REGIONAL MAPPING

DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY

PALAEOECOLOGICAL INTERPRETATION OF SOUTH AUSTRALIAN PRECAMBRIAN STROMATOLITES

by

WOLFGANG V. PREISS
PALAEONTOLOGY SECTION

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ABSTRACT

Despite the palaeoecological emphasis of most recent stromatolite research outside the USSR, controversy still exists regarding the environmental restriction of these organosedimentary structures and in some cases, analogies with modern occurrences have been maintained too rigidly. Palaeo-environments should be determined where possible by a combination of all biological and sedimentological evidence.

In South Australia, Cambrian and Precambrian carbonate rocks which form a substantial proportion of the thick sequence in the Adelaide Geosyncline, contain widespread stromatolites, which have been studied according to methods developed in the USSR and classified into the form taxa "group" and "form". The absence of independent biological environmental indicators in the Precambrian section necessitates a reliance on general stratigraphic and sedimentological data for the interpretation of regional palaeogeography and local environmental conditions. The Skillogalee Dolomite, older than the lower of two Late Precambrian tillites, contains one predominant form of stromatolite almost throughout its extent, although at least one additional form occurs locally. These stromatolites chiefly grew as biostromes in littoral and lagoonal settings on an extensive, level, carbonate-depositing platform, probably of restricted access to the open sea. The interspace and associated sediments show evidence of varying energy conditions, degree of oxidation and possibly salinity, but the same stromatolite persists, although there is some modification of morphology, such as the presence of micro-unconformities in the higher energy environments. The Umberatana Group, stratigraphically the interval including the two tillites, has basinal shales and siltstones in its lower part, but during a subsequent widespread regression, the marginal parts of the basin were shallowed sufficiently to allow the growth of stromatolites, probably in water depths ranging from shallow subtidal to low supratidal. In addition, in the northern central part of the basin, offshore banks of shallow water limestones may have been related to areas of diapiric activity. The stromatolites of the Umberatana Group most often occur as bioherms of varying sizes intimately associated with ooid and intraclast grainstones, crossbedded sandy limestones, and, in marginal areas, penecontemporaneous dolomites. Twelve forms of stromatolites have been distinguished in the Umberatana Group. Different forms may occur in sequences of seemingly indistinguishable lithofacies. These observations from the Adelaide Geosyncline strengthen the view that stromatolite morphology is at least partly biologically controlled, the defined taxa being largely independent of the local environment.

INTRODUCTION

Whereas stromatolite research in the USSR during the last decade has concentrated almost exclusively on taxonomic and biostratigraphic considerations, western investigators have until very recently (Cloud & Semikhatov, 1969) consistently refuted the possibility of stromatolite zonation, except for local correlation (Rezak, 1957). Their approach has been rather to examine the environmental aspects of stromatolites, both in the Precambrian and the Phanerozoic - in the latter case especially, stromatolites have often been of only marginal interest to sedimentologists and stratigraphers engaged in carbonate petrology and basin analysis in the search for petroleum. Hoffman (1969) gave an outstanding example of a basin study in the Precambrian, using stromatolites. The use of stromatolites for environmental interpretations was given impetus by studies of modern analogues, whose similarity to fossil forms has, however, sometimes been overstated (e.g. Bathurst, 1967, p. 458).

Interest in stromatolite environments commenced with Black's classic study of algal mats on Andros Island, Bahamas, Monty's re-examination of the algal mats of Andros Island (Monty, 1967) greatly extended knowledge of the ~~rock~~ role of algae, especially in lime-precipitation. The lack of rapid lithification may have prevented the algae from colonizing rough waters. In contrast, Shark Bay, Western Australia, is an environment in which modern algal mats form domed, columnar and club-shaped structures. Logan (1961) considered early lithification by interstital precipitation of aragonite to be responsible for the relief of the stromatolites. The Shark Bay stromatolites are reported by Logan to be restricted to the intertidal and supratidal zones and this environmental restriction of stromatolites has often been assumed to be universally valid.

The apparent restriction of modern stromatolites to the near-intertidal zone has frequently been used in subsequent palaeogeographic and environmental studies. Recently, however, the occurrence of subtidal stromatolites has become recognized, both in modern and ancient environments. For instance, Achauer and Johnson (1969) argued that stromatolites in certain Lower Cretaceous reef complexes were subtidal. Playford & Cockbain (1969) demonstrated that stromatolites in a Devonian reef of Western Australia grew on the fore-reef slope to a depth of 45 m below the equivalent reef crest; the degree of depositional dip of the fore-reef beds was determined from geopetal structures. Gebelein (1969) has described in detail the growth of recent subtidal stromatolites in Bermuda. He found that laminae are asymmetrically thickened over exposed downslopes of sea grass beds and that thickening of laminae occurs on the up-current side of a stromatolite. This fact had been recognized earlier by Hoffman (1967), who used it as a criterion for current directions. These observations make it clear that the presence of stromatolites in the record cannot be used as an unequivocal indicator of intertidal or supratidal environments. Stromatolite growth is restricted to shallow depths of water, probably less than 50 m, the limiting factor being the intensity of light transmitted to the sea floor. In clear water, light penetration may be considerable; moreover, some algae have photosynthetic pigments which absorb and utilize the longer wavelengths of light, transmitted to greater depths of water (Strain, 1951, p. 256, Tappan & Loeblich, 1971, p. 266). It is possible that algal growth at this depth may have been sufficiently prolific to allow the formation of stromatolites. Stromatolites by themselves cannot be used to recognize specific shallow-water zones; it is necessary to evaluate all biological and sedimentological evidence.

PRECAMBRIAN STRATIGRAPHY OF THE ADELAIDE GEOSYNCLINE

In the Precambrian sections of the Flinders Ranges, only sedimentological evidence is available for environmental interpretations, and even this may be partly obliterated by diagenesis and incipient metamorphism. In discussing the environments of the stromatolites, it will be necessary to consider the overall sedimentation patterns throughout the basin at times of stromatolite growth, but palaeogeographic reconstruction is hampered by the following difficulties:

(1) lack of precise time-correlation between stratigraphic sections,

(2) the sparse distribution of directional features in the carbonate and argillaceous rocks (they are well

developed in the sandstones) and

(3) the general absence of fossils (other than stromatolites) by which to recognize specific environments.

In its regional mapping programme, the South Australian Geological Survey has consistently correlated rock units over large areas according to similarities of lithology and general stratigraphic position. That such correlations have a time significance has been implied or explicitly stated. Except in rare cases where rock units have been shown to intertongue, the time-parallelism of formations has been assumed. While rock correlations are an essential part of Precambrian stratigraphy, and provide a broad time framework (such as that used in stromatolite biostratigraphy), it may be argued that they must lead to invalid palaeogeographic reconstructions. An extreme form of this viewpoint has been expressed by Shaw (1964), who concluded that all widespread non-volcanic rock units deposited in epeiric seas must be diachronous, both for sediments derived from within the basin and outside it. Clearly, environment, including nearness to shore, was the only factor considered to determine sediment type: as the environment shifts in time, so the rock unit becomes progressively spread over a larger area. But this neglects factors such as climate or changes in the relief of source areas, which may have an instantaneous effect on sedimentation over the whole or most of the basin. Certainly, many facies can exist side-by-side at any one time, and the resulting formations are diachronous, but such relations should be determined where possibly by mapping of facies changes, or by tracing volcanic markers, or by palaeontological correlation.

The discussion is particularly pertinent to the Adelaide Geosyncline* - itself a deeply subsiding, but bathymetrically shallow intracratonic epeiric basin. The Precambrian of the Adelaide Geosyncline contains no volcanic markers, nor is it likely that any technique of Precambrian palaeontology will ever have sufficient resolving power to demonstrate the diachrony of any of the widespread formations. Three methods which may be applied to palaeographic reconstruction are (1) the detailed mapping of intertonguing relationships, (2) the use of Walther's Law (Walther, 1894), i.e. that a vertical sucession of facies in a complete sequence, reflects the lateral facies distribution at any one time, and (3) mapping the regional distribution of lithofacies. In addition, if widespread glacial deposits are present, and these can be correlated intra-regionally with confidence, they may be used to define approximate time-boundaries. Current direction data may aid in interpreting basin shape and patterns of sediment transport.

Field work was concentrated on relevant sections of the Umberatana Group, mainly in the south-western part of the Northern and in the Western Flinders Ranges; sections were measured at stromatolite occurrences and at other accessible sites. Lithologies sedimentary structures, stromatolites and bedding attitudes were determined where possible. Rarely, it was possible to measure current directions from sedimentary structures, chiefly ripple marks, but insufficient data

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* The term "Adelaide Geosyncline" is retained here as convenient although the basin is by no means a typical geosyncline.

were obtained for statistical representation. In the laboratory, thin sections were examined and the measured sections used to draw a fence diagram, and supplementary thicknesses were calculated approximately from published maps. These were combined to compile isopach maps of rock units in the Umberatana Group.

Stromatolites were studied and classified according to the methods developed in the USSR, as described elsewhere (Preiss, 1972, in press), into the form taxa "group" and "form".

Fig. 1 is a summary of the stratigraphic nomenclature currently used by the South Australian Geological Survey for the Adelaide Geosyncline, and indicates inferred correlations and rock relationships. The following authors were responsible for the mapping and nomenclature of the various areas - Adelaide region: Mawson & Sprigg (1950), Thomson (1966a); North Yorke Peninsula: Mirams (1964), Thomson (1966a), Thomson (1969); Mid-North: Wilson (1952), Mirams (1964): Southern Flinders Ranges: Thomson et al. (1964), Binks (1968); Central Flinders Ranges: Thomson et al. (1964): Northern Flinders Ranges: Thomson et al. (1964), Coats et al. (1969), Coats et al. (1972).

ENVIRONMENTAL INTERPRETATION OF THE SKILLOGALEE DOLOMITE

Regional Distribution

In the Adelaide region, the Aldgate Sandstone, basal formation of the Torrensian Series of Mawson & Sprigg (1950), is overlain by pale dolomites (Castambul Dolomite), followed by phyllites, then dark grey dolomites with chert and fragmental magnesite (Montacute Dolomite). This sequence is generally correlated with the Skillogalee Dolomite of the northern regions (Wilson, 1952), a formation low in the Burra Group which unconformably underlies the lower of the two Late Precambrian tillites. A lower member, (predominantly pale dolomite) and an upper member (dark, cherty dolomite) of the Skillogalee Dolomite have also been observed in many sections in the Flinders Ranges. Dolomites, frequently with fragmental magnesite, are extremely widespread throughout the Adelaide Geosyncline at the horizon of the upper member. Forbes (1960), in a study of these magnesitic sediments, has rarely observed lateral facies changes, and reports the great continuity of individual beds. Carbonates are replaced laterally by shales in the Adelaide region, where carbonates are restricted to the Torrens Gorge - Montacute region, and a few other minor occurrences. The Skillogalee Dolomite becomes continuous north of about latitude 34°S. Fig. 2 illustrates the distribution and thickness variation of the Skillogalee Dolomite over the Adelaide Geosyncline (modified from Forbes, 1961), and indicates the localities from which stromatolites have been collected.

The following comments may be made about the distribution of facies:

(1) The Skillogalee Dolomite is thickest (over 600 m) in the western and northermost regions.

(2) Columnar stromatolites are well developed in the northern region, especially Depot Creek, Hawker (near the Worumba Diapir) and Witchelina, while occasional stromatolitic beds were found at Copley, Arkaroola, Mundallio Creek, Yatina and the Burra-Robertstown region. A float specimen was found near Spalding.

No definite stromatolites were found south-west of a line joining Mundallio Creek and Robertstown; wavy bedded dolomites in Port Germein Gorge are more likely to be slump-folded than stromatolitic.

(3) Magnesite is most abundant in the Copley region (17% of the section) but magnesite conglomerate beds are also well developed at Mundallio Creek, Johnburg, Hawker and Arkaroola and west of Witchelina. Occasional magnesite conglomerate beds also occur in the Weekeroo area (the most easterly occurrence of the Skillogalee Dolomite).

(4) Sand forms the greatest proportion of the section (more than 30%) in the Witchelina and the Crystal Brook regions, while between 10 and 30% sand occurs at Adelaide, Bundaleer (near Spalding), Depot Creek, Mundallio Creek, Copley, Arkaroola and Johnburg. (Forbes, 1960). From the distribution of sand in the section, Forbes concluded that there were highlands to the west of Beetaloo. Similarly, greater sand proportions at Witchelina than Copley and Arkaroola might suggest a landmass to the north-west.

The map also indicates the present distribution of the Skillogalee Dolomite, largely controlled by the tectonism which occurred in pre-tillite times. In some areas, especially on anticlines with diapiric cores, Mines Department mapping has shown that local uplift caused angular unconformities or stripping of the Skillogalee Dolomite. Such major local uplifts occur at Mt. Remarkable, Yednalue, Worumba, and possibly, north of Witchelina. North of Mt. Painter, a low angle unconformity indicates stripping of the Skillogalee Dolomite (and lower units) prior to the deposition of the tillite. Similarly, the Burra Group is totally removed in part of the Weekeroo area by a 30° unconformity (Talbot, 1967), while to the north-east, the tillite directly overlies basement. Thus at least in post-Skillogalee times, there were uplifts on the northern and eastern margins of the basin, but the general absence of facies changes in the vicinity of the local uplifts suggests that these were not active during sedimentation. Since no Skillogalee Dolomite is preserved on the Stuart Shelf to the west of the Adelaide Geosyncline, and sand is concentrated in the western Flinders Ranges, it may be argued that the western basin margin was near the present Lake Torrens - Spencer Gulf area. But the northern and eastern margins of the basin at this time cannot be defined.

Stratigraphy of the Skillogalee Dolomite at Depot Creek

The section at Depot Creek on the western margin of the Adelaide Geosyncline is typical of many areas, and was the one most intensively examined during this study. The contact between the Skillogalee Dolomite and the underlying sandstone is gradational; over a thickness of 35m, medium and coarse grained feldspathic sandstones are progressively replaced by flaggy grey and pink dolomites, partly with disrupted bedding. One such dolomite band contains small ellipsoidal vughs, up to 1 cm long, lined with drusy dolomite, and lastly filled with coarsely crystalline quartz. The origin of these structures is uncertain: superficially, they resemble birdseyes, but their cross-cutting relationship to some silty laminae suggests that they are secondary solution voids. Polygonal mudcracks and current ripple marks on reddish shale partings are rather common in the sandstone interbeds, and easterly flowing currents are indicated (directions measured were 107°, 97° and 137°). Laminated green and reddish (weathered) shales become prominent above this level, and are interbedded with flaggy sandy dolomites, stromatolitic dolomites and wavy or cross-bedded dolomite . Irregular chert lenses are more common in the upper part of the section, and always occur replacing dolomite. Minor sandstones with dolomitic cements persist.

At about 100m above the base of the lowest dolomite bed, shales and siltstones predominate; in one instance, cubic halite casts were noted in poorly bedded dark grey mudstones. Pink to buff coloured dolomites occur as partly laminated, partly massive interbeds. The more massive beds are frequently biostromal, or consist of contiguous bioherms, up to 1m in diameter. The thickest biostromes are up to 2m thick, and comprise a new stromatolite form of the group _Tungussia_ Semikhatov. The upper boundary of the biostrome is an erosional surface, on which the transverse sections of columns are exposed. Shale deposition resumed after this diastem, and was gradually replaced by influx of sand, to form an 8m thick bed of feldspathic sandstone.

