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An investigation of STRUCTURES CONTROLLING NATURAL DISCHARGE OF ARTESIAN WATERS in the southwestern Great Artesian Basin

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INTRODUCTION

The Great Artesian Basin (GAB) covers an area of approximately 1.7×10^6 km^2 in Queensland, New South Wales, South Australia and the Northern Territory. It is a multi-aquifer system comprising Jurassic and Cretaceous sediments of the Eromanga, Surat, and Carpentaria Basins (Fig. 1). The main aquifer is artesian throughout most of the basin, except around.the extreme southwest margin, and in areas of concentrated groundwater withdrawal. Recharge is mainly in the Great Dividing Range in Queensland, although a small amount also occurs around the basin margins in the other States. The principal groundwater flow direction is from northeast to southwest, that is, from the Great DividingRange towards South Australia (Fig. 1), following the main structural and

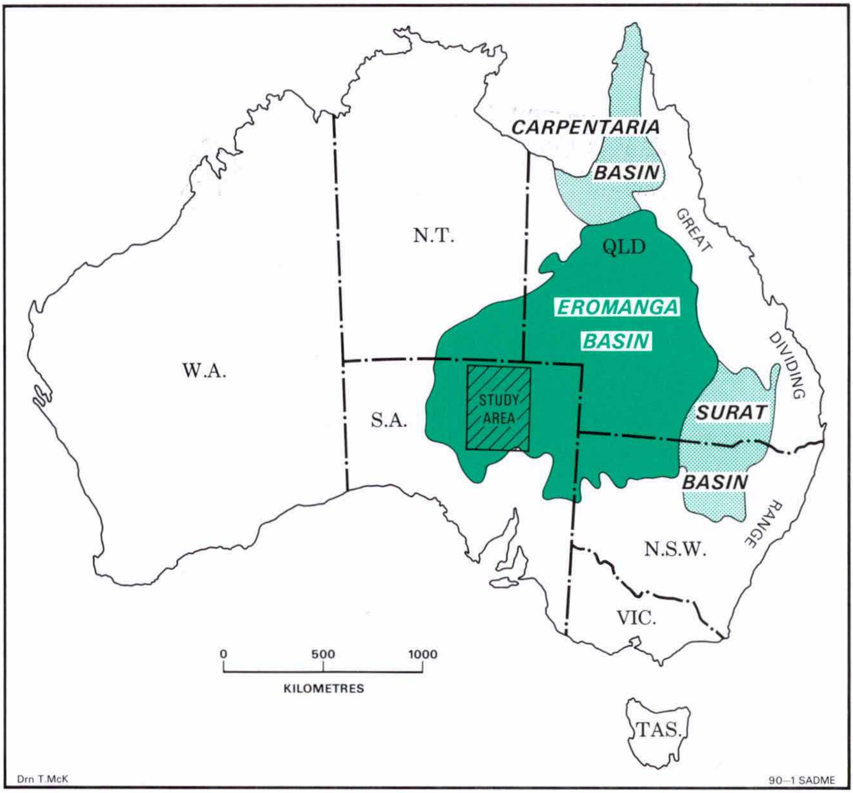

Figure 1. Locality map of the Great Artesian Basin and its subdivisions

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topographic gradients of the Eromanga Basin. Discharge of aquifer waters occurs through springs, artesian and pumped wells, and by diffuse discharge through confining beds.

The purpose of the investigation was to define factors controlling the formation of springs, with the aim of applying the results to locate areas of more subtle discharge. The study area is along the southwestern margin of the GAB from Dalhousie to Welcome Springs, an area of numerous springs (Fig. 3). The investigation of spring discharge involved the analysis of data from seismic, gravity, aeromagnetics, geology, and Landsat imagery.

GEOLOGICAL SETTING

In South Australia, the Great Artesian Basin comprises Eromanga Basin sediments. The main aquifer (aquifer 1) consists of sand and silt of the Algebuckina Sandstone and Cadna-owie Formation. The principal confining beds are the Bulldog Shale and the Oodnadatta Formation - a succession of marine silt and clay. The Coorikiana Sandstone occurs between the latter two formations, whilst the upper confined aquifer consists of the higher permeability interconnected sections of the Winton and Mackunda Formations (Fig. 2.). These units are overlain by Tertiary sediments of the Lake Eyre Basin.

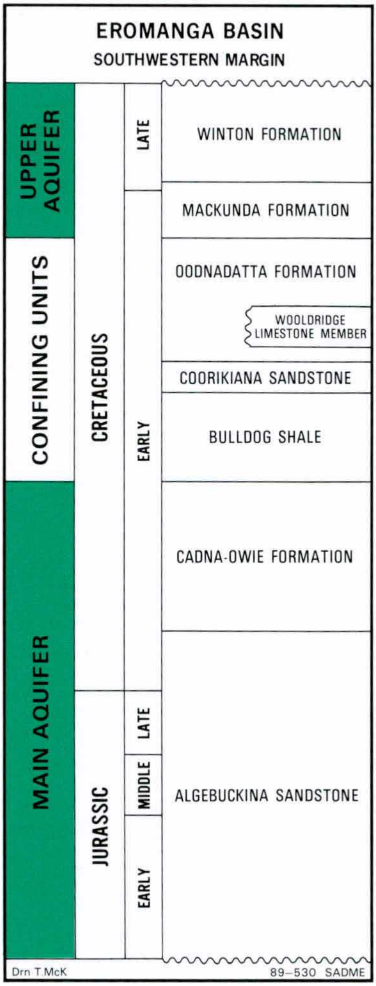


Figure 2. Stratigraphy of the southwest margin of the Eromanga Basin

STRUCTURE

Structural analysis of the continent of Australia shows that many of the major lineaments occurring in Phanerozoic sedimentary basins correlate with directions predicted by an east-west oriented stress-strain ellipsoid (Fig. 3). This may be due to global rotational forces setting up an east-west right lateral shear couple, the 'Epi-Adelaidean regional shear' of Veevers and Powell (in Veevers, 1984).

The orientation of fractures in the southwestern Great Artesian Basin can be interpreted using this strain ellipsoid. Faults and lineaments correspond to the synthetic/antithetic, 'P' fracture, and thrust systems as shown on the ellipsoid. Many major structures mapped in areas of outcropping Proterozoic rocks also show similar orientation.

In the area between the Willouran Ranges and the Peake and Denison Inliers, northwest-southeast ('synthetic') fault systems are strongly developed, showing east-west ('P' fracture) displacement between them. In other areas e.g. Lake Eyre, Francis Swamp, north-south ('antithetic') faults are prominent, also accompanied by 'P' fracture offsets. When two such faults intersect, a 'trapdoor structure' is formed enhancing the movement of fault blocks.

Faulted blocks undergoing structural relaxation or compression may form conduits or barriers to the movement of groundwater.

The study area was divided into a number of sections according to geographic locality. These are discussed below.

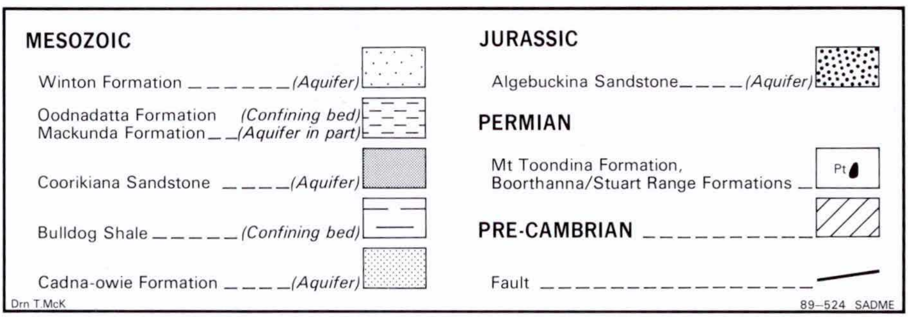
SPRINGS OF THE SOUTHWESTERN GAB

DALHOUSIE

All springs on DALHOUSIE are located in the Witjira National Park. They discharge more than 90% of all waters from springs in the South Australian part of the GAB (Boucaut *et al.*, 1986). This may indicate that a special set of conditions is causing such a high discharge rate (approx 650 L/sec.). These springs were examined using recent seismic information and detailed geological maps.

