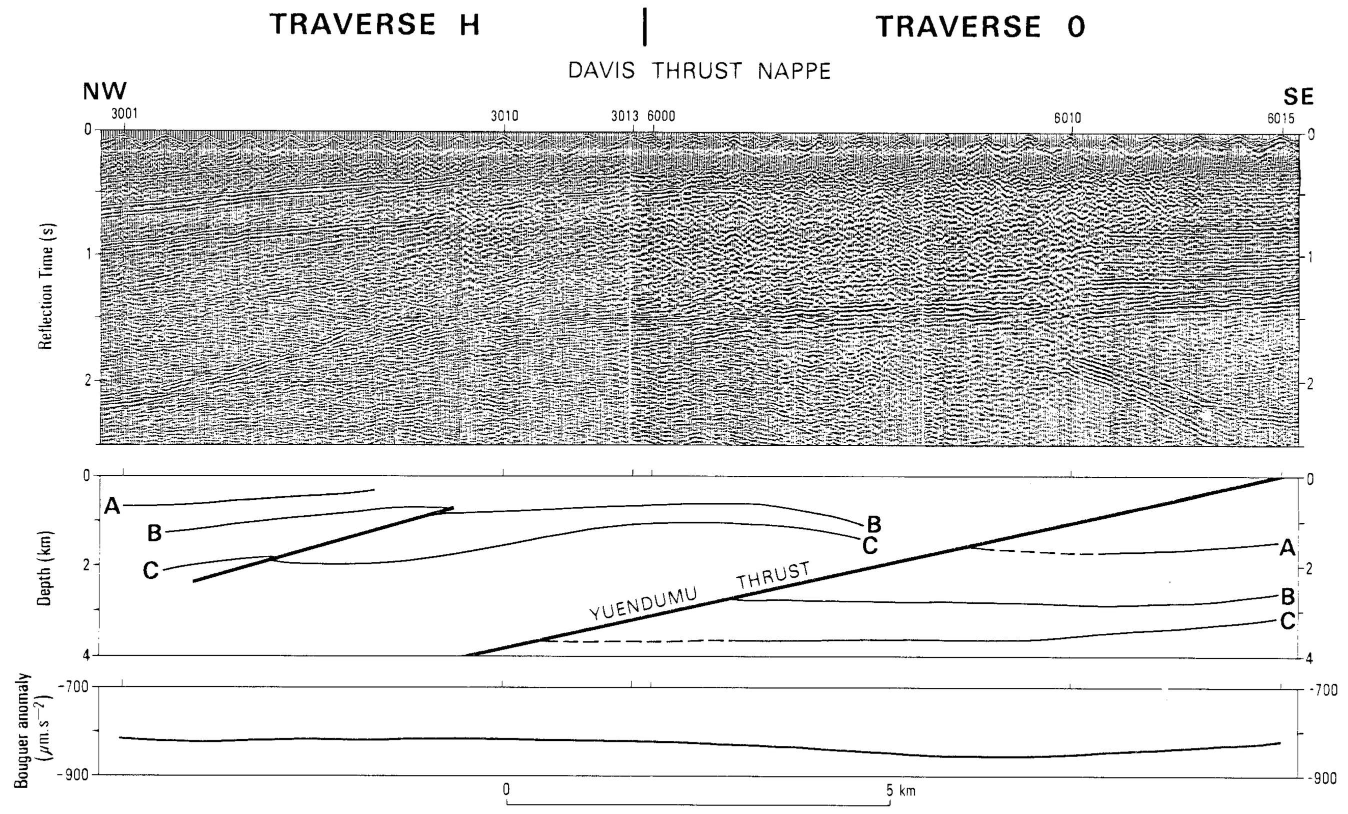
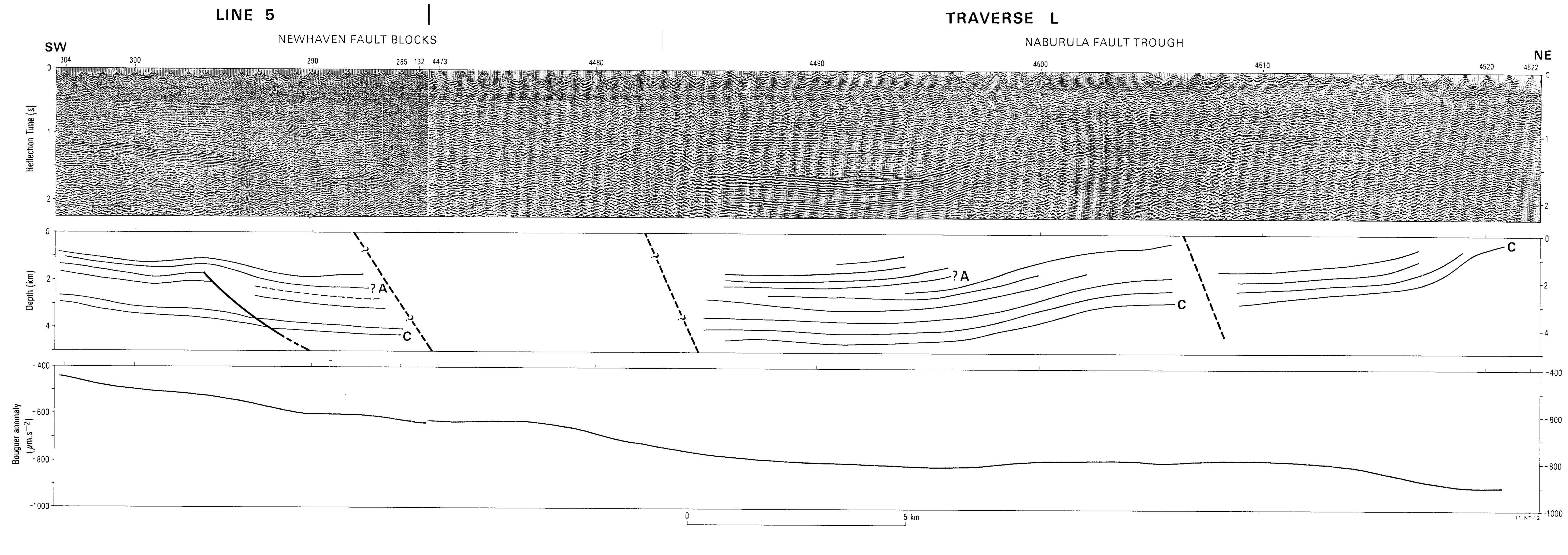