The upper member of the Skillogalee Dolomite, above this marker sandstone, is predominantly dark coloured, and contains numerous magnesite conglomerate beds, which are rare or absent in the lower member. Stromatolites occur only as isolated horizons, separated by platy and laminated but thick-bedded dolomites. Black chert either forms moderately continuous beds or irregular pods and lenses in dolomite. At least some of the chert is of late diagenetic origin, since it cuts across bedding or stromatolite columns. Interbedded magnesite clasts vary in diameter from 1 or 2 mm to 15 cm; in the latter case they are large, rounded curled mudflakes, which would have withstood virtually no transport. The *in situ* occurrence of small mound-like stromatolites within these conglomerates indicates that they were able to grow in essentially the same environment as that in which magnesite was forming. Forbes' suggestion that magnesite intraclasts were broken up by desiccation is especially applicable to these coarse conglomerates, in which many fragments are still curled. The Skillogalee Dolomite grades up into an essentially arenaceous sequence, in which arkosic sandstones with well rounded quartz grains and a dolomite cement predominate.

Other stromatolite localities.

A new form of *Baicalia*, *B. burra* (Preiss,1972, in press) occurs at all the other localities, and possibly at Depot Creek also. In the Burra area it occurs in biostromes up to 2m thick near the top of the upper member of the Skillogalee Dolomite. Magnesite is rare. Dolomites are generally very fine grained, except where recrystallized by metamorphism, and the sediment in stromatolite interspaces is predominantly micritic, with very rare intraclasts and ooids. This suggests growth in a relatively low-energy environment. Correspondingly, stromatolite columns are relatively regular and subcylindrical, with little evidence of contemporaneous erosion. Near Spalding magnesite conglomerates are common in the upper member, but stromatolites are rare (the only specimen found was in float).

The Skillogalee Dolomite is thin in the Yatina Section.

Here the stromatolites form small lenticular bioherms up to 1 m in diameter, which had relief over the surrounding depositional surface. Small intraclasts are common in interspaces, and there are slight micro-unconformities in the stromatolitic layering. The surrounding platy dolomites are micritic and dark coloured. Magnesite was not seen in the section, but the lower member, which here is flaggy rather than massive as is common elsewhere, contains on some bedding planes, rectangular markings resembling gypsum crystal casts.

Magnesites are very abundant in the Worumba section where stromatolite columns are more tuberous and irregular, and have more numerous micro-unconformities than at Burra or Yatina. The occurrences are biostromal, though the upper surfaces of biostromes are undulating, growth being concentrated at certain points along the bed. Magnesite conglomerate beds are frequently intercalated. Ooids and fine intraclasts are common in interspaces, suggesting intermediate energy conditions.

Similar conditions prevailed at Arkaroola where stromatolite beds are much rarer. Here the lower member consists dominantly of interbedded quartzites and siltstones, with pale coloured dolomite marbles at the base. Ripple marks and mud-cracks are very common in the quartzites. The upper member contains abundant magnesite conglomerates, with interbedded laminated dark grey dolomites, but stromatolitic biostromes were noted at only one horizon. Similarly, at Copley magnesites are extremely abundant, but stromatolites are restricted.

To the north, however, between Myrtle Springs and West Mount Hut biostromes are prolifically developed, with less magnesite. Here stromatolites grew in relatively the highest energy environment of all Skillogalee Dolomite occurrences; intrasparites fill interspaces between columns, and substantial erosional unconformities are evident in the stromatolitic layering, (Fig.3). Frequently large fragments of columns accumulated in interspaces and formed the base for new growth of columns. Biostromes are intercalated in laminated green shales, frequently mudcracked, representing lower energy phases.

It is seen that although Baicalia burra is almost ubiquitous in the Skillogalee Dolomite of the Flinders Ranges, its abundance varies and is difficult to relate to any particular sedimentological association.

Environment of deposition and palaeogeography

Forbes's (1960, 1961) conclusions regarding the depositional environments of the magnesitic rocks may be summarized as follows:-

(1) The frequent exposure and erosion of muds indicated by mud cracks and intraformational conglomerates, suggests a paralic environment.

(2) Dolomite was considered the closest approximation to a normal marine sediment, either as a primary precipitate, or more probably, as a penecontemporaneous replacement of calcium carbonate.

(3) Magnesite formed in the terrestrial environments, possibly by the admixing of continental alkaline water and magnesium-rich sea water, and was frequently eroded.

(4) The low carbon content of magnesite (compared to the dolomite rock) suggests that the magnesitic environment was unfavourable

to life.

(5) Repeated transgressions and regressions explain the cyclic alternation of marine and terrestrial sediments. During transgression, magnesite formed in marginal lagoons, while during regression, these sediments were eroded and reworked seawards, forming reverse-graded beds.

(6) Fig. 2, modified from Forbes (1961), shows the interpreted palaeogeography of the Adelaide Geosyncline during the deposition of the Skillogalee Dolomite. The central portion of the basin received magnesite detritus reworked from marginal lagoons during regressive phases, and dolomite muds during transgressions.

(7) Marginal uplifts, postulated from the relative amounts of terrigenous sedimentation, occur to the west and north of the Flinders Ranges; these are consistent with the known distribution of the Skillogalee Dolomite, and the positions of postdepositional unconformites. Marginal highlands apparently had the greatest relief west of Beetaloo, as deduced from the greatest proportion of sand in the Beetaloo - Crystal Brook areas.

Although in general, these conclusions are supported by my observations, a few points should be noted. Forbes suggested that the magnesitic environment was unfavourable to life, but at Depot Creek, stromatolites occur within a bed of little-transported magnesite clasts. Moreover, at the present day, blue-green algae are abundant in the hydromagnesite lagoons of the Coorong, South Australia. Forbes' marginal zone without magnesite (1961, Fig.5) is not well documented. Dolomites without magnesite conglomerates are common at both Crystal Brook and Robertstown, so that Crystal Brook is unlikely to have been less marine than Robertstown. The basin of deposition is likely to have extended northwards beyond the Willouran Ranges, since Skillogalee Dolomite also occurs in the Peake and Denison Ranges.

Throughout the area of the present Flinders Ranges, there must have extended a wide, extremely level platform of carbonate deposition. The absence of major lateral facies changes suggests that there was little variation in water depth from the margins to the centre of this platform, but deeper conditions probably persisted in the southern regions. Transgressions of the sea across the platform probably advanced northwards from the predominantly marine southern area. During transgressions, dolomite formed in extensive lagoons on the platform and magnesite in the most hypersaline marginal areas.

The origin of the dolomite and magnesite remains problematical; some may be formed syngenetically, but much of the carbonate is probably reworked. Alderman & Skinner (1957) reported primary dolomite precipitating from the Coorong lagoon waters, but current opinion favours the formation of syngenetic dolomite by the very early replacement of calcium carbonate (Freidman & Sanders, 1967, p. 294). Hydromagnesite forms in two ephemeral lagoons in the Coorong of South Australia (Von der Borch, 1965), but again its mode of origin is obscure. In the Persian Gulf, early diagenetic dolomite is reported associated with evaporites in sabkha (supratidal mud-flat) environments (Illing, Wells & Taylor, 1965) and an analogy could be drawn with dolomite with possible gypsum casts at Yatina. The association of bedded dolomites and conglomeratic magnesites appears to have no direct modern analogue. Magnesite, formed in coastal lagoons, was eroded during regressions and redeposited seawards as intraformational conglomerate. Much of the very fine grained dolomite, especially that forming the stromatolites, may also be of detrital origin, since there is no evidence of replacement and fine structures are excellently preserved. The Depot Creek area is likely to have been marginal at times as is suggested by the little transported magnesite intraclasts, but pebbles from other areas are usually well rounded.

Studies of the stromatolitic lamination, gross form, and interspace filling suggest highest energy environments in the Willouran Ranges area, and the lowest energy near Burra. The Willouran Ranges area was subject to strong wave and current action, and the stromatolites may have grown on exposed headlands. On the other hand, the Burra region may have been either lagoonal or a barred embayment, or slightly deeper water (Forbes, 1966, suggested a marine environment for this area), but a depth below normal wave base is precluded by the presence of stromatolites. In any case, the important point is that in these two extremes of environment, the one stromatolite form, Baicalia burra occurs. But the occurrences are not identical: the degree of regularity of columns and the presence or absence of contemporaneous erosional features are differences that can be ascribed directly to the energy of the environment.

ENVIRONMENTAL INTERPRETATION OF THE UMBERATANA GROUP

Regional thickness variation of the Umberatana Group

This section is concerned with the conditions of sedimentation throughout the basin during the interval of time between the major Late Precambrian glaciations of South Australia, which mark the top and bottom of the Umberatana Group. The sediments are preserved over very large areas, so that a regional palaeogeographic reconstruction can be attempted. The interval between the top of the lower tillite and the top of the upper (and its equivalents) was chosen for the construction of an isopach map because its boundaries are easily recognizable, and because it is a unit which, as a whole, is unlikely to be markedly diachronous. More-over, it represents the time during which stromatolite growth was most prolific, both in areal extent and in diversity; twelve forms have been distinguished. Fig. 4 is an isopach map compiled for this interval from sections measured from published Mines Department maps. Although the measurements are extremely approximate, and the map is therefore subject to considerable error, some trends are nevertheless evident:

(1) The overall axis of the basin is meridional, but ridges and troughs within it are frequently oriented E-W.

(2) The zone of maximum subsidence is a NNW-SSE trending trough centred in the south-eastern Central Flinders Ranges.

(3) Depth of subsidence decreases from here to the east and west, a ridge occurring between the trough and the western margin.

(4) In the Northern Flinders Ranges, a trough parallels the fold trends, and shallows to the north, east and south, suggesting a land mass peripheral to the north-eastern margin of the presently exposed sediments.

No rocks belonging unequivocally to this time interval have been found west of Lake Torrens, where Wilpena Group equivalents unconformably overlie earlier sediments of uncertain age (Pandurra Formation and Woocalla Dolomite) (Johns, 1968; Thomson, 1966a). The fact that within the Adelaide Geosyncline, the isopachs show rapid thinning to the west, suggests that Umberatana Group sediments were never deposited on the stable platform; the basin margin may have been situated somewhere near Lake Torrens and Spencer Gulf. A similar thinning occurring along the northern and eastern margins of the Northern Flinders Ranges, similarly suggests a land mass in these regions (the present exposed basement inliers at Mt. Painter and Olary are not remnants of this land mass, since they are overlain by a considerable thickness of Umberatana Group cover). In the south-eastern part of the COPLEY 1:250,000 Sheet area, the Umberatana Group is thin, suggesting proximity to the basin margin. The interpretative cross-section (Fig.5) across the ORROROO 1:250,000 Sheet illustrates the relationships and thickness variations of rock units from the margins to the centre of the basin in the Southern Flinders Ranges. These suggestions, based upon the patterns of thickness variation, are very largely confirmed by a study of the sediments themselves.

Regional stratigraphy

As now defined, the Umberatana Group commences with the glacials of the Yudnamutana Sub-Group, which rests unconformably upon eroded Burra Group sediments. The glacial sediments may have been deposited partly in shallow seas and partly as terrestrial moraines.

Tapley Hill Formation. This is an extremely widespread unit overlying the lower glacials with a sharp conformable or disconformable contact. The dominant lithology, a dark grey very thinly and evenly laminated siltstone, is present in all sections; in addition, various carbonate units may be interbedded. The persistence of a black shale at the base of the Tapley Hill Formation (Tindelpina Shale Member) has perhaps been overstated (e.g. Parkin et al., 1969, p.66) since in many areas, eg. Depot Creek, the Tapley Hill Formation sequence is siltstone throughout, except for thinly bedded grey dolomites, interbedded near the base of the formation. Such dolomites are widespread throughout the Adelaide Geosyncline; at Depot Creek, these are banded, dolomitic intrasparites and intramicrites containing fine rounded intraclasts and pellets, and represent a higher energy environment and more rapid deposition than the interbedded silts, so that periods of strong current action alternated with calm periods of slow settling of terrigenous silt. No stromatolites are known from this facies. Dolomites from other areas are chiefly micritic. The siltstones interbedded with the dolomites are dark grey, very thinly and uniformly laminated. Current structures are generally absent. The lamination is an alternation of 0.05 to 0.1 mm thick quartz-rich silt laminae and thinner organic-rich clayey laminae. Small amounts of carbonate cement are present.

T.H transgression would also explain absence

This lithology is maintained almost throughout the Tapley Hill Formation; however, current effects are visible in some places. In the type section south of Adelaide, much of the Tapley Hill Formation contains abundant current ripples, which indicate a fairly consistent south easterly current flow (Fig. 6). Most of the ripple marks are starved or isolated ripples (Walker, 1965) and contain slightly coarser silt-sized sediment. Rippled beds are separated from each other by evenly laminated silts several centimetres or tens of centimetres thick. Similar ripple marks near Clare indicate easterly-moving currents. The constancy of direction of the currents suggests that they are not tidal currents. In the far north-eastern part of the Flinders Ranges, the Tapley Hill Formation is apparently absent (Coats et al. 1969, Mt. Painter Province Map); here the Balcanoona Formation (normally above the Tapley Hill Formation) rests directly on the lower tillite. This probably is due to unconformity, but it is also possible that siltstones were not deposited in this area.

The following features characterize the Tapley Hill Formation. (1) its extremely widespread, continuous distribution, (2) its very fine, uniform lamination, (3) its dark colour (the silts and shales are often pyritic and rich in organic matter) and (4) the presence, locally, of isolated current ripples. These features suggest very slow deposition under reducing conditions, by settling of silts and clays. Occasionally, bottom currents laden with very little sediment, flowed down the palaeoslope towards the basin axis. The Tapley Hill Formation is best regarded as a basinal marine facies; its deposition, below wave base, is likely to have been in moderately deep water.

The interbedded dolomites of the basal Tapley Hill Formation are problematical. Since they probably formed in relatively shallower water, and the overlying silts in deeper water, the succession from dolomites to laminated silts is considered to mark a rapid marine transgression, perhaps related to a eustatic rise of sealevel after the cessation of the first major glaciation.

In most areas, the siltstones of the Tapley Hill Formation grade upwards into calcareous siltstones and silty banded limestones (Yankaninna Siltstone Member and equivalents). This unit is commonly cross-bedded; near Adelaide, south-easterly currents persist. At Maynards Well, North Flinders Ranges, large scale ripple marks of 15 cm wavelength consistently indicate south-westerly currents (Fig. 9).

Brighton Limestone. In most areas, the upper part of the Tapley Hill Formation becomes markedly calcareous, occasionally with thin limestone or dolomite interbeds (e.g. the Wockerawirra Dolomite of the Central Flinders Ranges). Well defined, thick limestone units occur above the Tapley Hill Formation near Adelaide and along the western margin of the Southern Flinders Ranges (Brighton Limestone and equivalents), while the Balcanoona Formation of the Northern Flinders Ranges is of similar facies and probably corresponds in age, at least in part, to the Brighton Limestone (see table, Fig. 1). Fig. 6 is an isopach map of the Brighton Limestone and its equivalents in the southern part of the Adelaide Geosyncline; their distribution has been deduced from 1:250,000 maps and from sections measured in the field. The map shows that the Brighton Limestone equivalent is mainly restricted to the western margin of the basin, and thins rapidly towards the east. At approximately latitude 32°, the Brighton Limestone lenses out to the north, as it does also south of latitude 33°. South of this latitude, there are lenticular limestone occurrences near Booborowie, near Kapunda, and at the type area south of Adelaide. The Brighton Limestone of the type section is probably not continuous with its equivalents in the north. East of the main outcrop of Brighton Limestone equivalent in the Southern Flinders Ranges, a very thick limestone lens occurs centred near Yednalue. The isopachs also show two centres of maximum limestone deposition near Melrose and near Depot Creek, separated by a reduced section immediately east of Port Augusta. Where the Brighton Limestone lenses out, its time-equivalents are either calcareous, Tapley-like siltstones with minor dolomites (Yankaninna Siltstone Member to the north) or wavy bedded and sandy siltstones (Tarcowie Siltstone to the south and east).