The springs of the Dalhousie area (Fig. 3) form two distinct groups. One occurs above a large collapsed basement high which may be a northerly extension of the Peake and Denison Inliers. Seismic line 86-AED (Fig. 4) passes through the main spring area and shows the presence of a collapsed anticline, shallow (uplifted) aquifer, a thinned confining bed and many faults (wrench induced flower and half-flower structures). Basement uplift and erosion of the Bulldog Shale brought the aquifer close to the present day surface. Proximity of the aquifer to the surface, high aquifer permeability and potentiometric surface above ground-level enables artesian water to discharge through weaknesses in the covering sediments. One fault shows some lateral displacement along an east-west ('P'-fracture) plane as indicated by spring locations and drainage patterns imply that a trapdoor strucural style may be present for this spring group. The springs are located on the upthrown (eastern) side of large north-south (antithetic) faults, suggesting that the faults may be sealing and that groundwater is flowing from the north or east.

The southern group of springs forms a distinct V (Fig. 3) implying the presence of two intersecting fault planes causing a thinning of the Bulldog Shale by uplift and stream-channel cutting.



Legend for Figure 3

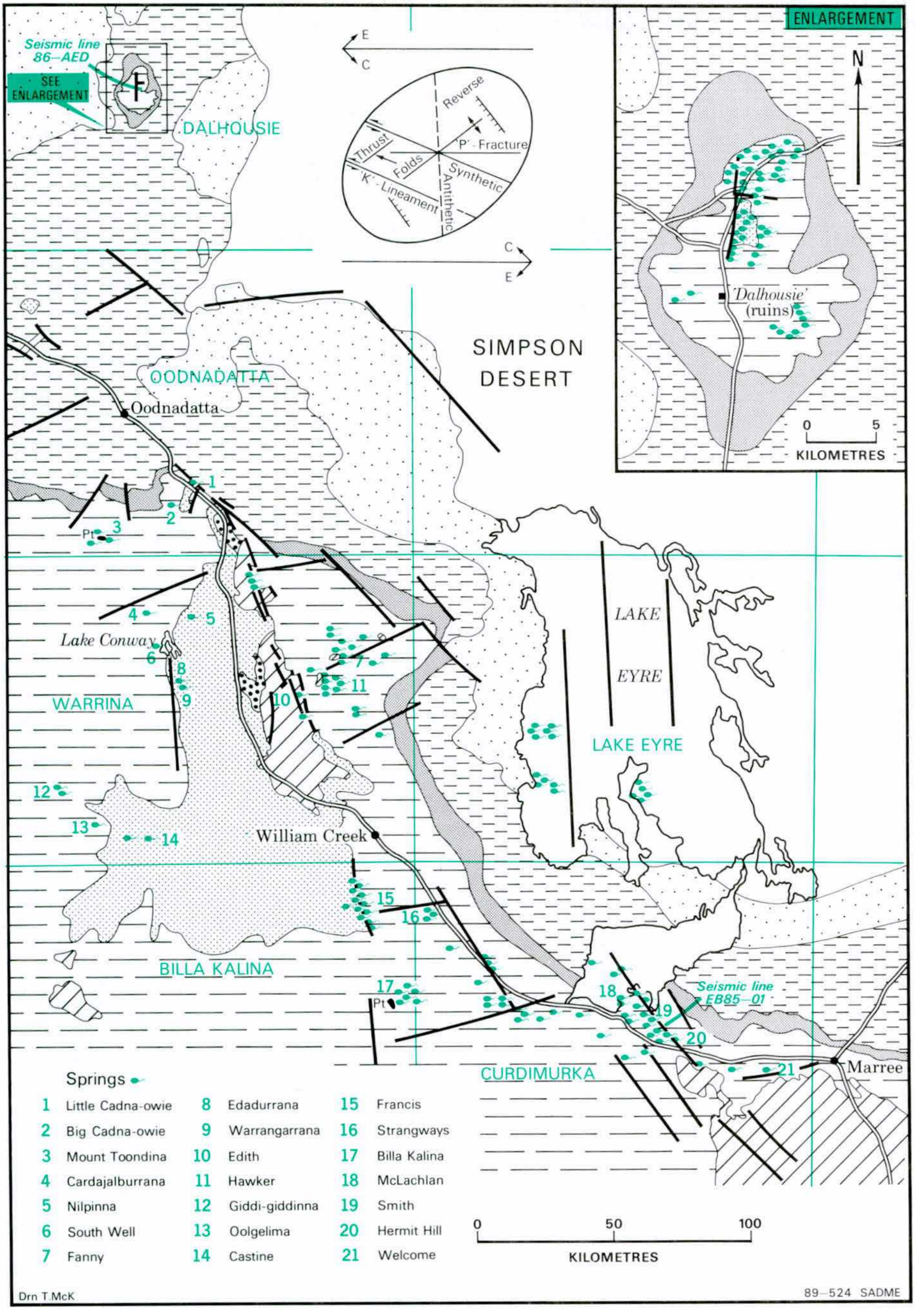


Figure 3. Springs and regional geology of the southwest margin of the Eromanga Basin

OODNADATTA

The springs on OODNADATTA (Little Cadna-owie, Big Cadna-owie; Fig. 3) occur near outcropping basement and in close proximity to major north-south (antithetic) and northwest-southeast (synthetic) faults. The fault orientations suggest the occurrence of trapdoor structures exposing Algebuckina Sandstone, Permian sediments and basement blocks, with the location of discharge points near to and on the western side of these faults.

Topographic relief and the distribution of faults in and around the basement at Algebuckina Hill suggest a collapsed trapdoor anticline. Collapse is indicated by the presence of the Neales River running west-east between two basement highs. Jurassic and Cretaceous aquifer material crops out on top of these basement blocks, whilst the river channel flows above a fallen block controlled by movements of the eastwest 'P' fracture system. No springs have been found in this area, which may be due to the major northwest-southeast (synthetic) fault north of Algebuckina Hill and Mount Dutton forming a barrier to the westerly flow of groundwater. Groundwater to the west of these inliers may originate from the west rather than the east.

WARRINA

Springs occurring on WARRINA can be divided into two groups, bisected by the Peake and Denison Inliers (basement areas north of William Creek, Fig. 3).

Springs west of the Peake and Denison Inliers area include Cardajalburrana, Wilpinna, Edadurrana, Warrangarranna and several near Lake Conway. Analysis of seismic sections by Delhi International Oil Corporation Arckaringa Basin investigations show that the springs generally occur above a large basement ridge extending north and west of the Peake and Denison Inliers. Faulting affects basement and Mesozoic sediments. Geological maps of the area indicate that the Cadna-owie Formation crops out to the east of the main line of springs which usually occurs in north-south oriented stream channels. (Fig. 4a) shows the main features controlling the occurrence of these springs.