TRAVERSE H | TRAVERSE O



LINE 5 | TRAVERSE L



SEISMIC SECTIONS
AND
GRAVITY PROFILES

NGALIA BASIN

SYMBOLS USED ON MEASURED SECTIONS

Lithology

- Sandstone:
  - *fine*
  - *medium*
  - *coarse*
- *Siltstone*
- *Claystone*
- *Shale*
- *Dolomite*
- *Conglomerate*
- *Infraformational breccia*
- *Diamictite, erratics*

Bedding thickness

- *Massive (>100 cm)*
- *Thick (30-100 cm)*
- *Medium (10-30 cm)*
- *Thin (1-10 cm)*
- *Laminated (< 1cm)*

Sedimentary structure

- *Graded lamination*
- *Cross-bedding*
- *Thin cross-bedding*
- *Medium cross-bedding*
- *Slumped bedding*
- *Unconformity*
- *Ripples, undifferentiated*
- *Ripples, asymmetrical*
- *Ripples, symmetrical*
- *Clay, mud pellets*
- *Load cast*
- *Flute mould, cast*
- *Current crescents*
- *Tracks and trails*
- *Macrofossils*

ABBREVIATIONS USED ON MEASURED SECTIONS

Mineralogy and Lithology

Ark(ark)	*Arkose(ic)*
Cy(cy)	*Clay(ey)*
Cgl	*Conglomerate*
Do (do)	*Dolomite (ic)*
Fs (fs)	*Feldspar (thic)*
Gl (gl)	*Glauconite (ic)*
Hem (hem)	*Hematite (ic)*
Fe (fer)	*Iron oxide (ferruginous)*
Kao (kao)	*Kaolin (itic)*
Lim	*Limonite*
Mn	*Manganese*
Mi (mi)	*Mica (ceous)*
Oqt	*Orthoquartzite*
Q (qc)	*Quartz (itic)*
Qt	*Quartzite*
Sst	*Sandstone*
Sh	*Shale*
Si (si)	*Silica (eous)*
Sltst	*Siltstone*

Qualifier

dk	*Dark*
lt	*Light*
sli	*Slight*

Colour

bk	*Black*
bl	*Blue*
br	*Brown*
choc	*Chocolate*
cr	*Cream*
gn	*Green*
gy	*Grey*
og	*Orange*
pk	*Pink*
pu	*Purple*
r	*Red*
wh	*White*
y	*Yellow*