In the type section near Adelaide the upper, calcareous part of the Tapley Hill Formation grades into scoured and cross-bedded silty limestones, with flat-pebble breccia-limestone lenses and rare dome-shaped stromatolites. This unit is overlain by pinkish and blue-grey partly cross-bedded ooid and intraclast grainstones with minor calcareous siltstones and fine sandstones at the base. The uppermost member of the Brighton Limestone is a pink to buff coloured laminated dolomite, containing flat-pebble breccias and oolites. Allochems are supported by micritic matrix, but the whole rock is dolomitized. Intraclasts are tabular, with well rounded edges. The laminated dolomites contain broad, concave-upward sharp-crested fold structures up to 20 cm wide; these occur in fine bands separated by erosional surfaces and are therefore of intraformational, not tectonic origin. The upper beds of these buff-coloured dolomites are thinly interbedded with green silts and gradually the deposition of terrigeneous clastics became dominant. The overlying beds are thinly bedded grey and green siltstones with purple, ripple-marked and desiccation-cracked mud laminae, indicative of frequent intermittent exposure.

In the Southern Flinders Ranges, an essentially similar sequence of facies is observed. The section at Depot Creek is typical. The transition from Tapley Hill Formation to Brighton Limestone is marked by periodic cessation of terrigenous sedimentation, accompanied by stromatolite growth. At the base of each stromatolite bioherm is a diastem; the surface of the silts was scoured, and stromatolites grew on the elevated points, while channels were filled with imbricated flat-pebble breccias (Fig.7). In places, columns are slightly elongated in an east-west direction which is consistent with a north-south trending shoreline (cf. Logan, 1961; Hoffman, 1967). Typically, the stromatolites commence as domes on erosional highs in the underlying silts, and frequently the lamination in the silts is also domed; this is interpreted as a compaction effect. Silt deposition was frequently resumed during the late stages of stromatolite growth, as indicated by intertonguing.

The flat-pebble breccias filling the erosional channels around the periphery of bioherms are poorly sorted, either with lime mud supported intraclasts, i.e. wackestones of Dunham (1962), or pellets and large intraclasts with sparry cement. The intraclasts are randomly stacked, or in places irregularly imbricated, and frequently cover spaces sheltered from lime mud sediment, but now filled with sparry calcite. In addition, sparry calcite and pellets of authigenic chlorite fill voids left by the selective leaching of intraclasts. Davies (1970) recorded flat-pebble breccias from the intertidal zone of the Gladstone Embayment, Shark Bay, W.A., formed by brecciation and upwedging of indurated crusts. These pebbles may in turn be reworked during storms. A similar origin is plausible in the Brighton Limestone example, but here the pebbles are chiefly dolomitic, as are those of the Alpine Triassic (Germann, 1969), unlike the aragonitic crusts of Shark Bay.

The transitional zone between the Brighton Limestone and the Tapley Hill Formation is followed by very massive limestones including large bioherms and thick ooid and intraclast grainstone beds. The bioherms of new forms of Acaciella Walter and locally Inzeria Krylov occupy various lateral and vertical positions in this unit, whose dominant rock type is a poorly bedded ooid grainstone with intraclasts themselves composed of cemented ooids. At many levels throughout the oolitic limestone sequence, there is evidence of contemporaneous scouring and cross-bedding. Cross-bedding in channel fills indicates easterly and south-easterly flowing currents. Ooid grainstone filling channels contains fewer large intraclasts than the surrounding sediment, and is crudely banded, oolitic laminae alternating with silty micrite laminae.

The bioherms within this facies vary greatly in dimensions (map, Fig. 8). Some are domed, and stood above the surrounding sediment surface with a relief of at least one metre, but most interfinger with the oolitic limestones, so that their relief at any one time must have been much less.

In the Melrose area there are bioherms of new forms of Inzeria and Boxonia, surrounded by similar oolitic and intraclastic limestones to those at Depot Creek, but here the field relations are less clear, due to poor exposure. At Yednalue, an essentially similar facies, again thoroughly winnowed, occupies a great thickness below the thick stromatolitic beds. In the extreme south of the Brighton Limestone equivalent outcrop near Tarcowie (south of Orroroo), strongly recrystallized ooid grainstones contain up to 20% quartz and feldspar sand.

The oolitic-intraclastic facies of the Brighton Limestone represents a very shallow marine environment of high energy, to provide agitation necessary to form regularly laminated ooids and to deposit them in thick beds, often with large scale cross-bedding and scouring. Moreover, the sediment is generally well-winnowed, again indicating strong current or wave action. The environment is interpreted as very shallow subtidal or littoral, in the zone of maximum wave action.

In places at Depot Creek, the oolitic-intraclastic facies is dolomitized. The dolomite has extremely sharp, discordant boundaries, and is interpreted as being late diagenetic or epigenetic, probably related to minor faulting. Since here the dolomitization is complete and cross-cutting it is probably not related to the selective dolomitization of dark laminae in stromatolite bioherms. Both ooids and sparry cement are completely replaced by hypidiotopic to idiotopic dolomite.

In the Horrocks Pass-Pichi Richi Pass area, the Brighton Limestone is thin and sandy. In Horrocks Pass, the uppermost part of the Tapley Hill Formation contains at least one small, lenticular channel fill of cross-bedded, sandy limestone, indicating approximate northerly current flow. But the dominant facies is a large-scale cross-bedded sandy and gritty limestone. In Pichi Richi Pass, the Brighton Limestone is reduced to three massive thick sandy dolomite beds. The sandy lithofacies may have formed in a small delta, with a westerly river supply.

The upper member of the Brighton Limestone, as seen at Depot Creek, is entirely dolomitic. Massive pink to buff coloured dolomites overlie the intraclastic-oolitic facies, and grade up by interbedding of reddish dolomicrites into the overlying Willochra Formation (dominantly red-beds), in a sequence similar to that of the Adelaide region. Sandy, fine intraclastic and oolitic dolomite facies grade into each other both vertically and laterally.

The lowest unit of this upper dolomitic sequence is a pink dolomitized fine grained limestone up to 13m thick with interbedded silty bands. In the northern part of the map area (Fig.8), channel-fill lenses and more extensive beds of partly cross-bedded poorly sorted, dolomite-cemented sandstone occur interbedded with the above dolomitized limestone. Stromatolitic bioherms of a new form of Katavia Krylov are intercalated between two such sandstone beds. Insufficient cross-bedding was visible to allow any generalization about current directions, but north, north-westerly and westerly flows were noted.

Overlying the sandstones in the north and the dolomitized fine limestone in the south, is a very continuous, 2m thick unit of thick-bedded oolitic and finely intraclastic dolomite. Intraclasts are small flat pebbles, 0.5 to 5.0 mm long, lying parallel or at a low angle to the bedding. Many are coated grains, with 0.1 mm thick rims of micritic dolomite, which might be interpreted either as algal boring or dolomitized superficial oolites (Illing, 1954). True ooids also occur, but their fine structure is largely obliterated by dolomitization. The sediments are frequently poorly sorted. Allochems are mostly supported by fine grained hypidiotopic dolomite interpreted as dolomitized lime mud, but some specimens are better winnowed and sorted, with up to 15% quartz and/or feldspar sand, cemented by sparry dolomite. The proportion of terrigenous clastics increases towards the north of the Depot Creek area. In places, voids up to 5 mm long, lined with drusy dolomite cement, occur between ooids, and are filled with a second generation of very coarse, sparry dolomite. The origin of the voids is not clear; they cannot be formed by the simple winnowing out of mud, since their roofs could not have been self-supporting. An origin by partial desiccation or expulsion of water, akin to the formation of birdseyes in lime muds (Shinn, 1968) is possible, but in the Adelaide region, well sorted dolomitized ooid grainstones contain similar calcite-filled voids, which in at least one specimen, show evidence that they were formed by solution. A transitional sequence of interbedded pink dolomites and thin purple shales passes up gradationally into the overlying Willochra Formation, in which thin dolomites persist for up to 16m. Typically, the dolomites are thinly bedded alternating sandy intrasparites, laminated intramicrites and thin layers of reddish dolomicrite. Most intraclasts are large and of tabular form and frequently grade laterally into undisturbed micritic layers, but small, coated grains and some true ooids also occur. Micritic layers were apparently disrupted, perhaps by desiccation, and redeposited as intraclasts more or less _in situ_. Davies (1970), considered that indurated crusts may be brecciated in place by thermal expansion and contraction, and by volume changes due to induration.

In places, the micritic layers are arched up to form adjacent concave-upward structures (similar to those of the Adelaide Region), but here the arching frequently left voids which are now filled with sparry dolomite; these structures suggest lateral compression of cohesive, partly indurated, dolomitized lime mud layers. Large void spaces, common in the fine grained, silty and micritic sediments, are usually concordant with laminae and intraclasts, but occasionally their floors truncate laminae; they resemble the planar birdseye structures of Shinn (1968) which he attributed to the repeated shrinking and swelling of lime mud in the intertidal and supratidal environments.

Dolomitization in the upper member of the Brighton Limestone is always stratiform, not cross-cutting, and has affected all carbonate sediments, so that no limestones are preserved. The presence of dolomitic ooids proves that the dolomite is secondary, not detrital, since ooids are precipitated as aragonite. The good preservation of fine structures and the fine grain size of the dolomite suggest a very early diagenetic replacement of lime sediments, probably in a supratidal mud-flat environment similar to the modern sabkhas of the Persian Gulf (Illing, Wells & Taylor, 1965 and Kendall & Skipwith, 1968). The pink and reddish colours of the dolomites are consistent with deposition under oxidizing conditions, as is suggested by the red-bed sequence above.

Willochra Formation. The overlying Willochra Formation consists of lenticular-bedded silts and sands, often poorly sorted, with very numerous thin, wavy, purple clay laminae, 1 to 5 mm thick. The rock frequently parts along these laminae, and where partings are well exposed, oscillation ripple marks, and mudcracks are observed extremely frequently. Mudcracks, often superimposed on ripple marks, are usually of sharply V-shaped cross-section, and filled with silt and fine sand. Most are polygonal, while some display a round or concentric pattern. Oscillation ripple marks generally have meridional axes, both at Depot Creek and Adelaide, and the few that are slightly asymmetrical indicate both easterly and westerly current directions. Occasional interference ripples trend NW-SE.

The clay laminae owe their purple colour to extremely finely disseminated hematite, which together with frequent mudcracks indicates frequent exposure to the atmosphere. The influx of coarser terrigenous clastics was resumed periodically. Sandy layers are commonly graded, and pass up into purple clay laminae. An extensive lagoonal or mud-flat environment of low energy is envisaged, periodically flooded, perhaps by storm waves, which deposited the graded silty and sandy beds. During the following quiescent periods, muds were deposited in extremely shallow water under very mild wave action producing the small-scale oscillation ripple marks. The mud-flats were then exposed and desiccated, before the next inundation and deposition of coarser clastics. Dolomite deposition was still important at the gradational base of the formation, but was entirely replaced higher in the sequence by clastic sedimentation.

The facies of the Willochra Formation is replaced to the north and east by green and grey beds, lacking evidence of subaerial exposure. The rippled and lenticular bedded Tarcowie Siltstone and the massive-bedded Uroonda Siltstone (occurring east of the Willochra Plain) are interpreted as slightly deeper water equivalents of the Willochra Formation. To the north of Warrakimbo

(PARACHILNA 1:250,000 sheet), the Willochra Formation passes into thinly laminated green silts and shales (part of the Etina Formation).

Etina Formation. In the type section south of Adelaide, the equivalents of the Lower Willochra Formation (the lowest purple slates immediately above the Brighton Limestone), are overlain by cross-bedded gritty and sandy limestones (the Marino Arkose), characterized by abundant large, fresh, red feldspar grains. Cross-bedding indicates varying current directions, both northerly and southerly, while interference oscillation ripple marks trend both EW and NNW-SSE. These varying directions suggest deposition in extremely shallow water, under the effects of tidal currents, and perhaps long-shore drift.

In the Quorn region, lenses of similar cross-bedded gritty limestones are scattered at various levels in the Willochra Formation. Near Buckaringa Gorge to the north these become continuous, and then thicken continuously northward; they form the southern extension of the Etina Formation of the Central Flinders Ranges. The distribution and thickness variations are shown on the isopach map of the Etina Formation (Fig.9). On the PARACHILNA 1:250,000 Sheet, gritty limestone interbeds in a predominantly green shale sequence, increase in number and thickness towards the north, so that the whole Etina sequence reaches a maximum thickness of nearly 1300m in the Oraparinna region. North of the vicinity of Arkaba, stromatolitic and oolitic limestones also become important. It is very probable that in the Central Flinders region, Etina deposition commenced long before it did near Quorn; the Etina Formation here may be partly time-equivalent to the Brighton Limestone in the south. North of Blinman, the Etina Formation thins gradually and may be differentiated into a lower thick, partly dolomitized part and an upper part consisting of green shales with interbedded, thin limestone, or in places, dolomitized limestone bands. These are to be correlated with the Balcanoona Formation and the Wundowie Limestone respectively, whose type area is near Balcanoona H.S. In the Northern Flinders Ranges, a thick wedge of Balcanoona-Wundowie sequence runs west from Balcanoona through Burr Well and Wundowie Bore, on the northern margin of an area of thin Umberatana Group sedimentation. To the north of this, the Balcanoona Formation and Wundowie Limestone thin and lens out.

The Balcanoona Formation of the Northern Flinders Ranges occupies a similar position to the Brighton Limestone in the south, and is in general of similar facies. In particular, in the Balcanoona area, a transition from laminated silts (Tapley Hill Formation) passes through flaggy dark grey limestone, flat pebble breccias and stromatolitic bioherms, massive bedded dark grey limestones consisting of irregularly columnar and wavy stromatolites into buff coloured dolomites with interbedded red shales. To the west of the Paralana Fault, the red shales of the Angepena Formation are replaced by green silts and shales of the Amberoona Formation (see Coats et al., 1969, Mt. Painter Province map).

Fig. 10 is a fence diagram showing the relationships of the Balcanoona Formation, Wundowie Limestone and the various red and green shale units of the Northern Flinders Ranges. The bedded, buff-coloured dolomites of the top of the Balcanoona Formation pass westwards into predominantly oolitic limestones, occasionally with stromatolitic interbeds. Here dolomitization does occur (e.g. at Angepena, Burr Well or Wundowie Bore), but the dolomite is coarse grained, cross-cutting and clearly late diagenetic or epigenetic, and may destroy the gross structures of the rock, even the bedding. The oolitic limestones of the Balcanoona Formation are typically ooid grainstones with ooids chiefly 0.75 to 1.0 mm in diameter, cemented firstly by drusy and then by granular sparry calcite cement. Composite ooids are also common. Authigenic quartz may replace ooid nuclei. Various micritic intraclasts, sometimes recrystallized, are incorporated in the sediment, but are generally of small size (less than 5 cm.).

The Wundowie Limestone interbedded in the Angepena and Amberoona Formations, is dominantly of stromatolitic facies. Commonly, individual limestone beds consist of contiguous domed stromatolite bioherms. Five different forms have been distinguished in different areas, all in essentially the same lithological context. Associated gritty limestones either overlie or underlie the stromatolites; in places bioherms were rapidly buried by the deposition of the coarse clastics. At Burr Well, cross-bedding and current ripple marks indicate mainly southerly flowing currents, while at Roebuck Bore, the gritty limestones are deposited in south-east to south trending channels. The Wundowie Limestone is likely to be diachronous, as is suggested by its highly variable stratigraphic position relative to the Balcanoona and Elatina Formations. Moreover at Burr Well, stromatolitic beds and lenticular gritty limestone beds intertongue at various levels with the interbedded green shales.

The environments of deposition of the Etina Formation, Balcanoona Formation and Wundowie Limestone are likely to have been very shallow subtidal. The abundance of stromatolites limits the depth of water to about 30 m while the well washed oosparites indicate a high energy regime, probably under intense wave action. There is no evidence of subaerial exposure; but in the Balcanoona area to the east, the uppermost bedded dolomite of the Balcanoona Formation may be supratidal or intertidal; this area is considered to represent the eastern basin margin. The cross-bedded gritty limestones, frequently filling scour structures in the Etina and Wundowie Limestone are likely to have formed in tidal channels.