Springs on the eastern side of the Peake and Denison Inliers are related to a basement ridge which extends from the ranges towards Lake Eyre. This is on the downthrown side of the major Peake and Denison fault system. The aquifer crops out only along the major fault system, that is, at Peake Ruins, in the saddle between the two basement ridges forming the ranges, and at the southern end of the Inliers, near William Creek. The springs are usually associated with magnetic highs (including outcropping basement), a set of north northwest-south southeast (?antithetic) trending faults, and easterly draining stream channels. The occurrence of basement highs is thought to bring the aquifer close to the surface, whilst the stream channels reflect the presence of east-west 'P' fracture lineaments, indicating that trapdoor structures may be present. In these areas, the Cadna-owie Formation is known to dip up to 70^{o} as a result of the drag-dip and block movement. A schematic section of this area is shown in (Fig 4b).

BILLA KALINA

Billa Kalina Springs and the Francis Swamp complex on BILLA KALINA appear to be associated with a southerly extension of the Peake and Denison basement highs, and have an antithetic fault- dominated structural style. An east-west 'P' fracture or transform fault system is inferred from spring locations and orientation of stream channels. Permian sediments crop out just to the west of Billa Kalina Springs and are fault controlled on the

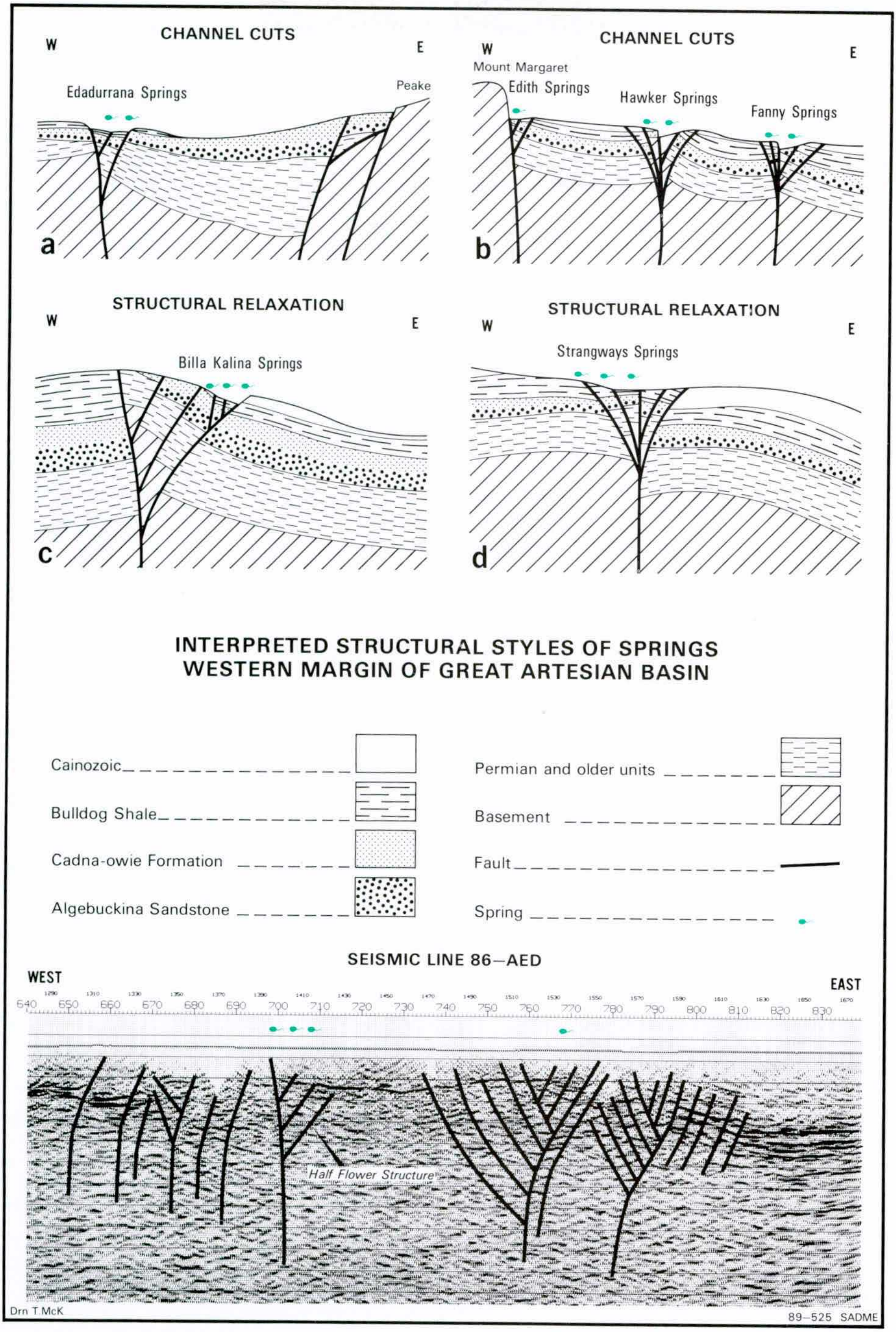


Figure 4. Seismic line and interpreted structural styles, southwest margin of the Eromanga Basin

western flank. The Cadna-owie Formation crops out between the springs and the Permian sediments, and extensively to the west of the major bounding fault. Spring discharge is controlled by sealed trapdoor structures allowing leakage to occur through a thinned and fractured Bulldog Shale (Fig. 4c). No Permian sediments crop out at or near Francis Swamp but discharge of groundwater is likely to occur by similar processes. Occurrence of outcropping aquifer-sediments and sealed fault-systems to the west of the spring complexes suggests that groundwater discharging from these springs is likely to come from the east or northeast.

CURDIMURKA

Springs from Strangways to Curdimurka Railway Siding on CURDIMURKA occur in a nearly straight line trending northwest-southeast (the synthetic of the stress-strain ellipsoid), interrupted by minor east-west ('P' fracture) offsets. The intersections of these two fault systems form trapdoor structures, and springs located at these points are associated with thinning of Bulldog Shale by regional uplift and stream erosion (Fig. 4d). The significance of the erosional effect of stream channels along a fault plane is shown by the comparison of two wells near Strangways Springs. One (6239-1, Strangways Bore) drilled in the channel of Warriner Creek intersected 38 m of Bulldog Shale, whilst another (6139-32, Beautiful Valley Bore) adjacent to the channel penetrated over 80 m of confining bed. This stream erosion has been acting over a long period of time, with the thinning of the Bulldog Shale being related to the uplift and erosion of one fault block relative to another.

Most of the springs east of Curdimurka Railway Siding are related to outcropping or subsurface basement highs. The dominant faults in this area are the synthetic of the stress-strain ellipsoid (Fig. 3), although spring and stream patterns imply the presence of 'P' fracture systems (and therefore trapdoor structures). In most cases the presence of a basement high indicates the thinning or total erosion of the confining bed, and the positioning of the aquifer at or close to the present day land surface. Stream channels are associated with basement highs, indicating that a localised lowering of the land surface has occurred by structural relaxation and downward movement of basement blocks. One spring that is not associated with a stream channel is Smith Springs (Fig. 3). Seismic line SADME EB 85-01 indicates that this group of springs is situated on a faulted basement high, that the aquifer has been uplifted and the confining bed eroded. Thus discharge of groundwater is likely to occur through faults penetrating to the surface.

CONCLUSIONS

A number of features are commonly associated with the occurrence of spring discharge. They include:

1) Basement highs bring the aquifer closer to the present day land surface, and cause the confining bed to be eroded.
2) Basement wrench faults have been reactivated and reach the surface. Discharge may occur through the main fault or through subsidiary faults or fractures.
3) Springs often occur at the intersection of two fault planes that have formed trapdoor structures. These structures allow relative movement of the constituent blocks, and depending on whether the blocks are undergoing relaxation or compression, will form a barrier or a conduit to groundwater flow.
4) Springs are usually located in present day topographic lows, often associated with eroding stream channels. Streams are structurally controlled, with block movement and erosion causing considerable thinning of the confining bed.