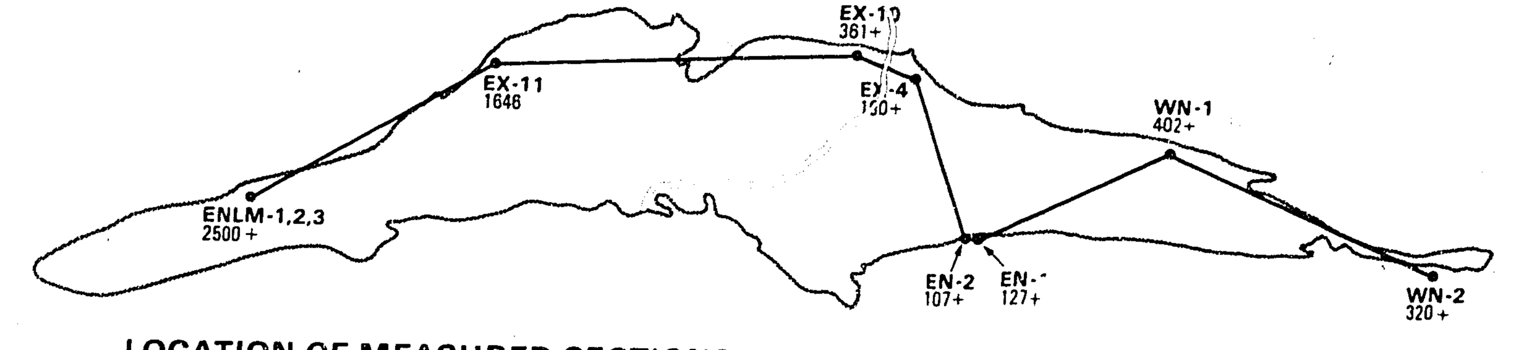
Grainsize

vf	*Very fine*
f	*Fine*
m	*Medium*
c	*Coarse*
vc	*Very coarse*

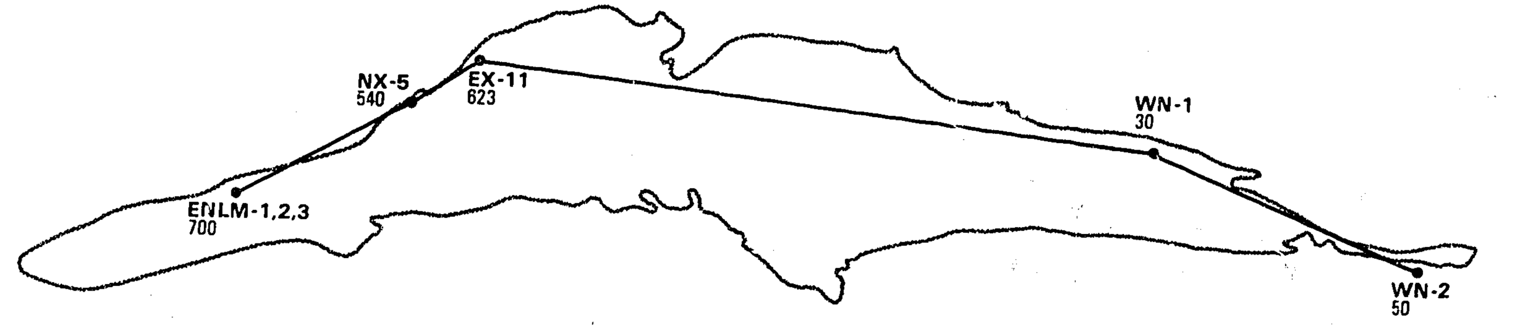
11/NT 36-1

MS - 1

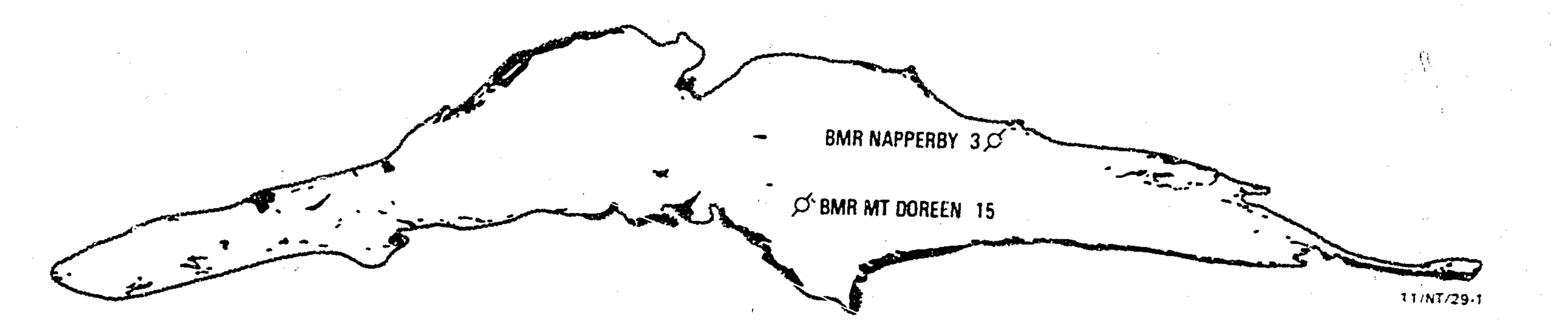
MEASURED SECTIONS IN THE VAUGHAN SPRINGS QUARTZITE



LOCATION OF MEASURED SECTIONS IN THE VAUGHAN SPRINGS QUARTZITE