The overall extent of these formations, as seen in Fig. 9 suggests shallow-water conditions over most of the northern part of the Adelaide Geosyncline at this time, thus distinguishing it from the southern region, where very shallow-water facies are restricted to the western margin. However, the bulk of the sediment of the Etina Formation and its equivalents is grey-green shale, which tells little of its environment of deposition. The limestone units are probably diachronous at least in part, so that areas of shallow water may have migrated laterally in time, within a slightly deeper basin. These shoals which were the sites of lime-deposition may have been in the form of EW off-shore banks, which, in turn probably sheltered the intervening areas of mud deposition from current and wave action. Thus the evenly laminated green shales may have accumulated in rather shallower water than if formed in the open sea. The laminated green silts and shales of the Amberoona Formation and Enorama

Shale (Thomson et al. 1964), are identical to those interbedded with limestones in the Etina Formation and its equivalents. If the above depositional model is accepted for the Etina Formation, then the absence of these sandy and oolitic limestones or other high-energy sediments in the overlying shales would indicate an overall deepening of the basin, though not necessarily synchronously everywhere.

Trezona Formation. The Enorama Shale of the Central Flinders Ranges is overlain by shales with interbedded stromatolitic and intraclastic limestones of the Trezona Formation (the "Hieroglyphic Limestone" of Mawson, 1938). Although the extent of this formation has not been accurately delimited, it is apparently restricted to the central portion of the Adelaide Geosyncline, being thickest in the Wilpena-Blinman region. The "hieroglyphic" beds are commonly reddish coloured limestones, consisting of curled minute mudflakes set in a sparry calcite matrix. Nearly all the mudflakes are now replaced by sparry calcite of another generation, apparently filling cavities left by their dissolution. The stromatolitic beds of the Trezona Formation consist of large elongated mounds at several localities and in several levels, interbedded in laminated shales, near the base of the formation. At Enorama Creek, the elongated mounds are consistently oriented with their long axes at 162°, suggesting that they were shaped by currents. Cuspate ridges on their surface trends at an azimuth of 60°, i.e. approximately perpendicular to the major elongation. The environmental significance of these structures is not clear; an analogy may be made with the tufted mats of Shark Bay (Davies, 1970). At this stage the regional significance of these observations cannot be assessed; moreover no independent evidence for current directions has so far been found in the Trezona Formation, as it has in the Pethei Formation of Canada (Hoffman, 1967).

The Umberatana Group closes with various facies of the Elatina Formation, and its tillitic equivalents.

Notes on diapirs. Coats (1965) showed that diapric movement occurred in some areas during sedimentation or was associated with minor angular unconformities at the base of the lower tillite. He quoted the presence in the sediments surrounding a diapir of detritus derived from the diapir as evidence of its activity during sedimentation. An example of this is the occurrence of conglomerate wedges on the flanks of the Enorama diapir, in the limestones of the Etina Formation. Thus diapiric activity during Etina deposition is established. But the Enorama, Oraparinna and Blinman Diapirs all lie on or near the axis of a trough of maximum deposition of Etina Formation and Umberatana Group. Despite spasmodic uplift on diapirs the basin continued to subside in this area, although no sediment could have accumulated over the actual diapirs during their shedding of detritus.

Fig. 9 shows the distribution of diapirs in relation to the Etina Formation and its extensions in the north. The close correlation between them is evident. It is suggested that the diapirs, which are concentrated in the thick axial zone of the Adelaide Geosyncline, may have been the factor responsible for periodic shallowing in this part of the basin. During periods of subsidence, green and grey muds would have settled in relatively deeper water; periodic diapiric uplift would have brought the sea floor above wave base, allowing the accumulation of sediments characteristic of shallow, agitated water, i.e. the sandy limestones of the Etina Formation. Provenance studies may reveal how much of the terrigenous detritus is derived from diapirs. In the south-eastern part of the basin, where there are only two small diapirs, the Etina Formation is absent. Here relatively deeper water conditions persisted throughout the time between the glaciations.

Palaeogeography of the Umberatana Group

The interpretation of the facies described in terms of palaeogeography is speculative, owing to the difficulties outlined. If a model of the Adelaide Geosyncline as an intracontinental, epeiric basin is accepted, them much of the lateral and vertical facies variation should be explicable in terms of transgressions and regressions of the sea. In general, the marginal areas will be the shallowest, and the central portion deeper, unless other factors intervene to raise or lower the basin floor.

The palaeogeographic interpretations are summarized by the maps A to H, Figs. 11, 12, 13, 14. Map A represents the beginning of Tapley Hill time. The meridional trend of the basin is already established, with land masses on the west (the Gawler Platform) and the north-east ("Paralania" of Sprigg, 1952). A trough probably extended north-westwards in the present Willouran Ranges. Following the cessation of glaciation, the melting of ice caused a widespread transgression; almost the whole basin was inundated, but the glacial sediments deposited near the shores of "Paralania" could have been emergent. The western margin of the basin, marked by the presence of pelletal dolomites probably deposited in very shallow water, was near the present western margin of the Flinders Ranges.

During the middle part of the Tapley Hill time (Map B), relatively deep water conditions persisted over the area, but the marginal zone near "Paralania" may have received carbonate sedimentation. The western shoreline is unknown, but may have been far to the west of Lake Torrens and Spencer Gulf. At this stage the transgression had reached its furthest extent, and laminated silts and muds were laid down by settling over wide areas. Periodically, sediment-impoverished currents flowed eastwards down the basin floor in the southern region.

The following stage (Map C) was a general regression, marked by shallowing of water in the western and north-eastern regions. In the type area south of Adelaide, silts were now mixed with significant amounts of lime mud, and deposited well within the depth zone of active, easterly flowing currents. In the Depot Creek region, sedimentation ceased periodically, and stromatolitic bioherms grew in shallow water on small erosional mesas, while flat pebbles and pellets derived from the local erosion of algal mats, accumulated in the intervening channels. Bioherms possibly similar to these grew on the north-eastern margin of the basin near Balcanoona. Elsewhere, in the basin centre, slightly deeper conditions persisted but even these were periodically disturbed during the next phase (Map D).

By now the basin had re-established its former restricted extent, with shallow marginal zones in the west and north-east, and a deeper central and south-eastern zone, near the basin axis. In the areas near Adelaide, Melrose and Depot Creek, well-washed and sorted oolites were deposited in the littoral or shallow subtidal zones under intense wave action. Stromatolite bioherms grew in the Depot Creek and Melrose regions, while in the intervening Port Augusta vicinity, sandy limestones accumulated perhaps in a delta with a western river supply. Thick banks of oolitic limestone similar to those of Depot Creek accumulated at

Orroroo and east of Yednalue. Deeper water persisted elsewhere (except for minor limestones at Booborowie and Kapunda,) but in the northern half of the basin, in the zone of the largest diapirs (few diapirs occur outside it), water depth was shallowed periodically by diapiric uplift. The sea floor was brought above wave base, and carbonate deposition, principally oolitic, commenced. Stromatolite bioherms grew in places, and local influxes of sand could have been derived from the erosion of diapirs.

The final phases of the regression (Maps E and F) affected only the marginal zones of the basin. Near Adelaide, Depot Creek and Balcanoona, supratidal dolomites were deposited, with a mild influx of quartz sand. Thick stromatolitic limestones grew on the oolite bank near Yednalue. Intermittent limestone deposition in the deeper central portion of the basin was encroaching further south, while the deposition of laminated silts continued elsewhere.

Terrigenous clastics now replaced dolomites in the supratidal flats of the basin margins, and carbonate deposition was reduced in the central part of the basin (Map F). In the western zone, storm waves brought sands, silts and muds onto the flats - subsequent exposure oxidized and desiccated the muds above each coarse cycle. At the next stage (Map G), the western and north-eastern belts of red muds were still marginal, with tidal channel deposits occurring in the sandy limestones near Adelaide, Kulpara and Buckaringa Hill. The south-eastern part was a shallow marine basin, while the northern central part continued to be shallowed periodically by diapiric activity. By now, the shallow water limestones extended through most of the axial part of the basin in which diapirs occur.

Oolitic limestones, stromatolitic bioherms and sandy limestone channel fills predominated in sediments formed in the agitated zone. After each burst of local diapirism, the basin floor again subsided, allowing more silts and clays to be deposited below wave base. Thus although diapirs rose periodically, shallowing the basin floor, the overall tendency was [illegible] the basin to sink, allowing a great accumulation of sediment. The The greater overburden in turn facilitated diapirism.

Map H shows the basin during a minor transgression which ensued. Limestone deposition ceased almost entirely. On the western margin, the land mass of the Gawler Platform probably rose and supplied the sands and silts of the Upper Willochra Formation, while to the east, only silts persisted (Tarcowie Siltstone). The remainder of the basin received laminated green muds and silts (Enorama Shale), in moderately deep water (except for oxidized red muds, Angepena Formation). Diapirs were inactive, but may have subsequently been reactivated in the Central Flinders Ranges, thus shallowing the basin there, and allowing the deposition of the Trezona Formation, in the area shown.

The palaeoecology of Umberatana Group Stromatolites

Brighton Limestone stromatolites. At Depot Creek the initial stages of the post-Tapley Hill Formation regression were marked by repeated minor diastems, and small, lenticular stromatolite bioherms [illegible] utilized the low, erosional remnants between channels cut into the marine silts, as high points on which to commence growth, (Fig. 7). Flat pebbles in the channels are variously imbricated; the frequent reversals of direction suggest the influence of tidal currents. Varying energy conditions are represented by winnowed grainstones and muddy wackestones (intramicrites). In interspaces, flat pebbles and comminuted pellets are partly winnowed, partly mud-supported, but always randomly packed. Columns probably acted as baffles preventing imbrication by currents. Stromatolite columns and mounds are frequently slightly elongated in response to E-W currents.

The stromatolites consist of alternating dolomitic and calcitic laminae. At least some of this dolomite is detrital, since pellets and intraclasts were transported as dolomite, but the origin of the idiotopic, granular dolomite in the dolomitic (darker) laminae is not clear. Dolomite laminae alternate with well winnowed pellet grainstone laminae, which had considerable void space, and grade down in places into lenticular calcite spar-filled voids resembling the fenestral structure of some Recent intertidal stromatolites at Shark Bay. Carbonate sediments were dolomitized penecontemporaneously in the supratidal zones, and during the periodic cessation of terrigenous silt influx these were reworked, possibly several times, and the detritus was incorporated into stromatolites and interspace sediments. Many flat pebbles are probably lithified chips of algal mats. But the mats were incapable of binding material coarser than sand size, so that the larger intraclasts remained in the interspaces. Shrinkage of laminae may have played a part in forming fenestral voids. The occurrence of winnowed flat-pebble breccias, variously imbricated, and voids in the stromatolitic lamination are suggestive of the intertidal zone of deposition, but the general absence of desiccation features <u>in situ</u> suggests rare exposure. An upper subtidal position is therefore envisaged, but sea-level probably fluctuated, with alternating cycles of terrigenous marine deposition, non-deposition and carbonate deposition.

Omachtenia utschurica in this unit had little more than 1 or 2 cm of growth relief between columns and interspaces, as indicated by the numerous bridging laminae; sedimentation in the interspaces kept up with stromatolite growth, but was periodic. Larger mounds with hemispherically domed laminae had at least 10 to 30 cm of relief above the surrounding erosional channels.

The stromatolites Acaciella augusta Preiss (1972, in press) and a new form of Inzeria occur within the oolitic-intraclastic facies of the Brighton Limestone, in bioherms often much larger than those of Omachtenia utschurica. In the Melrose region, Boxonia melrosa Preiss (1972, in press) and another new form of Inzeria occur in a similar sedimentalogical situation. These stromatolite bioherms are not localized on erosional highs, but extended laterally for up to 2km. At the margins, the bioherms either intertongue with the surrounding sediment, indicating the contemporaneity of the growth of the stromatolites and sediment buildup, or stood in relief above the sediment surface. The interpretation of depth of water is limited by the presence of oolites to the intertidal and shallowest subtidal zones. The sediments were distributed by strong, easterly flowing currents (this is interpreted as basin-wards). Cemented oolitic intraclasts partially dolomitized, were probably exposed and lithified nearer to shore, and reworked by these basin-ward currents. Alternatively the ooid grainstones could be beach ridge deposits laid down by ebb tides. Thus the bioherms accumulated in an essentially littoral environment.

Some Acaciella augusta bioherms are hemispherical with radially arranged columns at their margins. Their growth relief is up to 2 m. For the tops of these bioherms to avoid total desiccation, they must have been covered at least at high tide, indicating a low intertidal to subtidal environment. Others, in which continuous mats extend (as bridges) throughout the bioherm at various repeated levels, and protrude as tongues into the surrounding sediments, had virtually no growth relief. Such bioherms could have formed in the shallowest intertidal zone. Thus Acaciella augusta formed bioherms, possibly throughout the whole intertidal to shallowest subtidal interval. Energy conditions between columns varied, but were generally lower than outside the bioherms. The lamination in the interspace sediment indicates its accumulation after the growth of the adjacent portion of column, but this does not necessitate a high relief between column and sediment. Under low energy conditions, micrite accumulated in the interspaces, but periodically, small flat pebbles were introduced and stacked randomly. Interclasts are found in varying states of dolomitization, and may represent lithified, eroded algal mats reworked from higher levels. Columns were sufficiently closely spaced to dampen the high energy conditions prevailing outside the bioherms, and ooids were rarely transported into them.

The upper dolomitic member of the Brighton Limestone represents the shallowest zone of deposition, and also marks the first appreciable influx of terrigenous detritus. Lime mud sediment was penecontemporaneously dolomitized at the surface, preserving most fine structure. Deposition on supratidal flats is envisaged, and here algal mats were not conspicuously developed. They may have been present, but if so have left no recognisable trace in any modification of the sediments. If a continuous shallowing is assumed between the ooid grainstone facies and the laminated supratidal dolomites, then the bioherms of Katavia

f. nov. must have occupied an intermediate position, perhaps in the higher intertidal zone. But the bioherms had substantial relief, up to about 1 m, as is shown by downturned growth-surfaces at their margins. Thus they characterize a zone shallow enough to be subject to total dolomitization but deep enough for their upper surfaces to remain moist; this could have been achieved in the upper intertidal or in the lower supratidal zone during high tides. The question arises as to whether the poorly developed lamination of this form of Katavia is a primary feature or whether the lamination was obliterated by dolomitization. The good preservation of lamination in the non-stromatolitic supratidal dolomites suggests that the stromatolites may have had indistinct lamination originally.

The rarity of stromatolites in the Brighton Limestone near Adelaide is problematical. The essential similarity of the Tapley Hill Formation-Brighton Limestone-Willochra Formation sequence in the Adelaide and south-western Flinders Range areas suggest that these two areas passed through the same successive changes in water depth (though not necessarily synchronously). Thus at least at some stage of regression the water must have been of a suitable depth for stromatolite growth. By analogy with Depot Creek, stromatolites should be expected as bioherms in the oolitic facies; as yet only one example of mound-shaped stromatolites has been found in this facies. Present day stromatolites are restricted to hypersaline environments, but this can be interpreted as a biological restriction by browsing predators (Garrett, 1970) which generally find the hypersaline environment uninhabitable. Such predators were rare or absent during the Precambrian, so that we may expect the present salinity restrictions not to apply. A climatic factor may have been responsible, but if so, has left no trace in the sedimentary record.