KEYWORDS: Artesian/Springs/Great Artesian Basin/Aquifers/ Structure/Algebuckina Sandstone/Cadna-owie Formation/Bulldog Shale/Oodnadatta Formation.

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History of recognition and delineation of COASTAL AEOLIAN LANDFORMS of the EUCLA BASIN, South Australia

M.C. Benbow

INTRODUCTION

Coastal aeolian landforms have been recently recognised along the northeastern margin of the Eucla Basin in western South Australia (Benbow, 1986a,b, 1988) (Fig. 1). They include the 650 km Ooldea Range on the northeastern margin of the Nullarbor Plain and sand plains of the Bunda Plateau, the parallel Barton Range, located 40-70 km further inland, and the interconnecting Paling Range. Other coastal aeolian landforms recognised here include dune ridges and possible beach ridges. These landforms are believed to have formed during maximum transgression in the Eucla Basin at the end of the Eocene, a time of change in global climate (Benbow, 1990). Coastal aeolian landforms of such antiquity are not known elsewhere in Australia, nor do they appear to have similar well-preserved counterparts elsewhere in the world.

This note describes the history of the recognition and delineation of these landforms. The morphology, stratigraphy, age, and factors responsible for their formation and preservation are described elsewhere (Benbow, 1990).

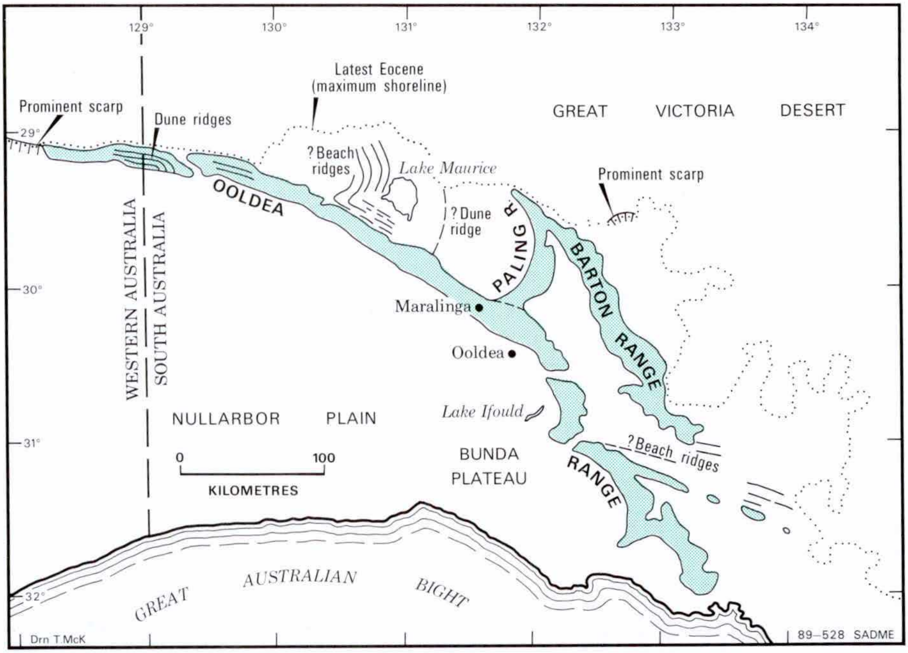

Figure 1. Coastal aeolian landforms, north-eastern Eucla Basin

DISCOVERY AND DELINEATION

The Ooldea Range was observed by European explorers in the nineteenth century between Ooldea and Lake Maurice (Jones, 1880; Brown, 1883, 1885, 1898; Tietkens, 1888; Giles, 1889). In the vicinity of Ooldea, the range stands clearly above the flat Nullarbor Plain and 'can be seen a considerable distance from the south' (Tietkens, 1888, p.35). Jones (1880, p.8) described the range here as being 'very defined on the south side, but broken into spurs and hollows on the north'. Jones, who was State Chief Surveyor at the time, had a keen awareness of the landscape he travelled across, evident in his map of the region on which he figured the Ooldea Range (Fig. 2). In contrast, Ernest Giles, who visited the Ooldea region earlier in 1875, did not refer to the range by name, nor did he mark such a feature on his maps. Instead, he marked the 'Edge of [the Nullarbor] Plain' (Giles, 1889). On moving north across the Nullarbor Plain toward Ooldea, he wrote 'For about twenty-five miles we traversed an entirely open plain ... mostly covered with the waving broom bushes; but now upon our right hand, to the north, and stretching also to the west, was a dark line of higher ground formed of sandhills and fringed with low scrub ... This new feature, of higher ground, formed the edge of the plain, and is the southern bank of a vast bed of sandhill country that lies between us and the Musgrave Ranges nearly 300 miles to the north' (Giles, 1889, p.78). Probably as a consequence of Jones' (1880) trips to the eastern Nullarbor Plain in 1880, H.Y.L. Brown included the Ooldea Range on the first geological map of the State (Brown, 1883). The full extent of the Ooldea Range has been realised only recently through regional photointerpretation (northwestern part; Krieg, 1971), LANDSAT imagery (northwestern limit, adjacent to the 'prominent scarp' of Lowry, (1970), and good quality topographic contour data (southeastern part; see below).