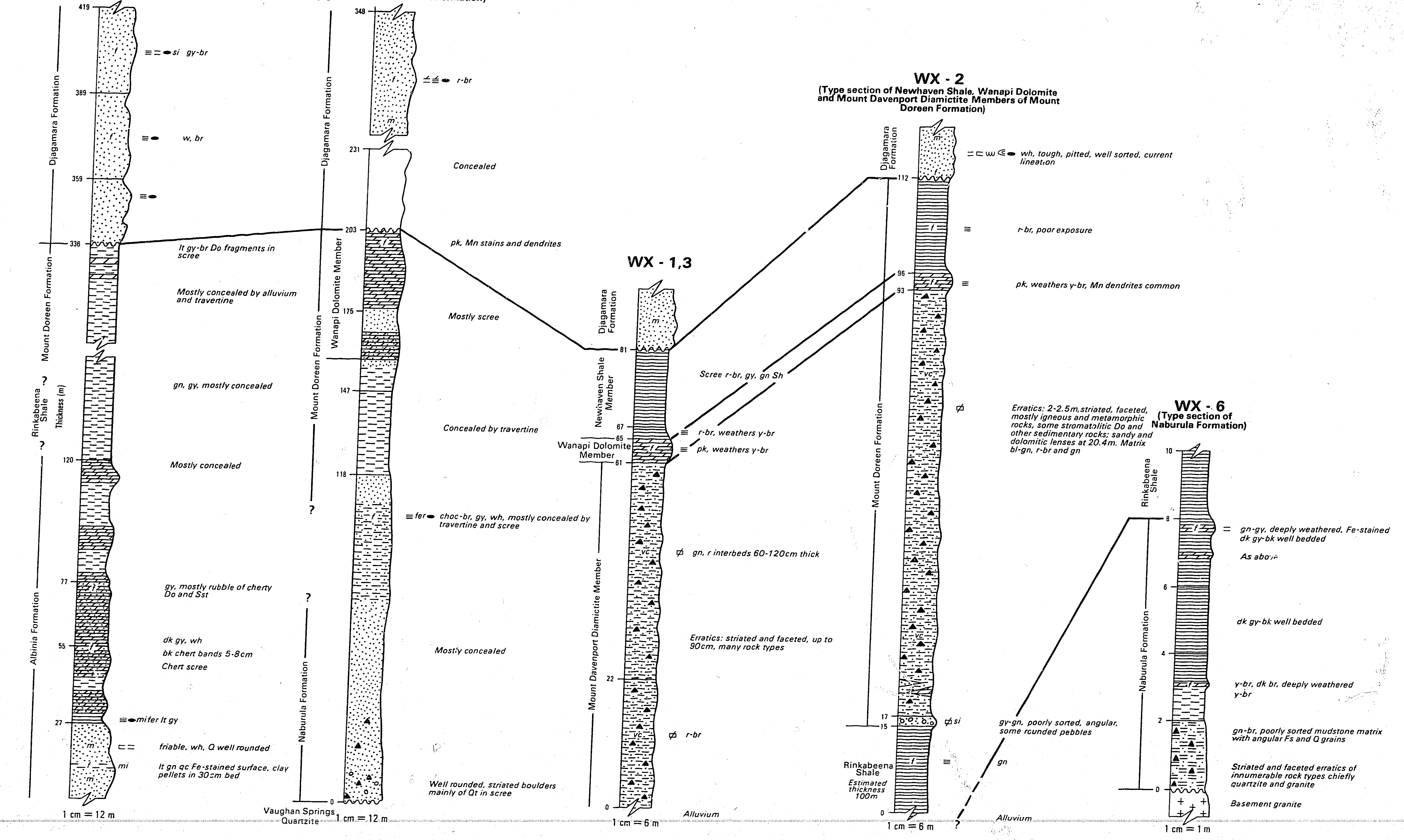


LOCATION OF MEASURED SECTIONS IN THE TREUER MEMBER OF THE VAUGHAN SPRINGS QUARTZITE

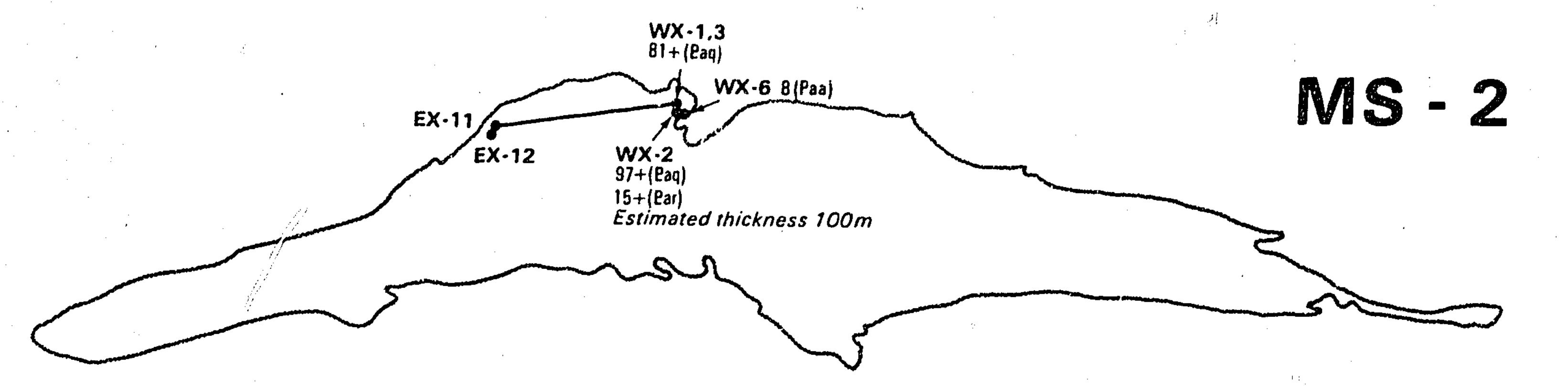


DISTRIBUTION OF VAUGHAN SPRINGS QUARTZITE

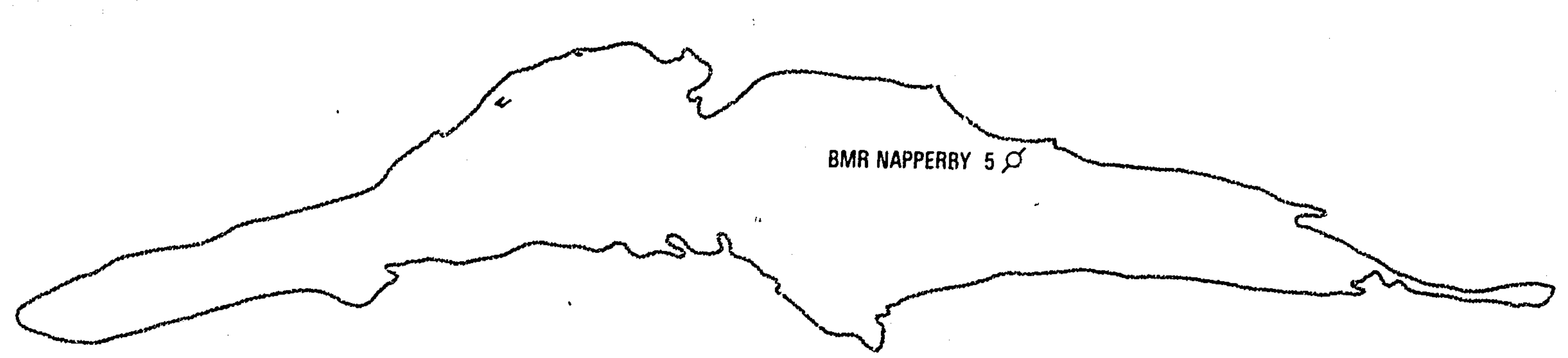
MEASURED SECTIONS IN THE ALBINIA AND NABURULA FORMATIONS, RINKABEENA SHALE, MOUNT DOREEN FORMATION