Etina Formation stromatolites. On northern Yorke Peninsula a sandy limestone bed, probably equivalent to part of the Etina Formation, contains stromatolites of the group Kulparia (Preiss & Walter). There was considerable influx of coarse terrigenous detritus, and current activity was sufficiently strong to transport coarse sands and grits to the site of stromatolite growth. Although quartz silt and fine sand were incorporated into the stromatolitic laminae, the algal mats were incapable of binding the coarser detritus, which accumulated in the interspaces as winnowed grainstones. A very high energy environment is therefore suggested, even within the stromatolite bed. The columns had little relief over the sediment surface; bridges are frequent on all columns, and indicate a relief on between 0.5 and 5 cm. The presence of a wall shows that columns projected above the interspaces by this full amount. This indicates that the influx of interspace sediment was periodic. The occurrence of sand dykes in the stromatolite bed suggests rapid lithification, before the deposition of the overlying sand bed. Fracturing was concentrated along the contacts between individual stromatolite mounds in the bed. There is little evidence of the precise environment of these stromatolites. The absence of desiccation features and of penecontemporaneous dolomitization argue for an environment which was seldom if ever subaerially exposed. A shallow subtidal location subject to strong wave action from the open sea to the east is envisaged.

Stromatolitic limestones are an important facies of the very shallow environments of the Etina Formation and its northern extensions. Of the stromatolites occurring in this interval, new forms of the groups *Tungussia* and *Linella* have been found to be very widespread. But the forms *Linella ukka* Krylov, *Inzeria* cf. *tjomusi* Krylov and a new form of *Jurusania* are apparently restricted to Burr Well.

Tungussia first appears in the vicinity of Arkaba, where it forms tonguing bioherms which interfinger with oolitic limestones. The columns are irregular and closely spaced, and have interspaces filled with quartz sand. Further north in Enorama Creek, the quartz sand supply was less, but ooids occur in abundance in the interspaces (as grainstones) and incorporated in the lamination of the stromatolites. The stromatolites were formed by mats which were able to trap significant amounts of medium sand-size detritus, if it was available. However, there is a limit to the amount that can be incorporated and still preserve the laminated microstructure due to algal binding. If excessive detritus is washed in, this microstructure is lost, and mechanically deposited ooid grainstones are formed, which are continuous with the interspace sediment. Highly irregular columns occur east of Blinman where they consist of red-coloured distinct, wavy banded laminae. Interspaces are filled entirely with lime-cemented quartz sand. However, to the north of Blinman, lower energy conditions appear to have prevailed at the sites of stromatolite growth, and there the columns are more regular, though still completely branched and coalesced. At Mt. Chambers, for example, interspaces between the variously oriented columns are filled predominantly with micrite and fine sand lenses, with sparse intraclasts although ooid grainstones occur immediately below the stromatolite horizon. In the Wundowie Limestone near Teatree _Tungussia_ occurs in tonguing bioherms which overlie and interfinger with oolitic limestones, but here there is greater variation of gross morphology, especially branching. The interspace sediment is predominantly micrite, with scattered ooids.

These observations suggest an overall decrease in the energy of water movement for stromatolitic beds in the northern areas. The sediment filling interspaces cannot directly indicate the energy of the environment surrounding the bioherm, since columns with any substantial growth relief must act as baffles reducing current velocities within the bioherms. Thus interspaces might be expected to accumulate more fine detritus than the area surrounding bioherms. This has already been noted for _Acacialla augusta_ bioherms. For coarse detritus to be brought into the interspaces and to cover the algal mats, as in _Tungussia_ in the Central Flinders Ranges, very high current or wave acticity is required. In the north, strong current or wave action persisted only outside bioherms, but was reduced within them.

Commonly, the tonguing margins of bioherms contain only irregular laterally linked stromatolites, which pass into columns in the central portions. If the above deductions about environmental energy are correct, it would suggest that the continuously laminated forms were subjected to higher energy conditions than the central, columnar parts of bioherms. This is contrary to the present day relation of stromatolites to environmental energy as observed at Shark Bay (Logan, 1961) where columns and "heads" grow on exposed headlands and laterally linked forms in the protected areas. A comparison is, however, limited by the different modes of occurrence, the Precambrian stromatolites forming discrete bioherms.

Linella f. nov. is the most widespread stromatolite in the Northern Flinders Ranges, and possibly occurs locally in the Central Flinders Ranges. These stromatolites form domed biostromes and lenticular beds, consisting of juxtapozed hemispherical to ellipsoidal bioherms, with a relief of at least 1 metre above the surrounding sediment. Where such bioherms occur in isolation or terminally to biostromes, their relation to the surrounding sediments is seen, e.g. at Burr Well. The bioherms grew to a height of about 1 metre, with inclined columns at their recurved margins. There was negligible influx of coarse detritus. After the bioherms had reached their full thickness, the surrounding area gradually accumulated fine, laminated muddy sediments (either micritic limestone or shale). Interspaces are also filled with fine micrite, but contain a few locally derived intraclasts. Similar bioherms at Myrtle Springs contain sandy lenses in the interspace sediment, showing an occasional influx of coarse terrigenous detritus. Sand predominates in interspaces at Arkaroola. The one form of stromatolite grew both in areas of high and low sand influx. In the overlying bed in each case the environment changed radically, and cross-bedded gritty limestones were deposited, partly in south-trending channels.

Linella ukka, known only from Burr Well occurs in low, domed bioherms, juxtaposed to form lenticular beds. Growth relief of the full bioherm thickness (0.5m) is probable, since solumns are radially arranged to sub-horizontal at bioherm margins, and the continuously laminated stromatolite at the top of the bioherm is completely curved over at the margins. In other places, the columnar zones grade laterally into wavy laminated stromatolites, which intertongue with the underlying oolitic and intraclastic limestones. It is possible that the type of bioherm margin is determined by its orientation relative to the dominant current directions, thus the abrupt, raised margins may have faced up-current (cf. the asymmetry of the stromatolites described by Hoffman, 1967). Interspaces are filled with intrasparite and minor bands of dolomitized micrite, suggesting alternating quiet and highly agitated conditions even within bioherms.

The middle and upper members of the Wundowie Limestone at Burr Well are entirely stromatolitic. Inzeria cf. tjomusi, in the middle member, shows a similar relationship of bioherm margins to that of Linella ukka. In a westerly direction the bed lenses out gradually, but in the east columns pass into flat-laminated stromatolites, similar to the substrate of the columns. Lower energy conditions than for Linella ukka are indicated by the absence of ooids, and the predominantly silty and muddy interspace filling. Jurusania f. nov. in the upper member, is the only known South Australian stromatolite to form subspherical bioherms. The contiguous bioherms are capped by an undulating layer of columnar stromatolites identical to those in the bioherms. The stromatolites forming the spherical bioherms grew around an irregular stromatolitic core (now so recrystallized that its original nature cannot be determined); when growth had proceeded so far that bioherms were in contact, they were covered with the draping columnar layer. Interspaces between columns are predominantly filled with intramicrite; intraclasts are mainly thin flat-pebbles, possibly locally derived from the erosion of mats. The muddy nature of the sediment suggests low energy conditions, which persisted throughout the following period of silt and mud deposition, under conditions of basin subsidence.

CONCLUSIONS

The present contribution is an account of field and laboratory observations of Adelaide Geosyncline stromatolites, combined with an interpretation of all published stratigraphic data for the stromatolite-bearing interval. The conclusions regarding palaeogeography are tentative, but they are consistent with what I believe is the present state of stratigraphic knowledge of the South Australian Precambrian, and the geotectonic framework envisaged for the Adelaide Geosyncline.

Within the Adelaide Geosyncline there is almost unlimited scope for further detailed sedimentological studies of the stromatolitic units to test the suggestions made here. In addition, the lateral variations of stromatolitic beds will need to be studied in relation to changes of lithofacies. Only then will it be possible to precisely delimit the environmentally controlled variation of stromatolites and to use particular stromatolite features as specific environmental indicators. The following generalizations are the main results of the present study.

(1) Modern work on Recent stromatolites shows that stromatolites predominantly occupy the intertidal and lower supratidal zones but there is mounting evidence that they also extend into the subtidal, both in the Recent and in the geological record. Many Adelaide Geosyncline forms may have grown in the shallow subtidal zone, but there is no evidence of growth in water deeper than this.

(2) The biostromal stromatolites of the Skillogalee Dolomite (Baicalia burra and Tungussia f. nov.) grew on a broad carbonate-depositing platform in a variety of calm and highly agitated environments, probably ranging from lagoons to exposed headlands. The diagnostic morphology of Baicalia burra is consistent under these varying conditions, supporting the idea that these characters are genetically rather than environmentally controlled, but it displays minor modifications of column irregularity and contemporaneous erosion with increased environmental energy.

(3) Following the Sturtian glaciation, a possibly eustatic rise of sea level caused an extensive marine transgression. During the following regression, the marginal western and north-eastern areas became favourable sites for stromatolite development.

(4) In the western areas the biohermal stromatolites Omachtenia utschurica, Acaciella augusta, Boxonia melrosa, and new forms of Inzeria grew in shallow subtidal to intertidal zones, while Katavia f. nov. occupied a shallower interval (upper intertidal to supratidal). The degree of agitation of water was high, at least outside the bioherms.

(5) In the northern part of the central deeper basin, marine conditions of sedimentation were periodically interrupted by diapirism, thus producing off-shore an environment favourable to stromatolites. Here bioherms of new forms of Tungussia and Linella are widespread. Energy conditions varied, but were always higher than for the interbedded thinly laminated shales.

(6) Although environment plays a role in shaping the gross morphology of stromatolites, and perhaps even their microstructure, the forms identified from South Australia are relatively stable in relation to environmental changes. The same form may be recognizable in different environments, while conversely, similar environments supported a variety of stromatolites. This in turn confirms the conclusion that since stromatolites change systematically in time, they probably reflect control by evolving characters of the algae or assemblages of algae forming them.

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Fig. 1. Correlation and rock relationship diagram of the Adelaide Geosyncline. The nomenclature of the type section near Adelaide was erected largely by the pioneer geologists of South Australia, while the South Australian Geological Survey is responsbile for the nomenclature of the Flinders Ranges.

FIG. 1 STRATIGRAPHIC CORRELATION AND ROCK RELATIONSHIPS IN THE PRECAMBRIAN OF THE ADELAIDE GEOSYNCLINE

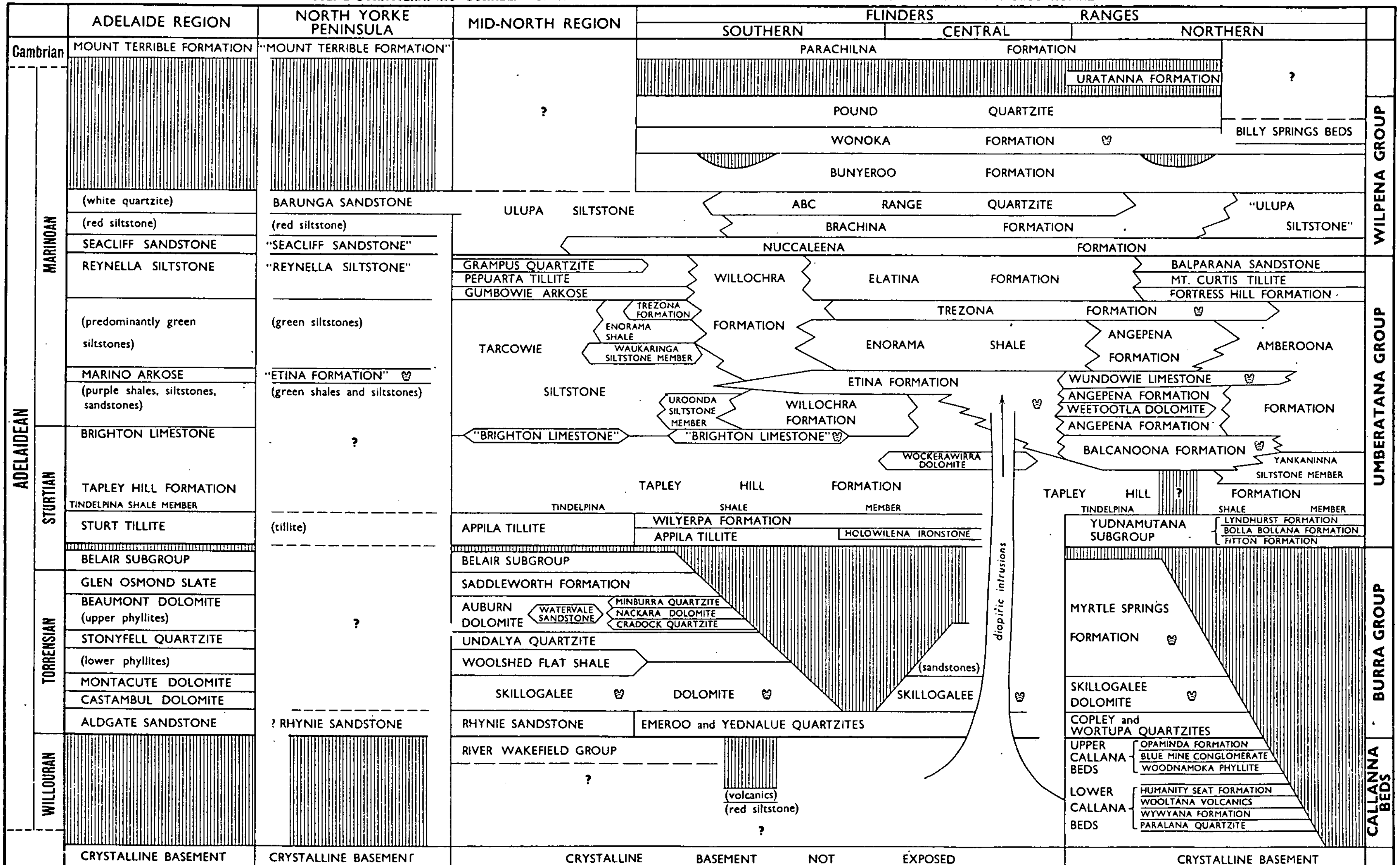

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Fig. 2. Distribution and isopachs of the carbonate rocks of the Skillogalee Dolomite, modified from data by Forbes (1960, 1961) and recent Mines Department mapping.