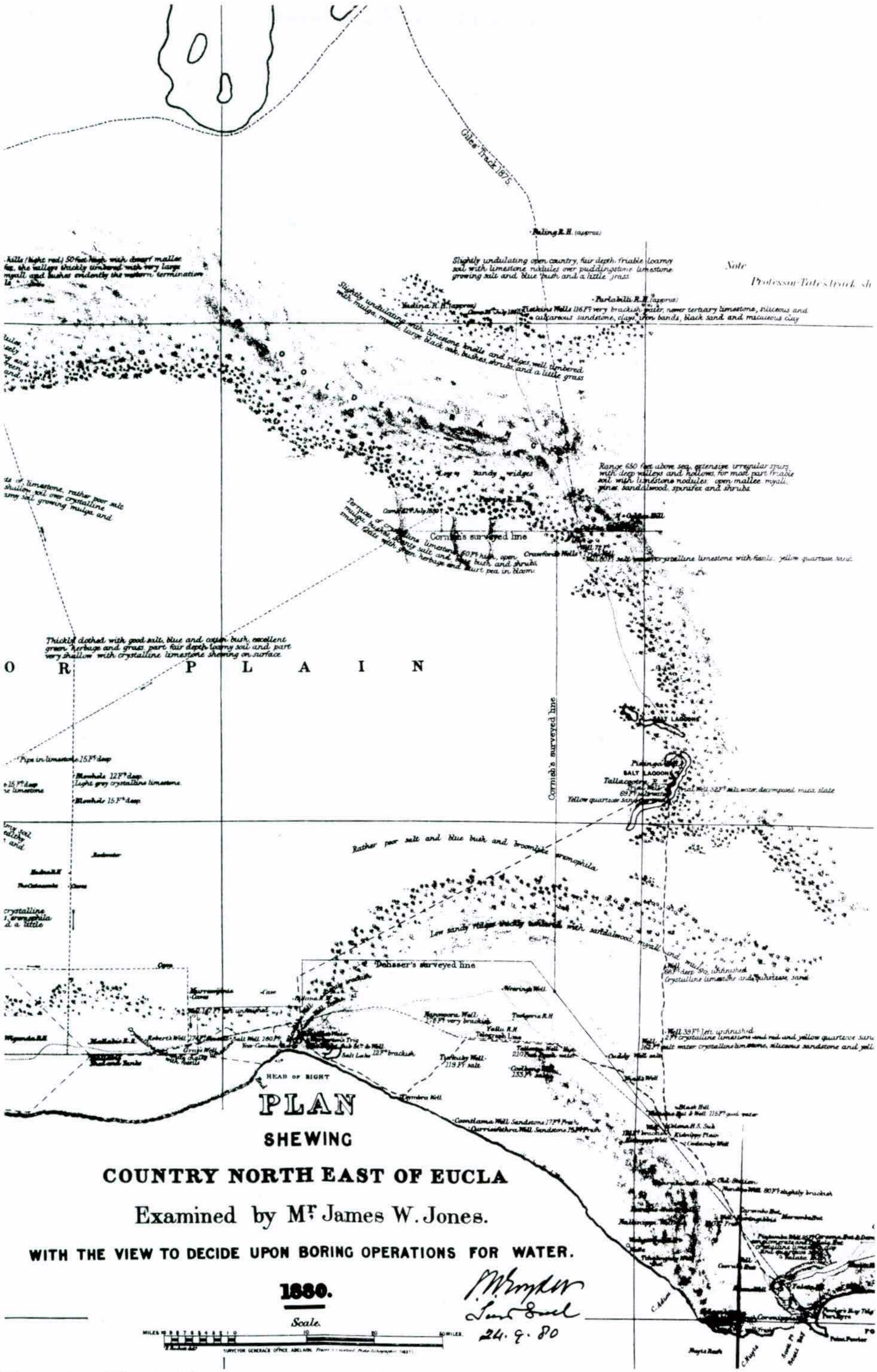

Figure 2. The Ooldea Range as mapped in 1880. (Adapted from Jones, 1880)

The Barton Range is a recently discovered feature (Pitt, 1980). It occurs within the dunefield of the Great Victoria Desert and unlike the Ooldea Range is not an obvious feature on the ground. Its discovery resulted from the contour map compilation of barometrically measured elevation data gathered during regional gravity surveys of the 1960s and 1970s (Mannik and Morony, 1976; Pitt, 1980). Upon acquisition of more detailed and accurate elevation data, this range and the Ooldea Range have been better defined and more completely delineated. These data, described by Benbow and Crooks (1988), include Royal Australian Survey Corps 1:50 000 scale orthophoto mosaics with 10 m contours.

Discovery of the Paling Range and of possible beach ridges near the southeastern end of the Ooldea Range, took place during the SADME compilation of 1:250 000 and 1:500 000 scale contour maps. Drilling of the possible beach ridges, first recognised by Crooks (pers. comm., 1984), is yet to occur to confirm their origin.

LANDSAT IV imagery revealed the presence of possible dune ridges within the western part of the Ooldea Range and of possible beach ridges in the Lake Maurice region. Detailed photogrammetrically measured profiles across the western part of the Ooldea Range, in the vicinity of Serpentine lakes, confirmed the presence of a succession of parallel dune ridges (Benbow and Crooks, 1988; figs 5a, b). Field examination of the possible beach ridges, in an area of little detailed geological exploration, is yet to be undertaken.

The regional setting and portrayal of these landforms is most clearly seen on the 1:500 000 contour map of western South Australia compiled by Alistair Crooks. A colour plate reduction of this map is reproduced in Benbow and Crooks (1988).

GEOGRAPHICAL NOMENCLATURE

Various names have been given to the Ooldea and Barton Ranges. Jones (1880) used the name 'Ooldea Range' but also used the variations 'Ooldea Hills' and 'Ooldea sandhills'. Tietkens (1888) also used the name 'Oldea Sandrange'. Pitt (1980) later applied the names 'Ooldea Sand Range' and 'Barton Sand Range' to their respective features. The term Ooldea Range has been used on various published topographic and geological maps of South Australia including Brown's (1883) geological map of the State. The terminology applied to the other landforms of similar morphology and origin, namely the Barton Range (Benbow, 1986a) and Paling Range, is consistent with published usage for the Ooldea Range. The nomenclature used in this note has been approved by the Geographical Names Board of South Australia.

ORIGIN OF THE OOLDEA, BARTON AND PALING RANGES

Of the origin of the Ooldea Range, Brown (1885, p.4) stated 'No hard rock other than limestone is visible in crossing the Ooldea Range, which may be either an elevated portion of the Nullarbor Plain, or a sand-covered area of granite and metamorphic rocks - which is most likely the case'. A similar view was held recently as Pitt (1980, p.8) stated 'the structure, is ill-named, as it is clearly composed of lithified, older rocks underlying present-day aeolian sands'. Some support for this view was given by Tietkens (1888) for the region south of Ooldea, as crystalline basement crops out in the vicinity of Lake Tallacootra and Euria Well on the flank and near the crest of the range respectively. Hunting Geology and Geophysics (Australia) Pty Ltd (1981), which carried out a geomorphological study of the eastern Nullarbor Plain and Great Victoria Desert using 1:250 000 scale false-colour LANDSAT imagery, interpreted the two parallel ranges to be major monoclinal flexures of 'recent' age. More recently Tapley (1988) undertook a study of the application of NOAA-AVHRR Satellite Imagery in interpreting palaeodrainage and geological structures over the Canning and Officer Basins. He said that 'Thermal imagery supports Pitt's (1979) statement that the structure is misnamed. Such a warm target must be composed of much denser, older rocks with relatively higher thermal inertia properties than the overlying, present-day sands' (Tapley, 1988, p.422).

Barnes (1956, p.2) said 'This sand concentration (at Maralinga), possibly represents the old shoreline in the Miocene times'. Although Barnes (1956) and Ludbrook (1961) figured cross-sections of the range through Maralinga, they did not name the feature and appeared to be unaware of the range's significance. Krieg (1971, p.7) is the first to have recorded a possible coastal dune origin for the Ooldea Range. However, he discounted that possibility since 'such an interpretation requires the dune system to have survived erosion since Miocene times', that is, after deposition of the Nullarbor Limestone. Thomson (1980) who portrayed a major part of the Ooldea Range on the State 1:1 000 000 geological map, considered this feature to be a coastal dune, of uncertain age. (Thomson, pers. comm., 1989).

The coastal dune origin of the ranges is apparent by their morphology, as portrayed in the regional topographic contour map of Pitt (1980). This is made clearer in the detailed contour maps which have become available more recently (Benbow and Crooks, 1988). These maps indicate that the ranges have a morphology similar to the parallel Pleistocene and Holocene coastal dunes of the southeastern part of Australia. This origin is confirmed by the fact that drilling (Barnes, 1956; Ludbrook, 1961; Pechiney (Aust) Exploration Pty Ltd, 1973; Ashton, 1975; Whitby, 1976; Dampier Mining Co. Ltd, 1976a,b; Bladier, 1981; Smith, 1984; Taylor and Tedder, 1987) indicates that the ranges are composed of siliciclastic sand up to 175 m thick; that is, no shallow crystalline basement or bedrock is present beneath the main extent of the ranges.

The good quality hypsometric data used in this study has proved invaluable in portraying and understanding regional landforms of western South Australia. As a direct result, major insight has been provided about the Cainozoic geological history of the eastern Eucla Basin (Benbow, 1990). The delineation of these coastal dunes has significantly enhanced the mineral potential of the region. Coastal dunes and beach ridges along the southern margin of Australia are prospective for heavy mineral sands. The Late Eocene dunes are especially prospective in view of the recent discoveries in Pliocene coastal sand near Horsham in the Murray Basin.

KEYWORDS: Coastal Landform/Geomorphology/History/Eucla Basin/Ooldea Range/Barton Range.

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The Early Cambrian MILENDELLA LIMESTONE MEMBER (Kanmantoo Group), a stratigraphic marker horizon in the Karinya Syncline

B.J. Cooper

INTRODUCTION

This note provides a description, formal definition and correlation of a prominent limestone marker unit - Milendella Limestone Member - that characterises the Early Cambrian Carrickalinga Head Formation (Kanmantoo Group) in the Karinya Syncline region, northeast of Adelaide (Fig. 1). A brief consideration of associated mineralisation and regional correlation is included.