MS - 2

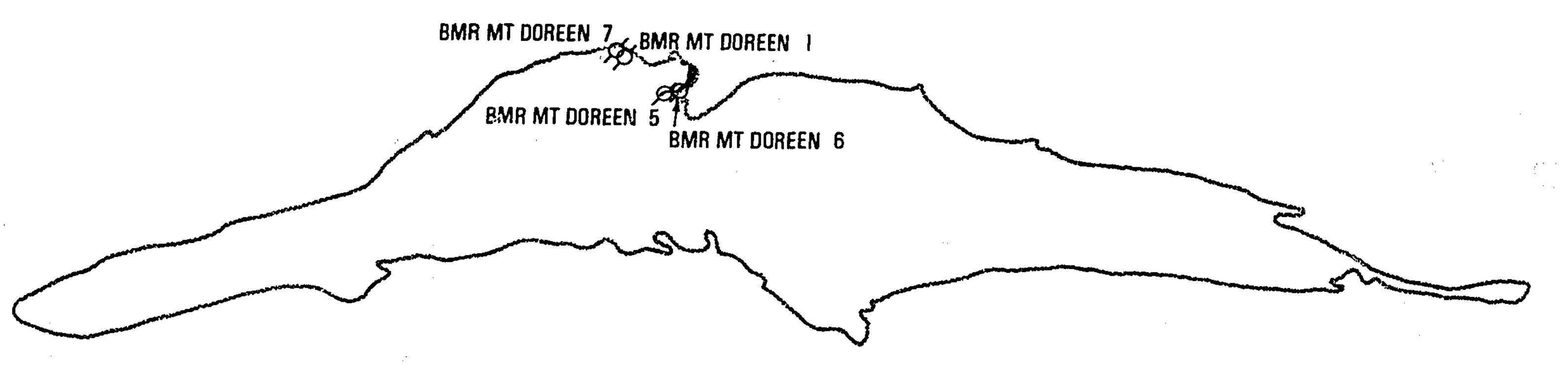


LOCATION OF MEASURED SECTIONS IN THE ALBINIA AND NABURULA FORMATIONS, RINKABEENA SHALE, MOUNT DOREEN FORMATION

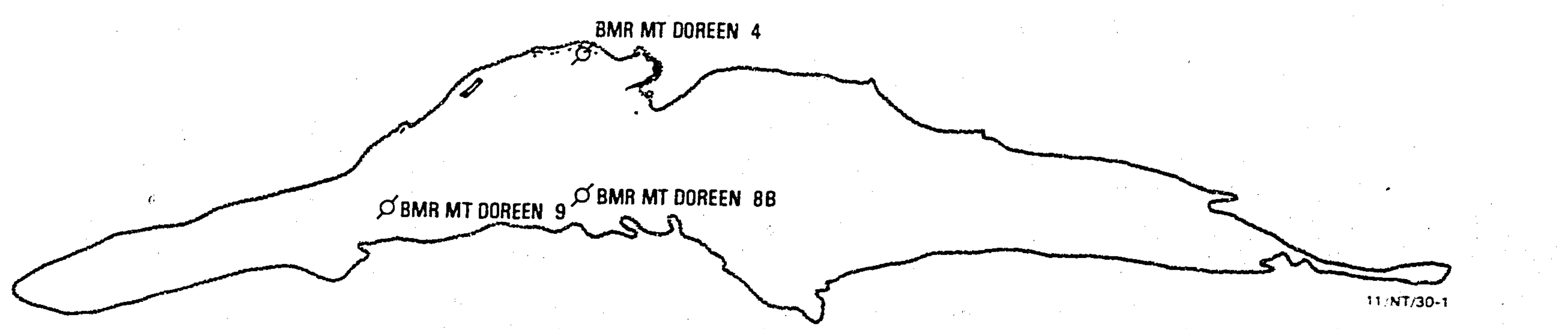


DISTRIBUTION OF ALBINIA FORMATION

DISTRIBUTION OF NABURULA FORMATION



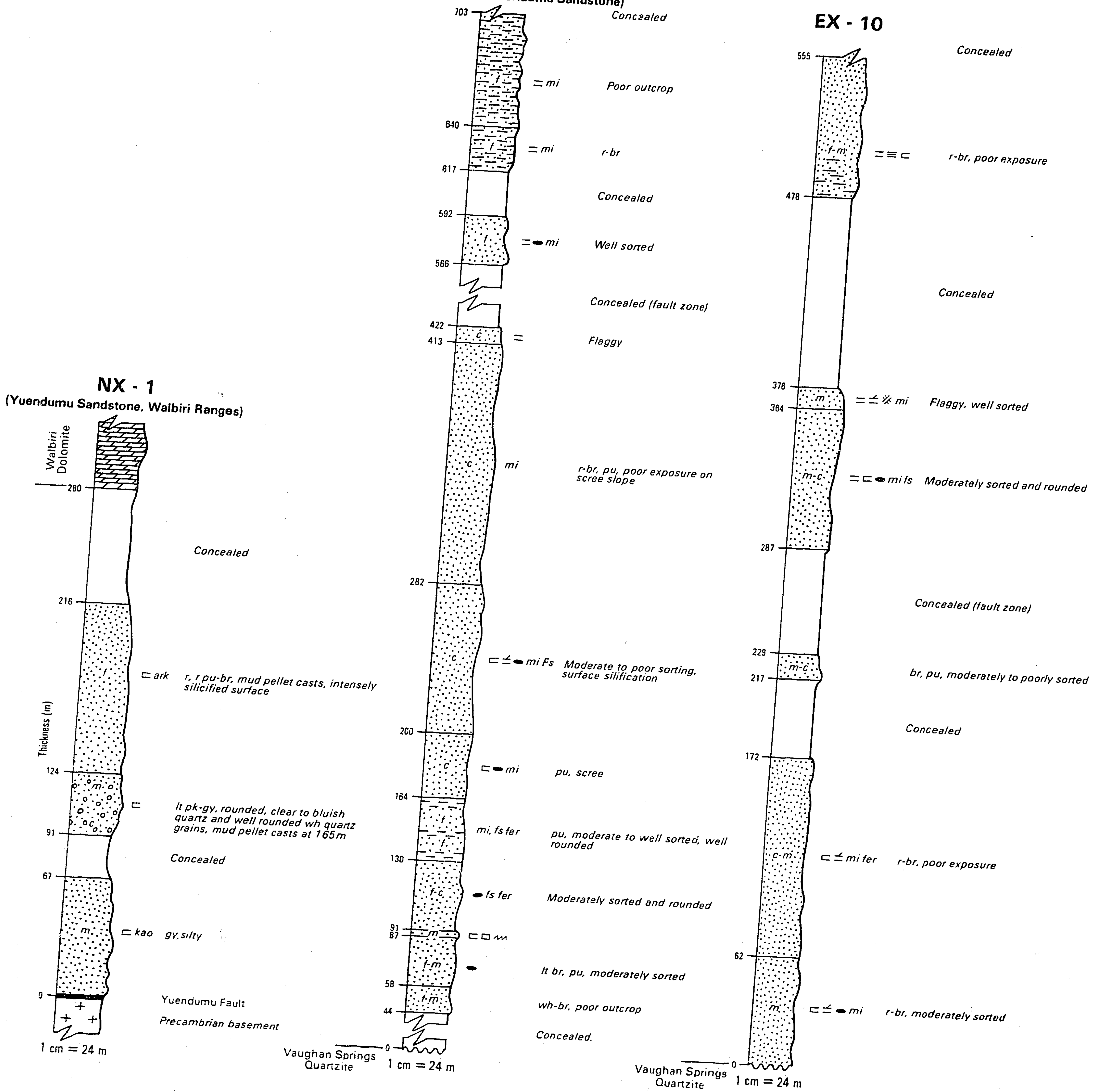
DISTRIBUTION OF RINKABEENA SHALE

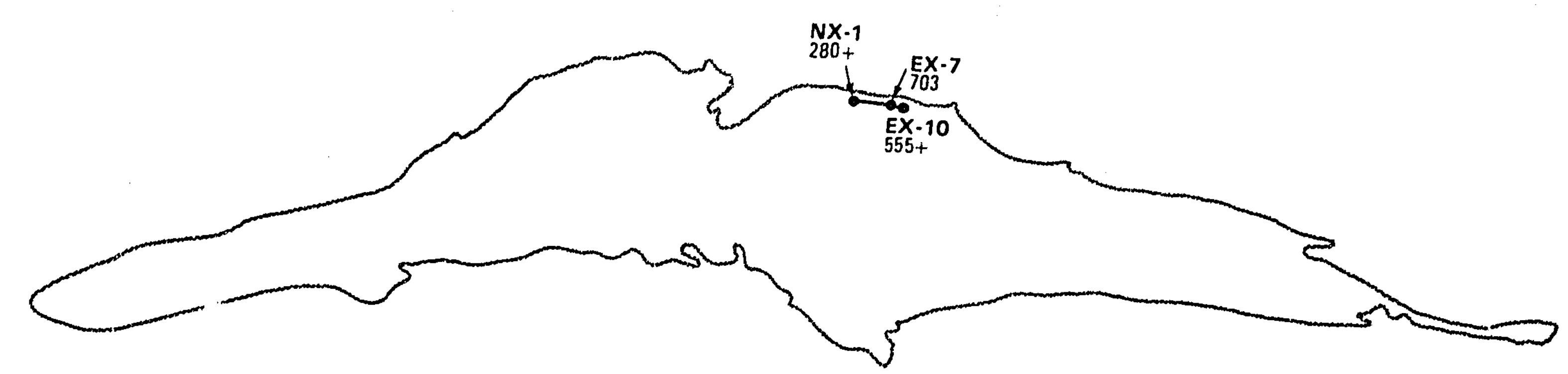


DISTRIBUTION OF MOUNT DOREEN FORMATION