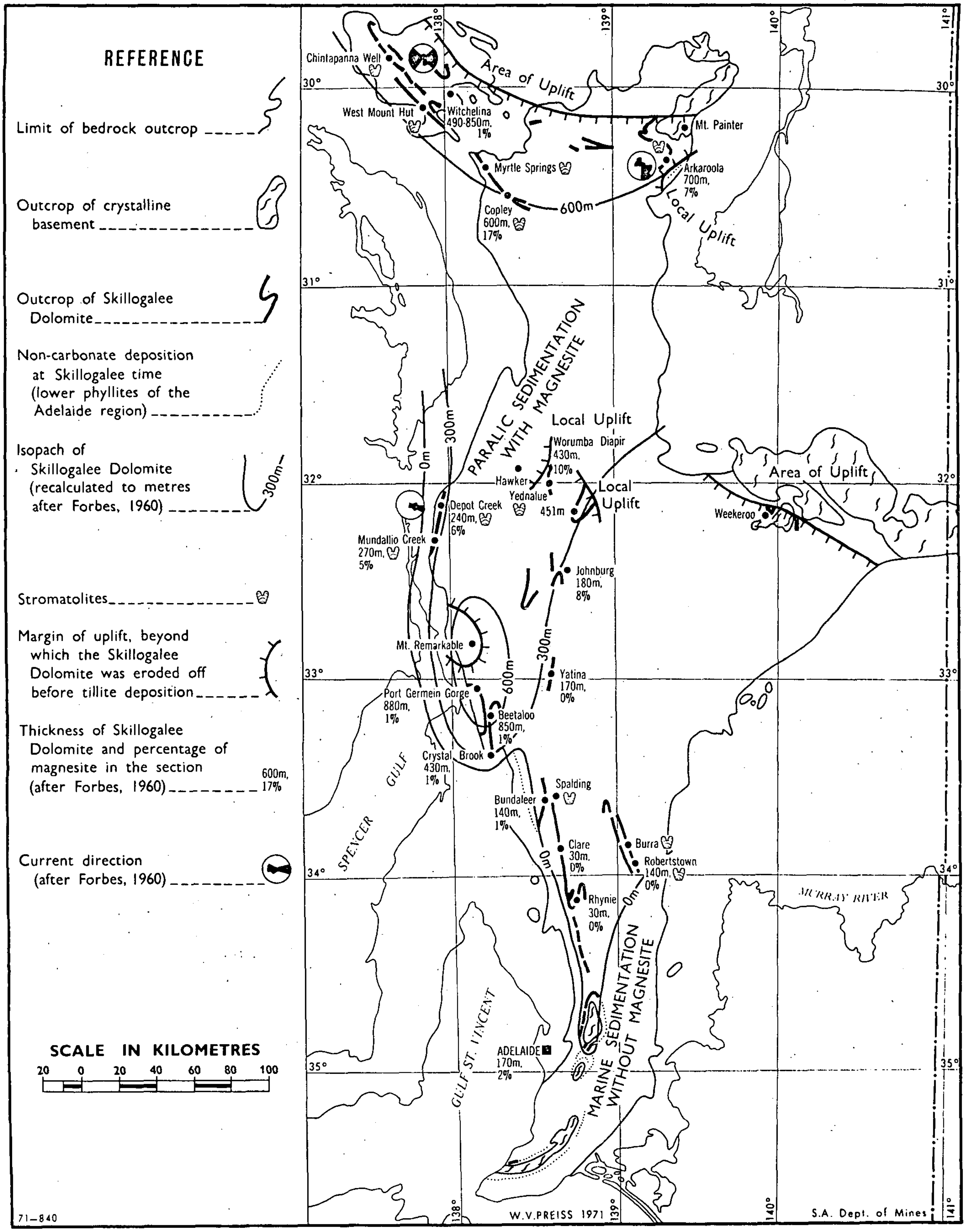
REFERENCE
Limit of bedrock outcrop
Outcrop of crystalline basement
Outcrop of Skillogalee Dolomite
Non-carbonate deposition at Skillogalee time (lower phyllites of the Adelaide region)
Isopach of Skillogalee Dolomite (recalculated to metres after Forbes, 1960)
300m
Stromatolites
Margin of uplift, beyond which the Skillogalee Dolomite was eroded off before tillite deposition
Thickness of Skillogalee Dolomite and percentage of magnesite in the section (after Forbes, 1960)
600m, 17%
Current direction (after Forbes, 1960)
SCALE IN KILOMETRES
20 0 20 40 60 80 100
71–840
138°
139°
140°
141°
30°
31°
32°
33°
34°
35°
Area of Uplift
Chintapanna Well
West Mount Hut
Witchelina 490-850m, 1%
Mt. Painter
Myrtle Springs
Arkaroola 700m, 7%
Copley 600m, 17%
600m
Local Uplift
PARALIC SEDIMENTATION WITH MAGNESITE
Local Uplift
Worumba Diapir 430m, 10%
Hawker
Yednalue
451m
Local Uplift
Area of Uplift
Weekeroo
Depot Creek 240m, 6%
Mundallio Creek 270m, 5%
0m
300m
Johnburg 180m, 8%
Mt. Remarkable
300m
600m
Yatina 170m, 0%
Port Germein Gorge 880m, 1%
Beetaloo 850m, 1%
Crystal Brook 430m, 1%
Spalding
Bundaleer 140m, 1%
Clare 30m, 0%
Burra
Robertstown 140m, 0%
Rhynie 30m, 0%
0m
0m
SPENCER GULF
MURRAY RIVER
MARINE SEDIMENTATION WITHOUT MAGNESITE
GULF ST. VINCENT
ADELAIDE 170m, 2%
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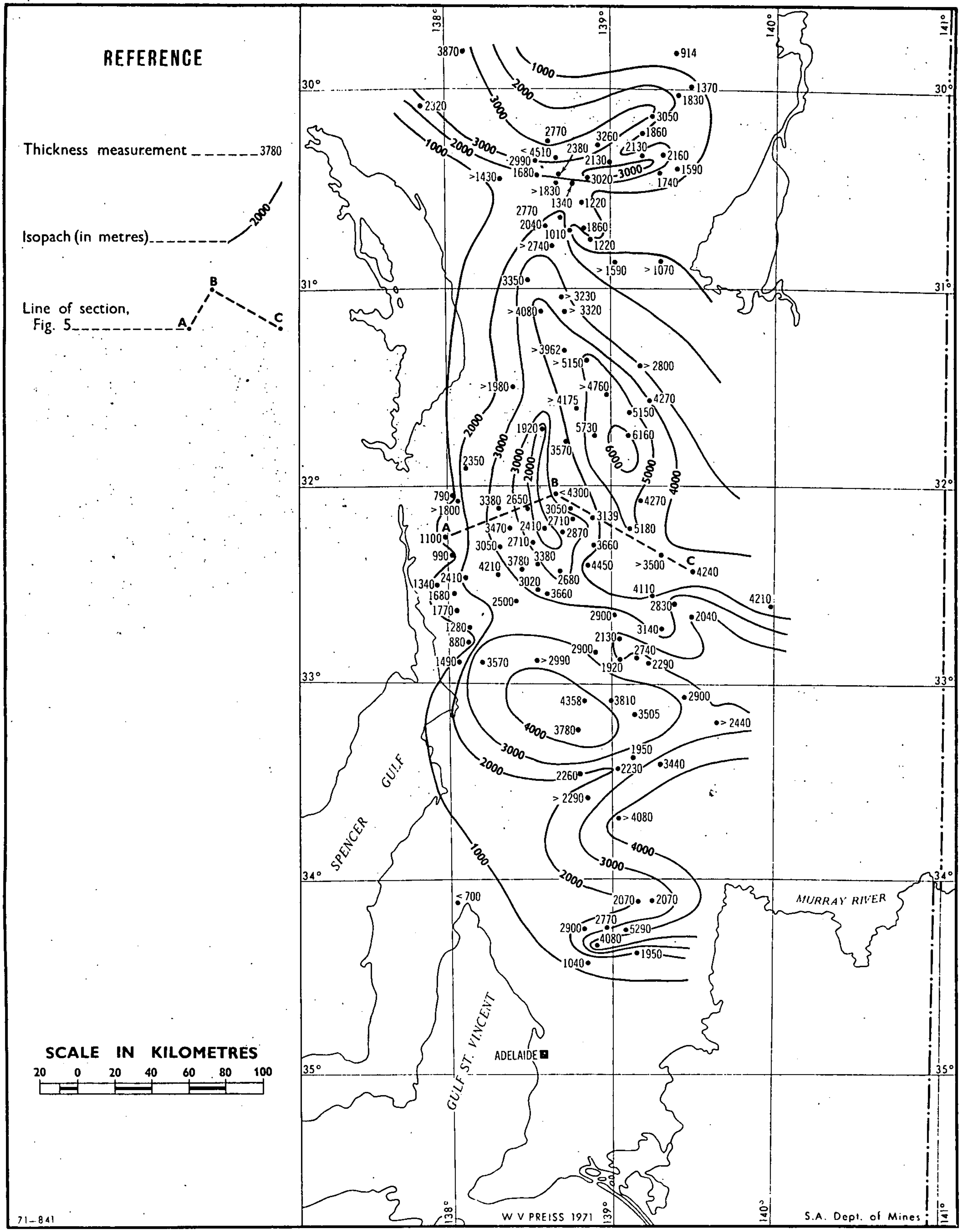
Fig. 3. Etched slab of stromatolitic dolomite, Skillogalee Dolomite, Willouran Ranges. In this area the stromatolite, _Baicalia_ _burra_, grew in an environment of high energy. At numerous levels, laminae are truncated by penecontemporaneous erosion, and draped over by new laminae, producing micro-unconformities. The interspaces between columns are filled with intraclast grainstone, including large fragments broken from the stromatolite columns, which then served as a base for new growth.

Fig. 3

Fig. 4. Isopach map of part of the Umberatana Group, between the top of the lower glacials and the top of the upper glacials. Thicknesses were measured approximately from Mines Department maps, and are least reliable in the southermost area due to relatively tight folding.



REFERENCE
Thickness measurement 3780
Isopach (in metres) 2000
Line of section, Fig. 5 A B C
SCALE IN KILOMETRES
20 0 20 40 60 80 100
SPENCER GULF
GULF ST. VINCENT
MURRAY RIVER
ADELAIDE
30°
31°
32°
33°
34°
35°
138°
139°
140°
141°
71-841
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Fig. 5. An interpretative cross-section across the northern part of the ORROROO 1:250,000 map area based on sections measured in the field and from the map at the localities indicated. At Yednalue, the thickness of the Tapley Hill Formation is uncertain due to folding. At Melton the top of the section is not exposed.

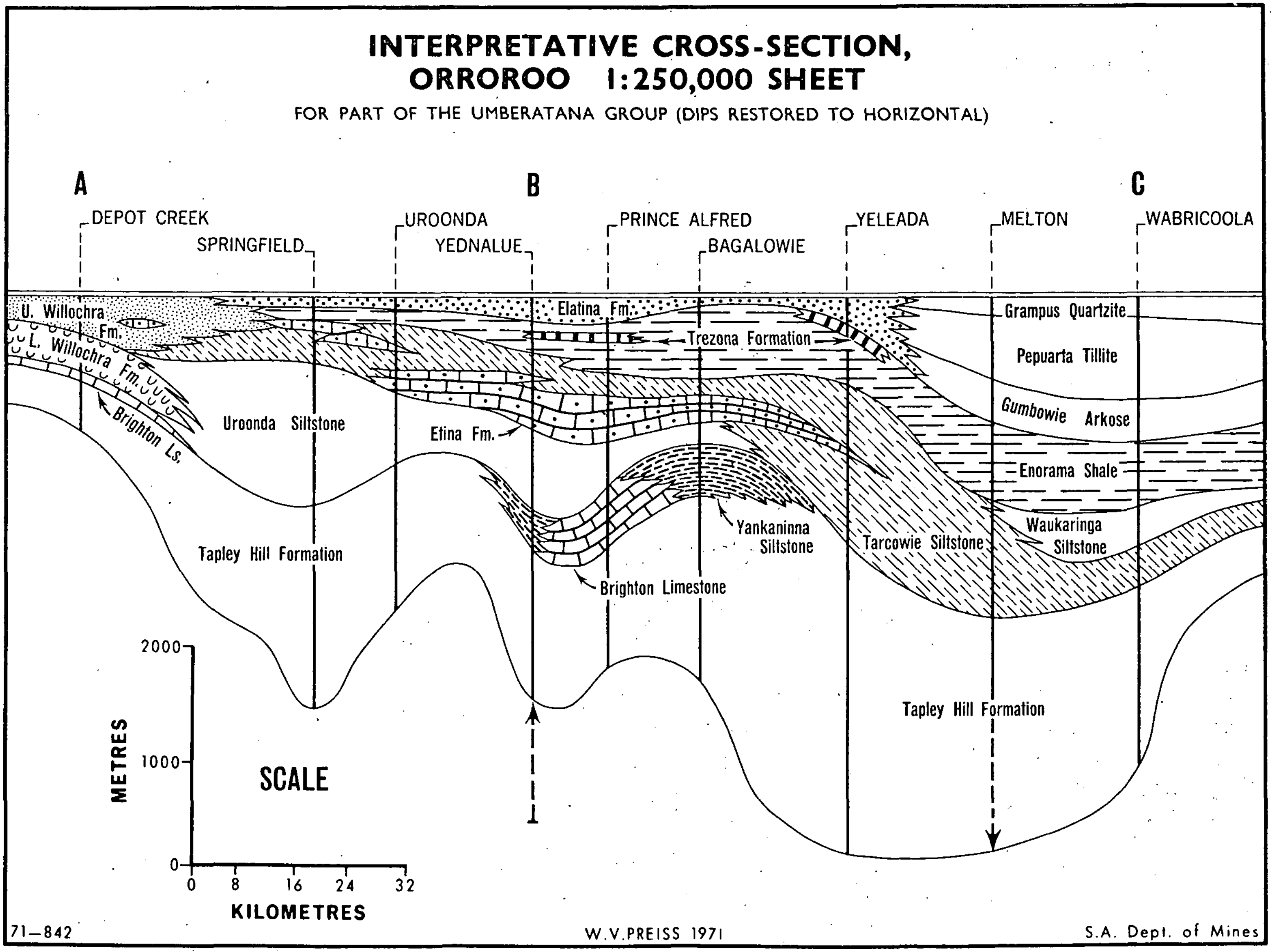
INTERPRETATIVE CROSS-SECTION,
ORROROO 1:250,000 SHEET
FOR PART OF THE UMBERATANA GROUP (DIPS RESTORED TO HORIZONTAL)
A
B
C
DEPOT CREEK
SPRINGFIELD
UROONDA
YEDNALUE
PRINCE ALFRED
BAGALOWIE
YELEADA
MELTON
WABRICOOLA
U. Willochra Fm.
L. Willochra Fm.
Brighton Ls.
Uroonda Siltstone
Elatina Fm.
Trezona Formation
Grampus Quartzite
Pepuarta Tillite
Gumbowie Arkose
Enorama Shale
Etina Fm.
Yankaninna Siltstone
Tarcowie Siltstone
Waukaringa Siltstone
Brighton Limestone
Tapley Hill Formation
Tapley Hill Formation
2000
1000
0
METRES
SCALE
0
8
16
24
32
KILOMETRES
71—842
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Fig. 6. Distribution and isopachs of the Brighton Limestone and its equivalents. The outcrop pattern was deduced from Mines Department maps. Thicknesses were partly measured accurately in the field, and partly estimated from the maps. Current directions were measured from the Brighton Limestone, the overlying Willochra Formation and the underlying Tapley Hill Formation.