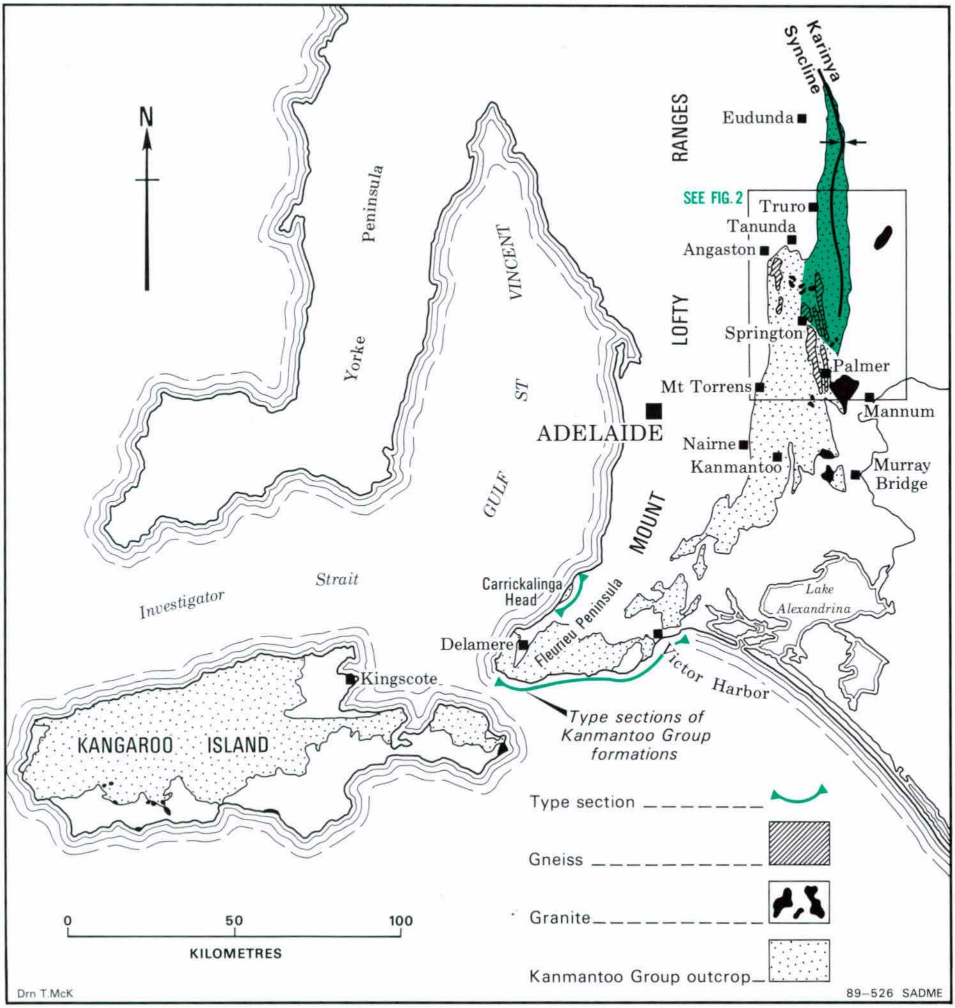

Figure 1. Locality map of Kanmantoo Group outcrop and Karinya Syncline

STRATIGRAPHIC SETTING

KANMANTOO TROUGH

The Kanmantoo Group (Fig. 2) embraces a succession of thick, dominantly terrigenous sandstone and siltstone sediments that were deposited in a rapidly subsiding basin (Kanmantoo Trough), and subsequently deformed during the Late Cambrian-Early Ordovician Delamerian Orogeny. Thicknesses ranging from 9 000 m (Daily *et al.*, 1976) to about 18 000 m (Thomson, 1969a) have been estimated. The Carrickalinga Head Formation forms the basal unit of this succession. It has been interpreted as a deep-water submarine fan deposit (Madigan Inlet Member) with shallowing through time (Gatehouse *et al.*, in press).

Gradational variations in lithology are common throughout the Kanmantoo Group, although major lithological changes seem to be persistent (Mancktelow, 1979). Distinctive lithologic markers are extremely useful although the only well documented marker is the Talisker Calc-siltstone with its Nairne Pyrite Member (Kleeman and White, 1956; Skinner, 1958; Thomson 1969a; Daily *et al.*, 1976; Belperio, 1985).

Biostratigraphically useful fossils are lacking in the Kanmantoo Group, though trace fossils (Daily and Milnes, 1971; Daily *et al.*, 1976), and hyolithids (Gatehouse *et al.*, in press) in the basal unit, the Carrickalinga Head Formation, confirm the Early Palaeozoic age. The trilobite-bearing succession around Emu Bay on the north coast of Kangaroo Island which is marginal to the Kanmantoo Trough and lithostratigraphically correlatable with the standard stratigraphic succession at the level of the Carrickalinga Head and Balquhidder Formations (Moore, 1983; Fig 2.) is also important. The trilobites from the Carrickalinga Head Formation, and probable equivalents of the Tunkalilla Formation on Kangaroo Island (Emu Bay Shale) suggest that the Kanmantoo Group has a late Early Cambrian age. The Kanmantoo Group also overlies a well-dated Early Cambrian carbonate succession (Normanville Group) (Fig. 2) and a further chronological constraint is provided by Late Cambrian radiometric ages for intruding granites (Milnes *et al.*, 1977).

KARINYA SYNCLINE

The Karinya Syncline is located about 150 km west northwest of the type sections of the formations of the Kanmantoo Group (Fig. 1). Recent geological mapping has confirmed the applicability of Daily and Milne's (1972) lithostratigraphic scheme in this area with the recognition of Carrickalinga Head, Backstairs Passage, Talisker Calc-siltstone and Tapanappa Formations (Gatehouse, 1988). This work also confirms significant facies differences, notably the abundance of calcium carbonate and calc-silicate minerals. A shallower depositional setting with more limited clastic supply than the South Coast type sections has been inferred (Gatehouse *et al.*, in press) with a shoreline towards the west being suggested by palaeocurrent studies (Mills, 1964).

The Karinya Syncline region experienced four folding episodes and faulting during the Delamerian Orogeny (Mills, 1964). The Karinya Syncline itself was generated during the initial (D_1) deformation, which also produced widespread slaty cleavage. D_2 folding is recognisable in the Karinya Syncline (Fig. 3), and is particularly well developed in the Milendella-Sanderston area, immediately south of the Karinya Syncline. D_3 and D_4 folding are less pronounced than earlier deformations. The former has produced a widespread crenulation cleavage that has internally deformed the limestones and calc-silicate rocks, thus obliterating original sedimentary features. The D_4 deformation, closely coeval with D_3