MS - 3

MEASURED SECTIONS IN THE YUENDUMU SANDSTONE



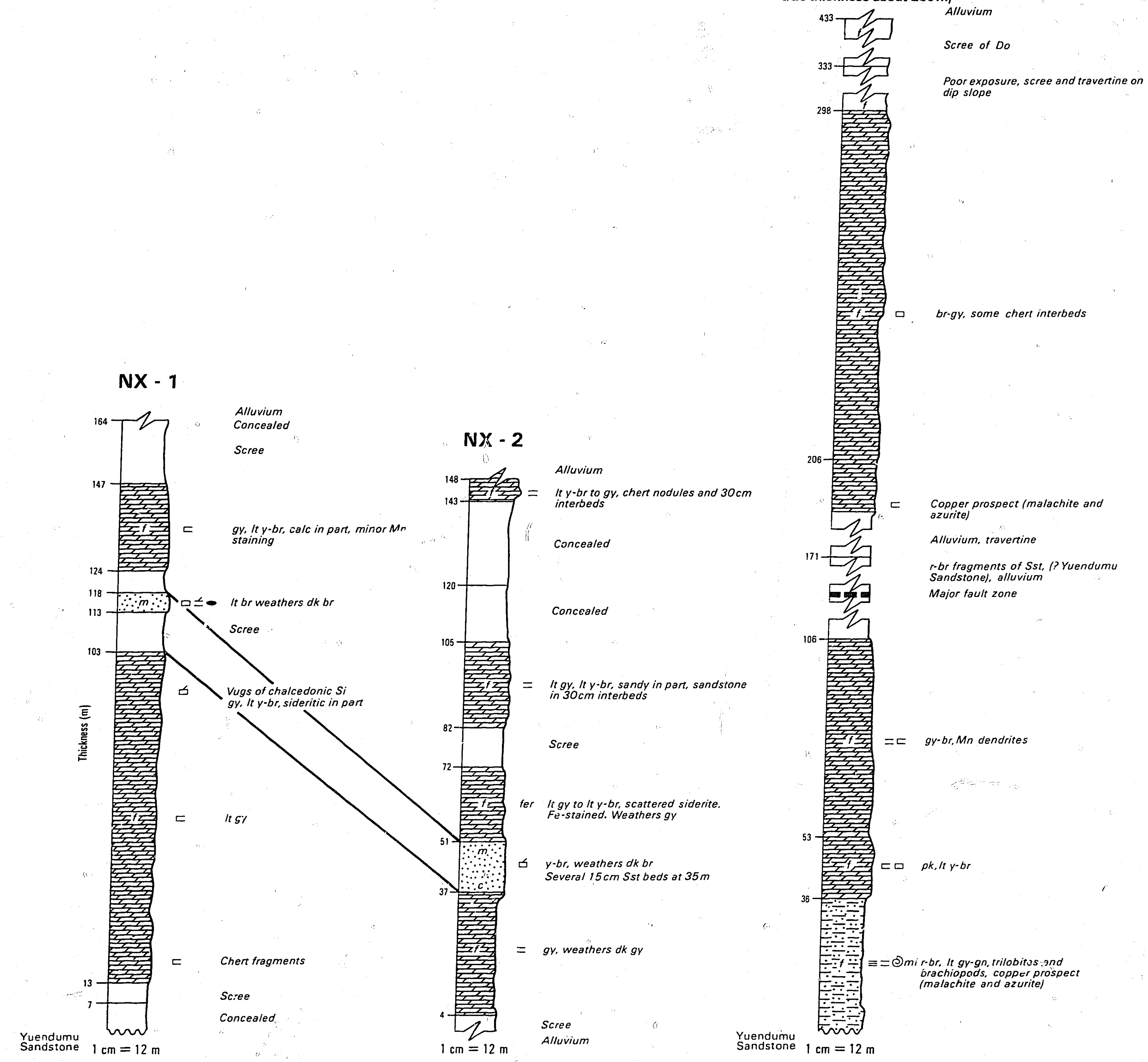


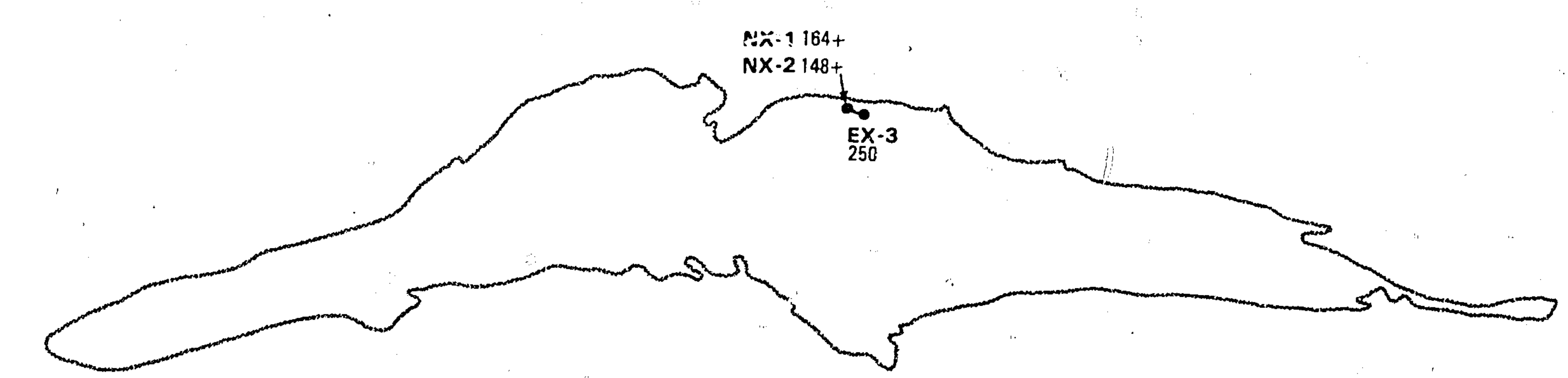
LOCATION OF MEASURED SECTIONS IN THE YUENDUMU SANDSTONE

DISTRIBUTION OF YUENDUMU SANDSTONE

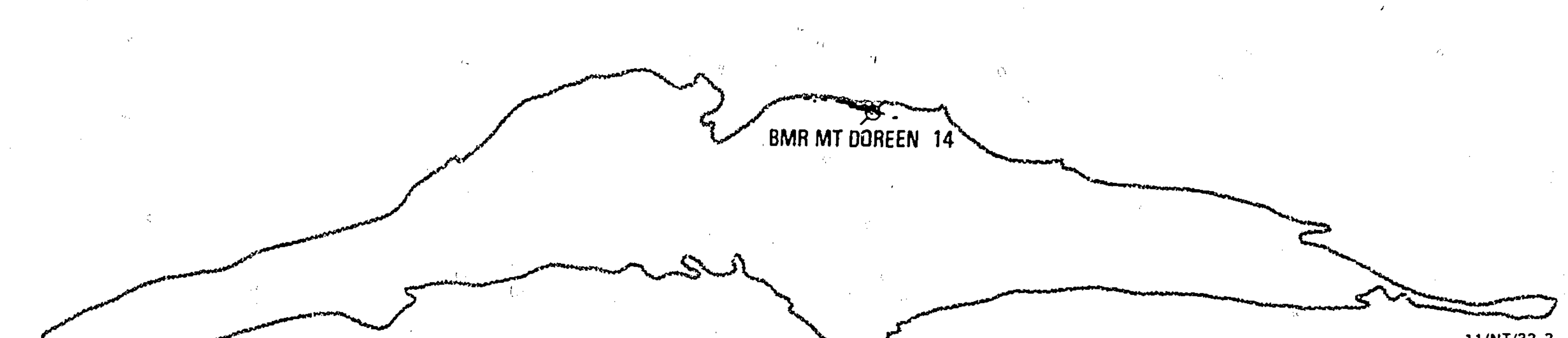
MS - 4

MEASURED SECTIONS IN THE WALBIRI DOLOMITE





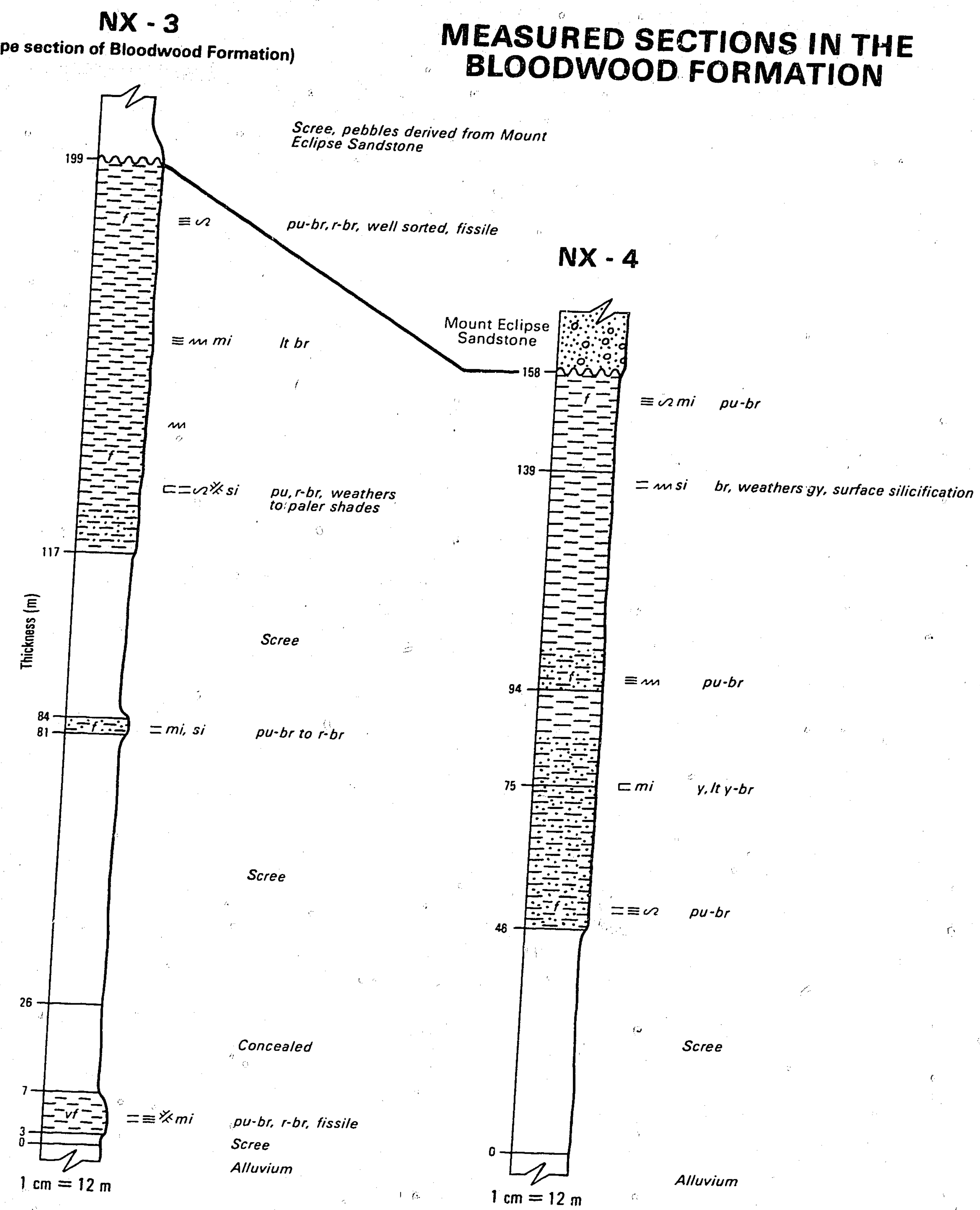
LOCATION OF MEASURED SECTIONS IN THE WALBIRI DOLOMITE