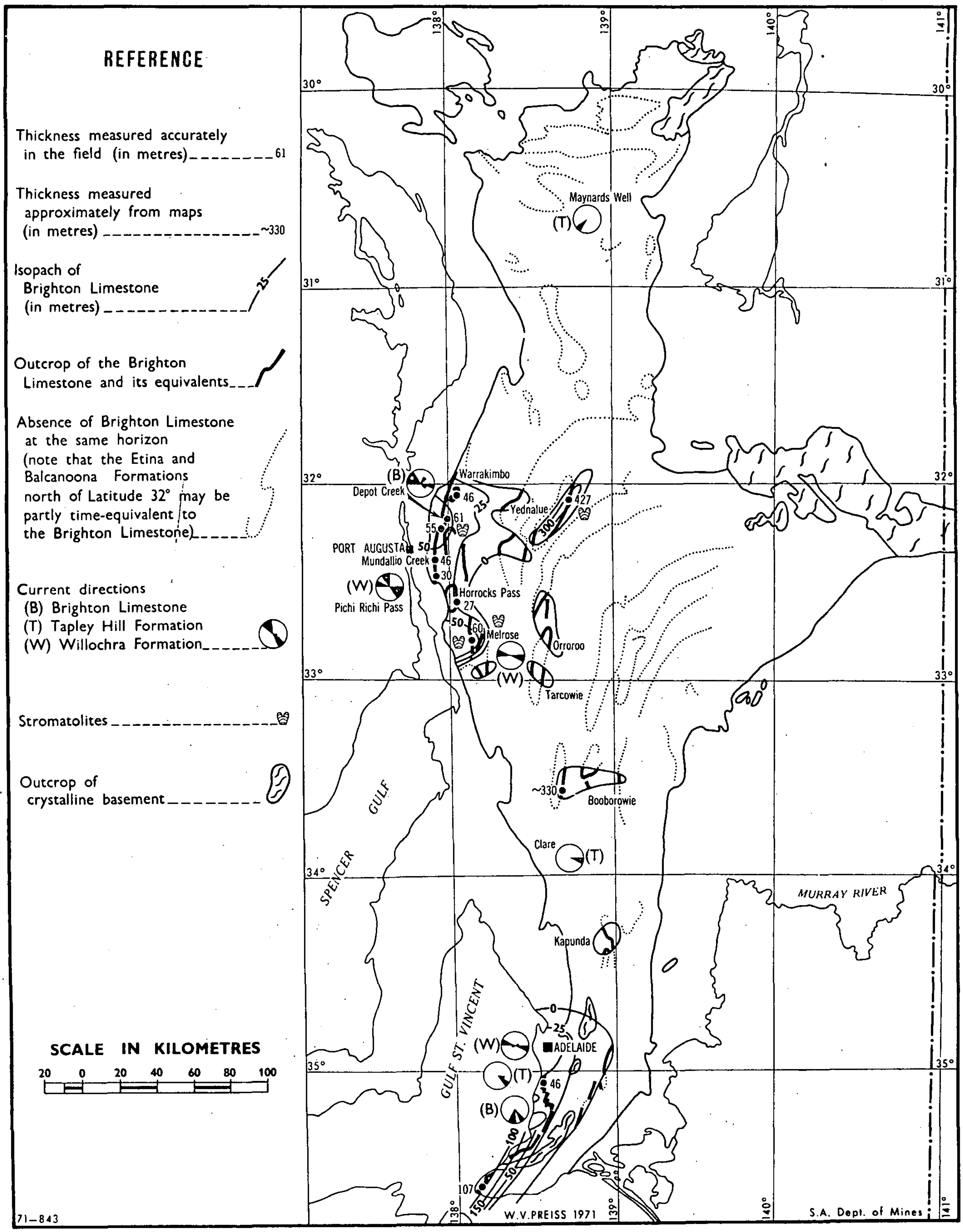
REFERENCE
Thickness measured accurately in the field (in metres) 61
Thickness measured approximately from maps (in metres) ~330
Isopach of Brighton Limestone (in metres) 25
Outcrop of the Brighton Limestone and its equivalents
Absence of Brighton Limestone at the same horizon (note that the Etina and Balcanoona Formations north of Latitude 32° may be partly time-equivalent to the Brighton Limestone)
Current directions
(B) Brighton Limestone
(T) Tapley Hill Formation
(W) Willochra Formation
Stromatolites
Outcrop of crystalline basement
SCALE IN KILOMETRES
20 0 20 40 60 80 100
71–843
30°
31°
32°
33°
34°
35°
138°
139°
140°
141°
Maynards Well
(T)
(B)
Warrakimbo
Depot Creek
46
61
55
25
Yednalue
427
300
PORT AUGUSTA
50
Mundallio Creek
46
30
(W)
Pichi Richi Pass
Horrocks Pass
27
50
60
Melrose
Orroroo
(W)
Tarcowie
GULF
SPENCER
~330
Booborowie
Clare
(T)
MURRAY RIVER
Kapunda
0
25
(W)
ADELAIDE
(T)
46
(B)
GULF ST. VINCENT
100
50
107
150
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Fig. 7. Stromatolites of the transition between the Tapley Hill Formation and the Brighton Limestone, Depot Creek. The dark grey bedded rock is siltstone, whose surface was eroded to form small mesas (in the position of the hammer) and channels (at right). Stromatolitic mounds grey on the elevated points (laminated, pale coloured in photograph) while the channel was filled with flat pebble breccia.

Fig. 7

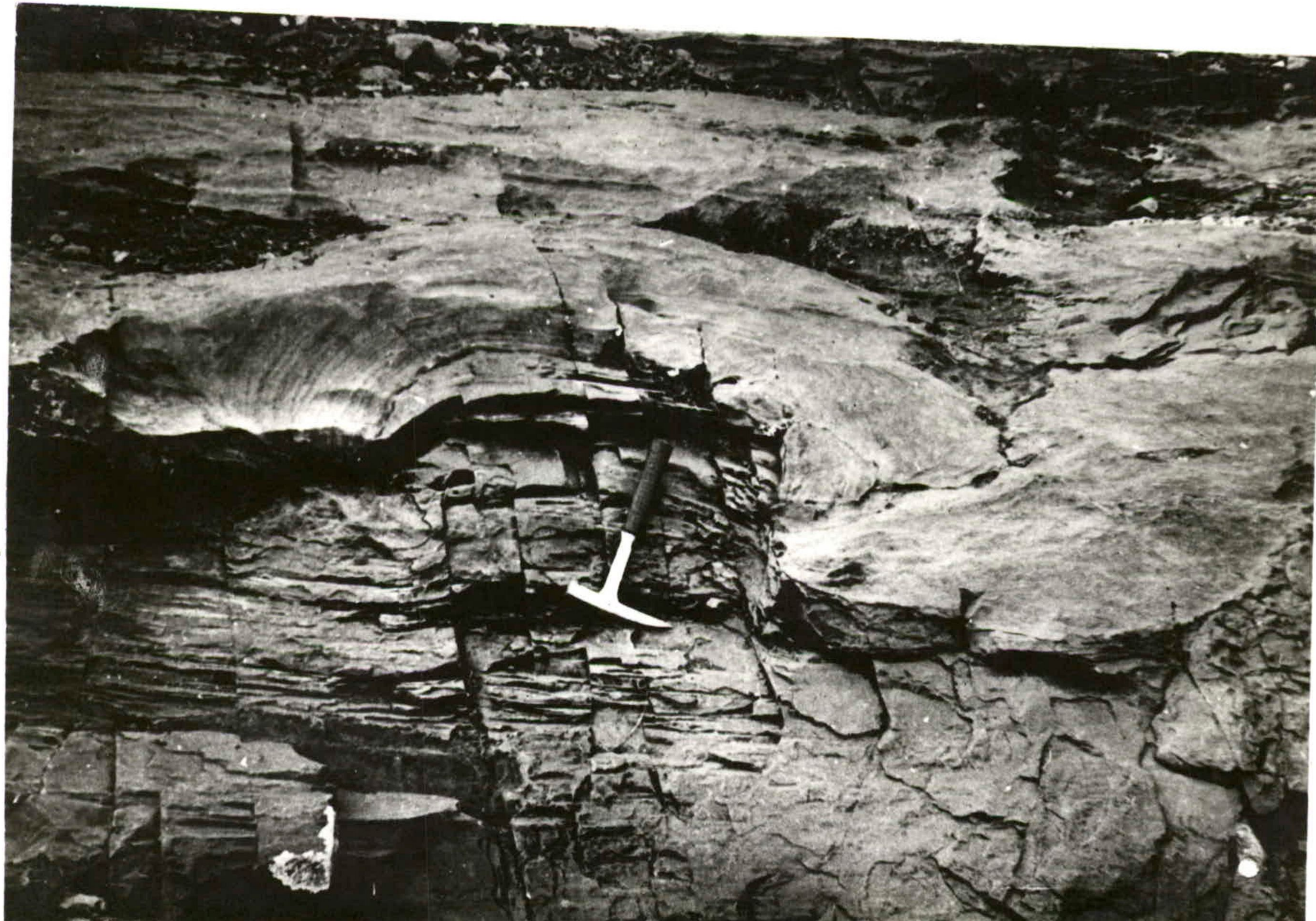

Fig. 8. The geology and lithofacies distribution of the Brighton Limestone, Depot Creek, based on detailed mapping.

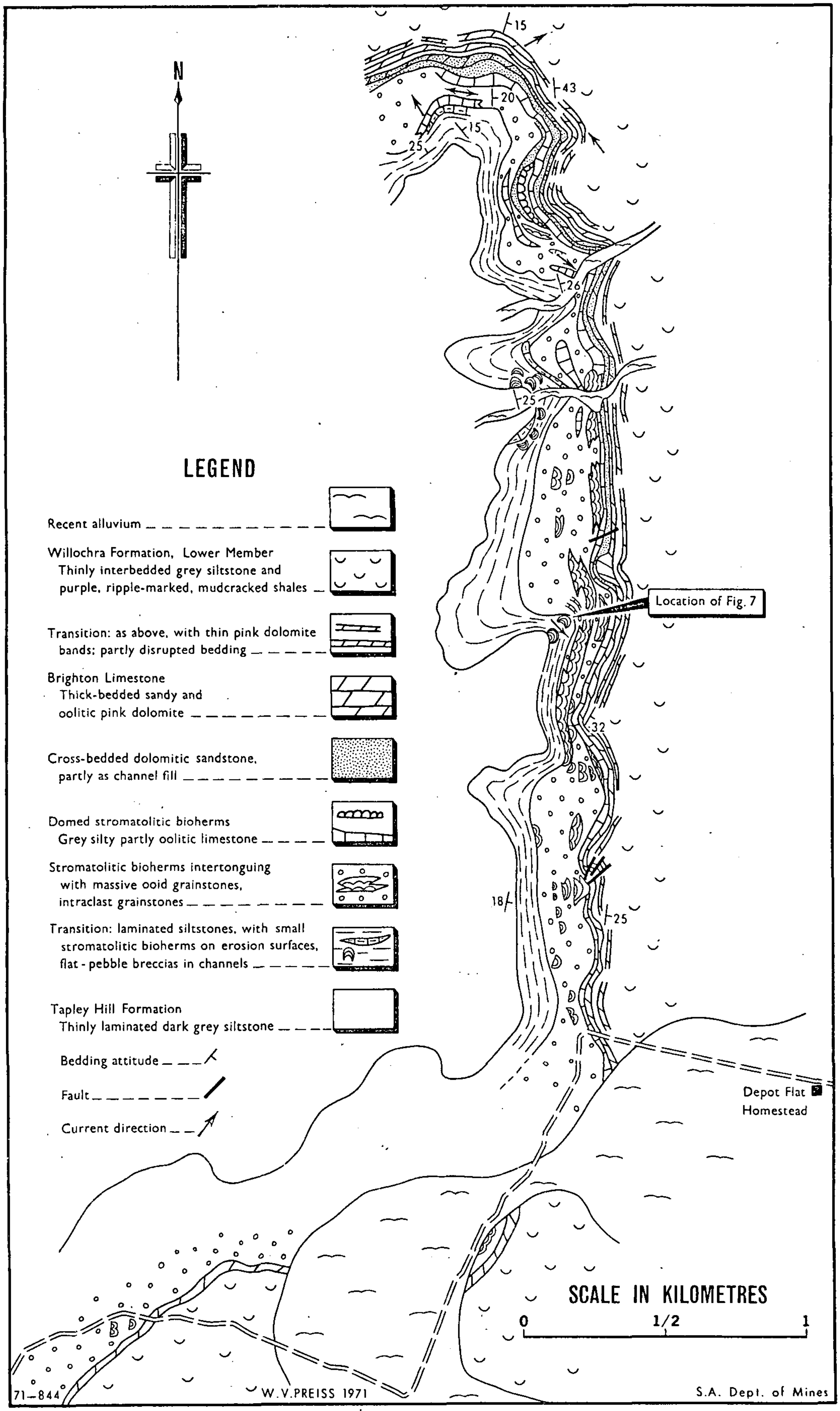
N
LEGEND
Recent alluvium
Willochra Formation, Lower Member
Thinly interbedded grey siltstone and purple, ripple-marked, mudcracked shales
Transition: as above, with thin pink dolomite bands; partly disrupted bedding
Brighton Limestone
Thick-bedded sandy and oolitic pink dolomite
Cross-bedded dolomitic sandstone, partly as channel fill
Domed stromatolitic bioherms
Grey silty partly oolitic limestone
Stromatolitic bioherms intertonguing with massive ooid grainstones, intraclast grainstones
Transition: laminated siltstones, with small stromatolitic bioherms on erosion surfaces, flat-pebble breccias in channels
Tapley Hill Formation
Thinly laminated dark grey siltstone
Bedding attitude
Fault
Current direction
Location of Fig. 7
Depot Flat Homestead
SCALE IN KILOMETRES
0
1/2
1
71–844
W.V.PREISS 1971
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Fig. 9. Distribution and isopachs of the Etina Formation and its equivalents in the Northern Flinders Ranges, in relation to the distribution of diapirs. The outcrop pattern was deduced from Mines Department maps, and thicknesses were partly measured accurately in the field and partly estimated from maps.