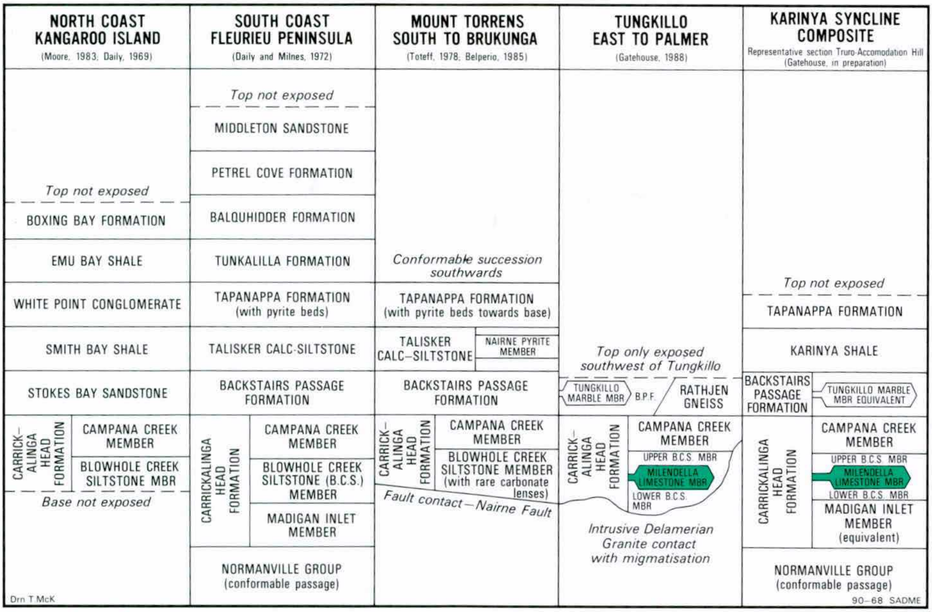

Figure 2. Correlation chart of the Kanmantoo Trough showing the stratigraphic position of the Milendella Limestone Member

folding and apparently associated with faulting, produced locally mappable folds involving the Milendella Limestone Member in the region west of Kanappa. The Karinya Syncline is traversed by at least two prominent faults subparallel to strike, as well as numerous minor faults. The value of the Milendella Limestone Member as a stratigraphic marker is amply demonstrated by its ready recognition through such folded and fault-disrupted regions.

The Karinya Syncline region experienced regional metamorphism with progressively higher metamorphic grades to the south and west with some fault off-set of the isograds (Mills, 1964). Biotite, andalusite-staurolite and sillimanite zones have been determined by Offler and Fleming (1969) and Mancktelow (1979). The probable, widely diffused regional deposition of calcite in addition to the prominent limestone marker described here has led to an unusually abundant development of scapolite in those areas metamorphosed at or above andalusite-staurolite grade. Mineralisation is so extensive that this regional scapolite province is quoted in textbooks (White, 1959; Deer *et al.*, 1963).

In the Karinya Syncline, the Milendella Limestone Member provides apparent stratigraphic control of mineralisation including anomalous concentrations of copper, lead, zinc, silver, and gold (Thomson, 1969b). According to Mills (1976), this mineralisation is not stratabound, even though commonly it occurs at the base of the limestone. The association of metallic minerals with local faulting, coupled with several different mineral assemblages, indicated post depositional mineralisation originating from several generations of fluids which moved upwards through the strata along fault zones (Mills, 1964). Upward movement was facilitated by fault brecciation within clastic units of the basal Kanmantoo Group, but was inhibited by the plastically deformed and impermeable Milendella Limestone Member. Thus mineral deposits accumulated at the base of this latter stratigraphic horizon.

MILENDELLA LIMESTONE MEMBER - DEFINITION

Derivation

Milendella is a small township near the southern end of the outcrop belt of the Milendella Limestone Member (lat. 34° 49' S long. 139° 12' E).

Rank

The Milendella Limestone Member is a member of the Carrickalinga Head Formation within the Kanmantoo Group (Daily and Milnes, 1971, 1972).

Synonymy

Lower Marbles, Narcoota Series (Hossfeld, 1935, pp.35, 45-47).

Marbles of Milendella-Sanderston region (White and Thatcher, 1957, geological map).
Saccharoidal marble, Kanmantoo Group (Coats, 1959, geological map).

Milendella Marbles (White, 1959, pp.285-306).

Impure limestones, Kanmantoo Group (Johns, 1963, pp.30-31, 34, 37).

Milendella Limestone Member. (Thomson, 1969a, p.103; Thomson, 1969b, geological map; Thomson, 1976, p.556).

Type Section

In the first published reference to the 'Milendella Marbles', White (1959) did not clearly specify a type section. However, he did refer (White, p.293) to 'extensive outcrops of marble and associated calc-silicate rocks ... about 1/2 mile west of Milendella village ... (which) ... extend to the edge of the Mannum (geological) sheet'. Consequently this region should be regarded as the type area. This region also contains the most highly deformed and metamorphosed outcrops of the unit and is further complicated by an adjacent irregular granite intrusion. A reference section or stratotype (depending on interpretation) is proposed based on the excellent and easily accessible section outcropping across the bluff on the south side of the Marne River, immediately east of Jutland Road (Angaston 1:50 000 sheet, Grid Reference (G.R.) 331661622, Hundred Jutland, northwest corner of section 492 Fig. 3). A further valuable outcrop section, which is structurally more complicated than the Marne River section, is located on the southern side of Truro Creek, adjacent to the north-south Accommodation Hill-'Wyeroo' track (Truro 1:50 000 sheet, G.R. 335661885, Hundred Jellicoe, southeast corner of section 51 Fig. 3).

Distribution

The unit occurs in a restricted north-south outcrop belt extending from Milendella in the south to 50 km north beyond Accomodation Hill (Fig. 3). Lateral depositional continuity of at least 7 km may be presumed in the Karinya Syncline.

A single but complex belt of outcrop occurs between Milendella and Sanderston. North of Sanderston, the Milendella Limestone Member repetitively crops out on both limbs of the Karinya Syncline. This repetition probably results from deformation, but the presence of three or four parallel bands of marble on both limbs of the syncline at its southern end does not preclude the possibility of more than one carbonate horizon over a restricted stratigraphic interval. A single limestone band typifies the Milendella Limestone Member north of Mount Karinya.