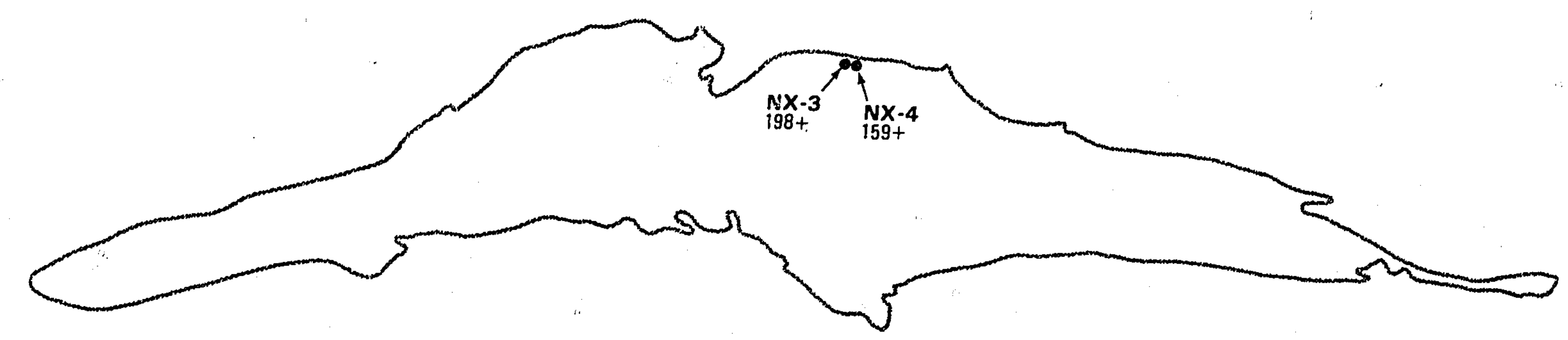


DISTRIBUTION OF WALBIRI DOLOMITE

MEASURED SECTIONS IN THE BLOODWOOD FORMATION

MS - 5



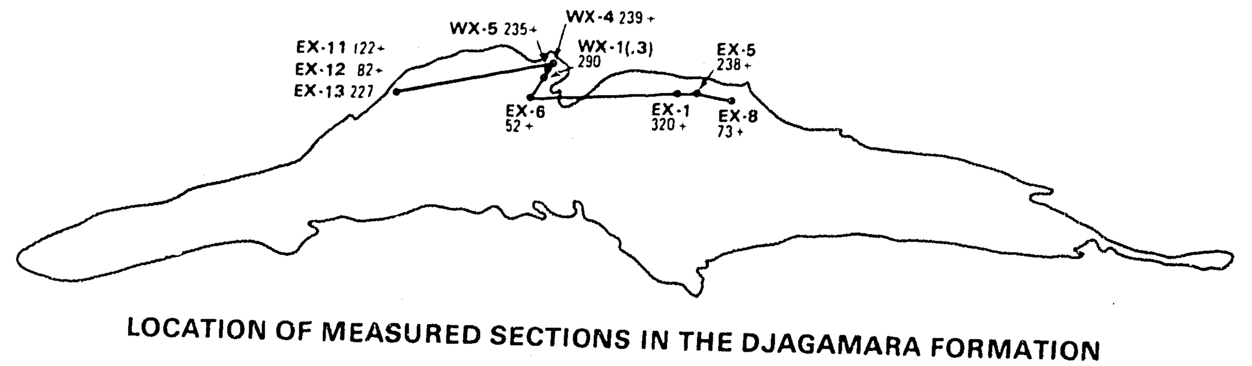


LOCATION OF MEASURED SECTIONS IN THE BLOODWOOD FORMATION

DISTRIBUTION OF BLOODWOOD FORMATION

MEASURED SECTIONS IN THE DJAGAMARA FORMATION

MS - 6

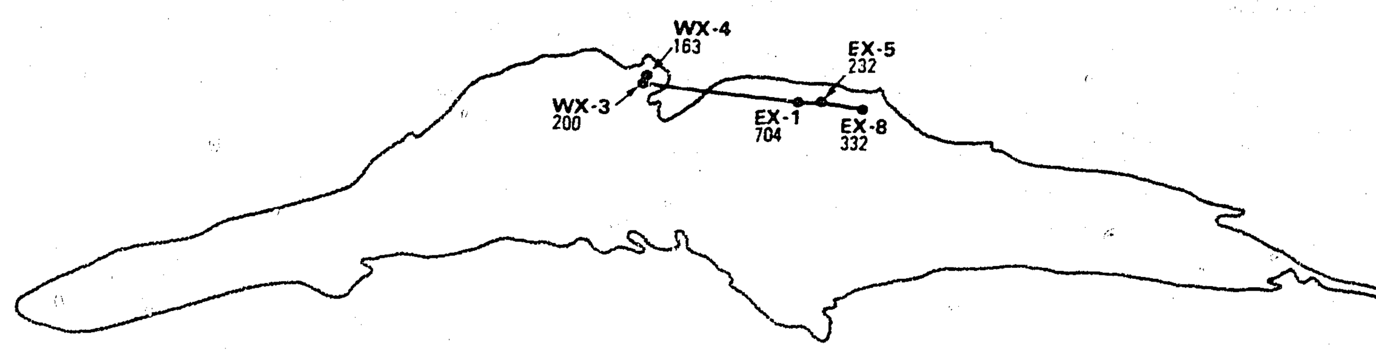


LOCATION OF MEASURED SECTIONS IN THE DJAGAMARA FORMATION