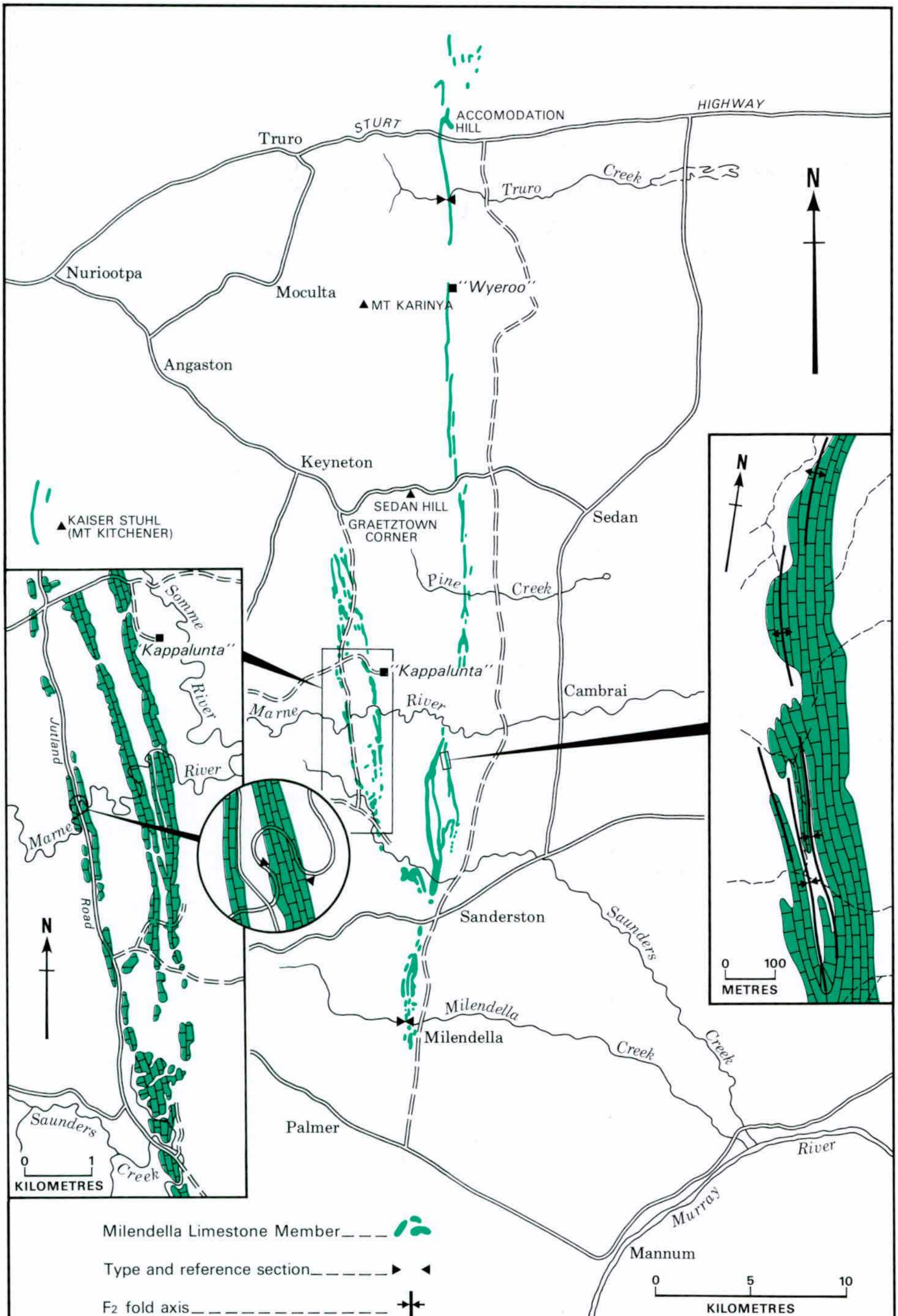

Figure 3. Distribution of the Milendella Limestone Member.

Thomson (1969b) also mapped the Milendella Limestone Member, in a small area south of Tanunda and west of Kaiser Stuhl (Mount Kitchener) (Fig. 3). This occurrence is more than 15 km west of outcropping Milendella Limestone Member in the Karinya Syncline.

No sub-surface records of the Milendella Limestone Member are known.

Lithology

The unit is a laminated blue-grey limestone or white marble. The term 'limestone' is used here for formal descriptive purposes; though, at many localities the unit is more correctly termed a marble. It grades with progressive metamorphic recrystallisation from a dark blue-coloured limestone through blue-grey and grey-white limestone to light brown and white marble. Grainsize varies from fine to coarse. The limestone commonly has a streaky or layered appearance due to very thin discontinuous bands of phyllite, which presumably originated from mud laminae in the primary deposit. Johns (1963) and Mills (1964) indicate that the unit contains no more than 80% calcium carbonate with the remainder composed of muscovite or potash feldspar, the latter altering to scapolite at higher metamorphic grades. In a few places, Mills noted that the unit passed into a true calc-silicate rock with a calcium carbonate content less than 50%.

The massive nature of the Milendella Limestone Member coupled with the conspicuous white colour of both the weathered and unweathered limestone enhances its potential as a stratigraphic marker.

Palaeontology

No fossils are known from the Milendella Limestone Member even though the unit is presumed to have been deposited under marine conditions. Subsequent metamorphism probably has obliterated any fossils originally present.

As part of this investigation, the Milendella Limestone Member was examined systematically for microfossils. Spot samples of blue-grey limestone were collected at the following localities:

- Saunders Creek Quarry near Sanderston, Hundred Angas, section 529, Angaston 1:50 000 sheet, G.R. 336461536.

- Near Kappalunta H.S., Hundred Jutland, adjacent N.E. corner section 465, Angaston 1:50 000 sheet, G.R. 332261655.

- Quarry north of Sturt Highway, Accomodation Hill, Hundred Dutton, section 121, Truro 1:50 000 sheet, G.R. 335261918.

- Adjacent main road, Sedan Hill, Hundred Jellicoe, Section 828, Angaston 1:50 000 sheet, G.R. 33671738.

In addition, measured sections at the reference localities (located previously) along the Marne River and Truro Creek were collected. In all, 14 one kilogram samples were dissolved in 10% acetic acid and the residues searched, without success, for microfossils.

Relationships

The Milendella Limestone Member occurs stratigraphically within a siltstone succession, which has been correlated with part of the Blowhole Creek Siltstone Member at the Kanmantoo Group stratotype (Gatehouse *et al.* in press). Toteff (1977) noted minor limestone and calc-silicate lenses within the Blowhole Creek Siltstone Member near Mount Torrens, thus supporting this lithostratigraphic correlation. Consequently the Blowhole Creek Siltstone Member is divided into informal and indistinguishable upper and lower units in the region of the Karinya Syncline.

The Milendella Limestone Member is clearly delineated, within the Carrickalinga Head Formation. At the reference section, a gradation from micaceous siltstone of the Blowhole Creek Siltstone Member (lower unit) through alternating bands of siltstone and limestone into typical Milendella Limestone Member takes place across 2.8 m of section. Along Truro Creek a sharp change to calcareous lithologies at the base of the Milendella Limestone Member occurs, although a significant terrigenous component appears about 20 m above the base. At both localities the sharp top of the Milendella Limestone Member suggests a rapid return to a terrigenous source typical of the Blowhole Creek Siltstone Member. Laterally the Milendella Limestone Member passes into calc-silicate rocks and siltstone as demonstrated by local lensing of the unit north of 'Wyeroo' (Fig. 3).

Thickness

At the reference section the Milendella Limestone Member is 72 m thick while at Truro Creek 96 m were measured. Due to folding, the section thickness at Truro Gorge is approximate only. Thickness is variable as shown at the reference sections, although it reduces to zero in some areas. For example, on the road up Cooke Hill, west of Sanderston, only 2 m of limestone were recognised whereas a few hundred metres south of the road, the unit is about 25 m thick.

CORRELATION

The correlation chart of the Kanmantoo Group from selected sections (Fig. 2) illustrates the chronostratigraphic position of the Milendella Limestone Member based on current information. As discussed previously, the section on the north coast of Kangaroo Island is here regarded as a marginal part of the Kanmantoo Trough.

Recent Cambrian correlation charts of South Australia have provided a single or simplified column for the Kanmantoo Trough (eg. Thomson *et al.*, 1976; Cook, 1982; Shergold *et al.*, 1985). Here several detailed columns are provided so that a perspective of lateral change within the basin, and the limitations of individual sections is portrayed. All currently accepted and formally named formations and their members are included. Recent work by C.G. Gatehouse (pers. comm.) on the Karinya Syncline shows that the Karinya Shale Member of Thomson (1969a,b) should be raised to formation status while the calc-silicate marker of Mills (1964), which was placed stratigraphically above the Milendella Limestone Member in the Backstairs Passage Formation, is interpreted as a Tungkillo Marble Member equivalent. Correlatives of the Madigan Inlet Member in the Karinya Syncline differ from the type section in having greater sand content and minor carbonate lenses, as well as by their transitional passage from the shale/volcanic association of the underlying Normanville Group. It is here labelled Madigan Inlet Member equivalent.

The chronostratigraphic implications provided in Figure 2 are interpreted from the physical interrelations of strata determined by surface geological mapping of the Kanmantoo Trough over the past 30 years coupled with regional lithostratigraphic correlations. The latter is supported by modern sedimentologic determinations of environment (eg. Gatehouse *et al.*, in press). No diagnostic fossils are available yet for biostratigraphic correlation within the Kanmantoo Trough.

KEYWORDS: Stratigraphy/Kanmantoo Group/Carrickalinga Head Formation/Milendella Limestone Member/Definition/Karinya Syncline/Type Section.

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