DISTRIBUTION OF DJAGAMARA FORMATION

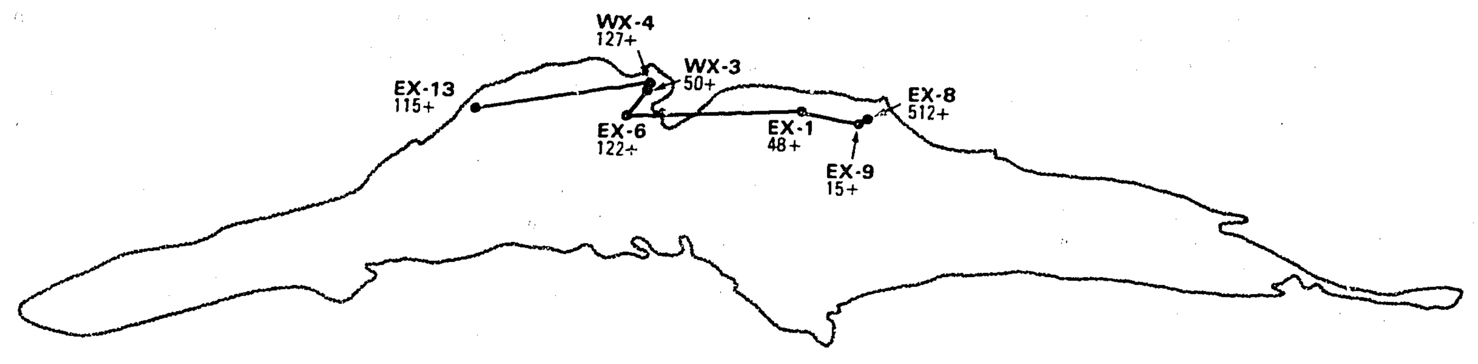
MEASURED SECTIONS OF THE KERRIDY SANDSTONE AND MOUNT ECLIPSE SANDSTONE

MS - 7

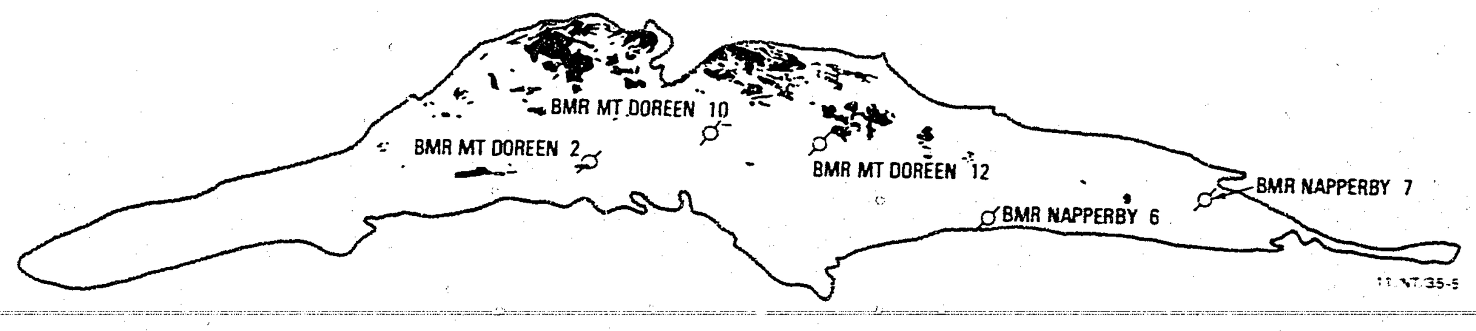


LOCATION OF MEASURED SECTIONS IN THE KERRIDY SANDSTONE

DISTRIBUTION OF KERRIDY SANDSTONE



LOCATION OF MEASURED SECTIONS IN THE MOUNT ECLIPSE SANDSTONE



DISTRIBUTION OF MOUNT ECLIPSE SANDSTONE