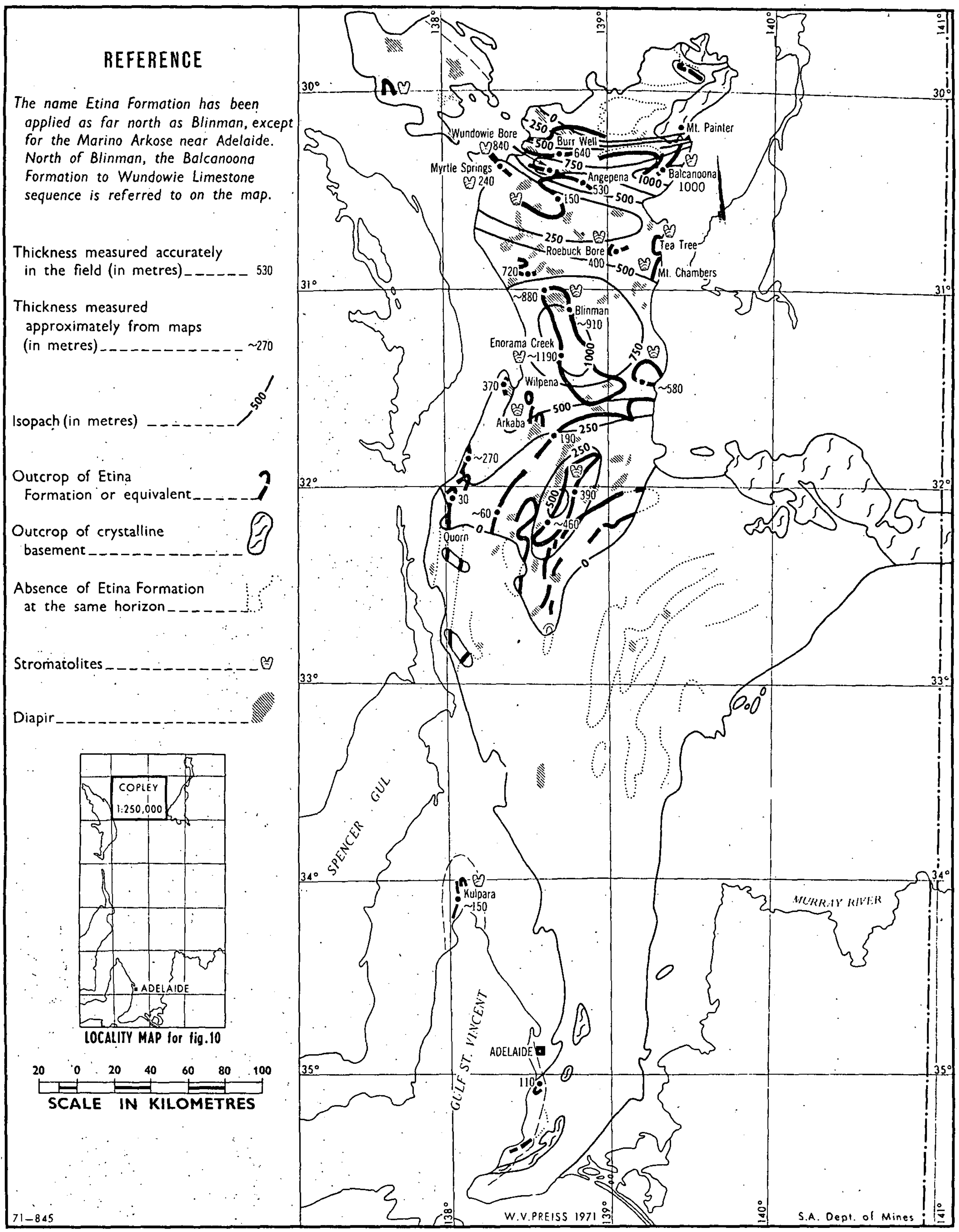
REFERENCE
The name Etina Formation has been applied as far north as Blinman, except for the Marino Arkose near Adelaide. North of Blinman, the Balcanoona Formation to Wundowie Limestone sequence is referred to on the map.
Thickness measured accurately in the field (in metres) 530
Thickness measured approximately from maps (in metres) ~270
Isopach (in metres) 500
Outcrop of Etina Formation or equivalent
Outcrop of crystalline basement
Absence of Etina Formation at the same horizon
Stromatolites
Diapir
COPLEY 1:250,000
ADELAIDE
LOCALITY MAP for fig.10
20 0 20 40 60 80 100
SCALE IN KILOMETRES
71–845
Wundowie Bore
840
Burr Well
640
Mt. Painter
Myrtle Springs
240
Angepena
530
Balcanoona
1000
150
Roebuck Bore
400
Tea Tree
Mt. Chambers
720
~880
Blinman
~910
Enorama Creek
~1190
370
Wilpena
~580
Arkaba
190
~270
390
30
~60
~460
Quorn
SPENCER GUL
Kulpara
~150
GULF ST. VINCENT
MURRAY RIVER
ADELAIDE
110
30°
31°
32°
33°
34°
35°
138°
139°
140°
141°
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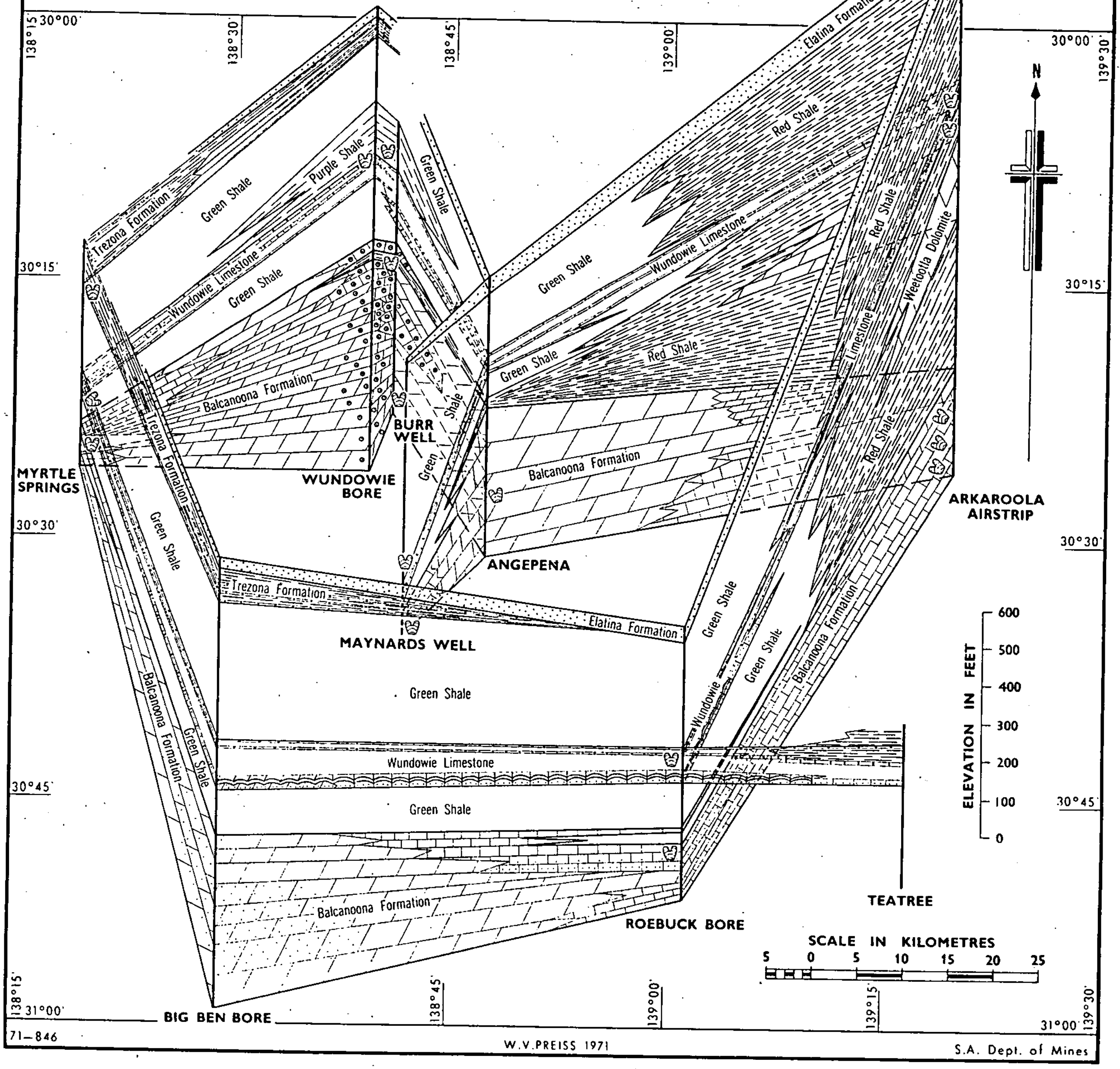
Fig. 10. A fence diagram for the upper part of the Umberatana Group on the COPLEY 1:250,000 map area, based on sections accurately measured in the field. Important facies changes are the change from the green and grey shales and siltstones to red in the central eastern area, the disappearance of the Weetootla Dolomite to the west, and the intertonguing, at least locally, of the Wundowie Limestone with shales. A disconformity possibly exists below the Elatina Formation in some area. The disconformity possibly exists below the Elatina Formation in some areas. The predominantly oolitic Balcanoona Formation is secondarily dolomitized in its very thick sections at Wundowie Bore, Burr Well, and Angepena, but not at Myrtle Springs or Maynards Well, where its thickness is reduced. The possibly penecontemperaneous (?supratidal) dolomites of the Arkaroola - Balcanoona region do not occur elsewhere.

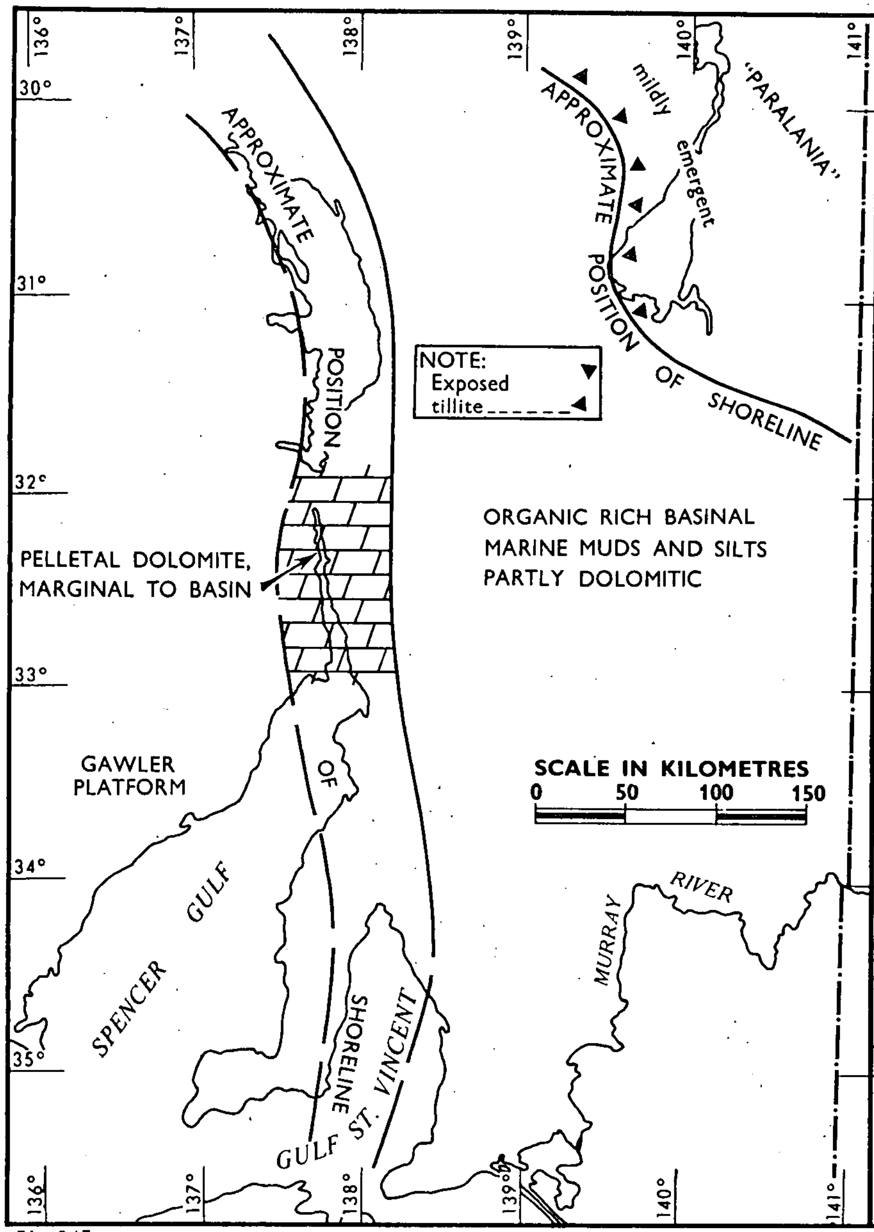
FENCE DIAGRAM FOR PART OF THE UMBERATANA GROUP

COPLEY 1:250,000 SHEET

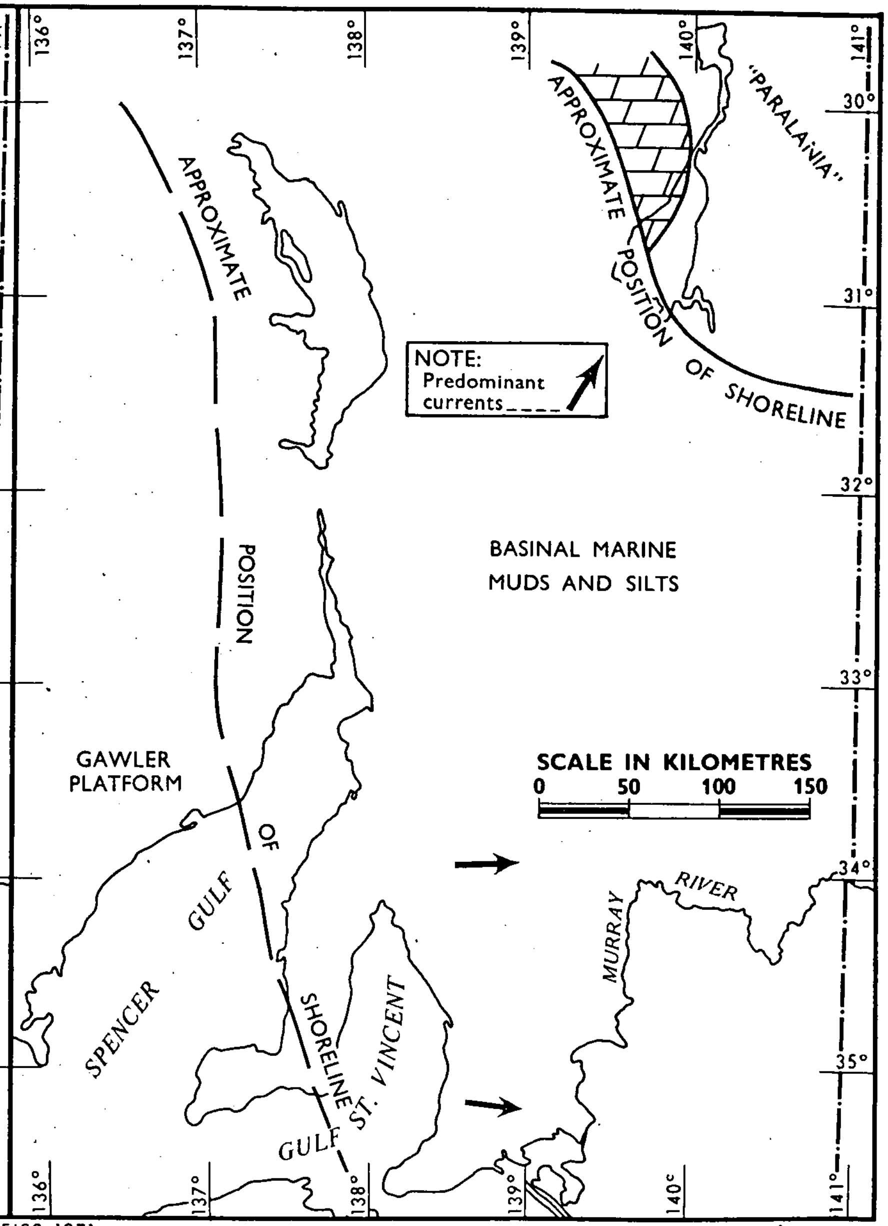


Figs.11 to 14. Palaeogeographic reconstructions of the Adelaide Geosyncline during the time interval between the two Late Precambrian glaciations. The interpretations are discussed in the text.

'A' EARLY TAPLEY HILL TIME: transgressive phase



'B' MID TAPLEY HILL TIME: widespread transgression



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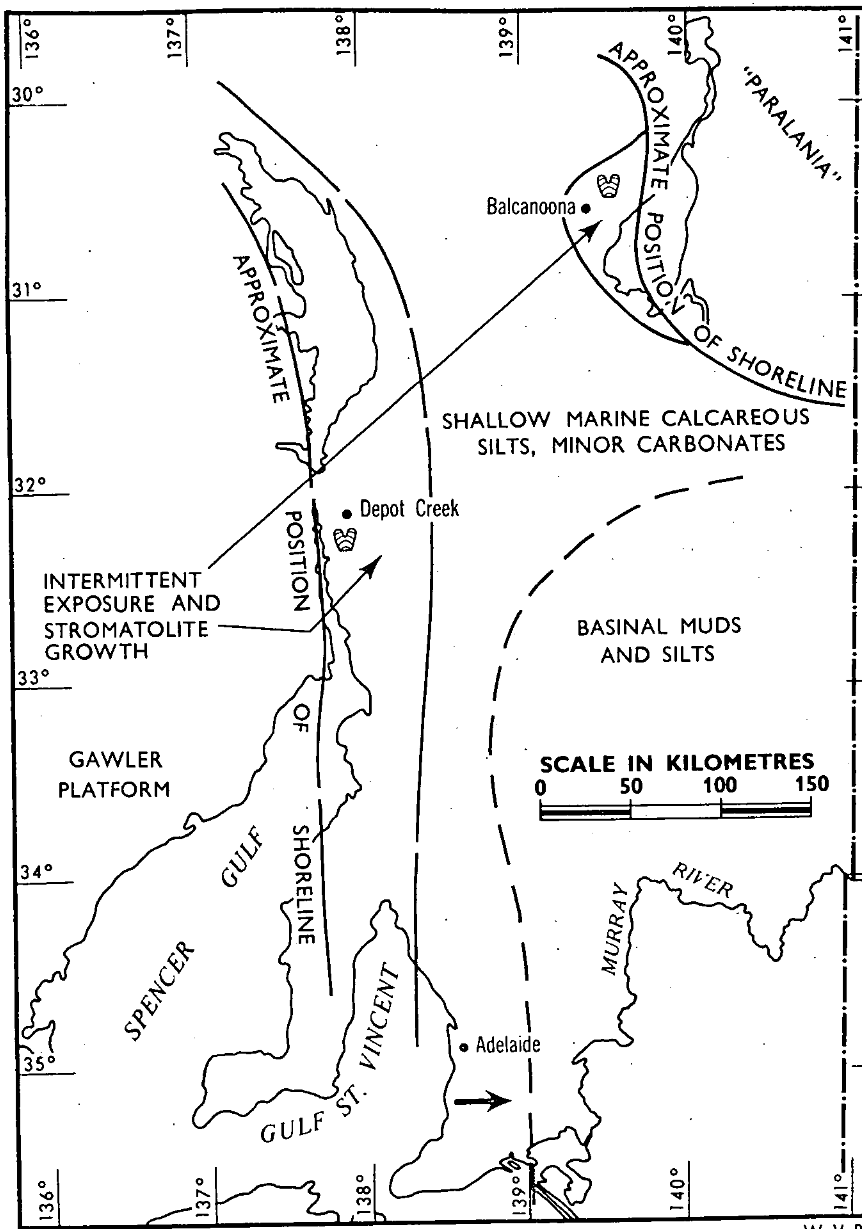
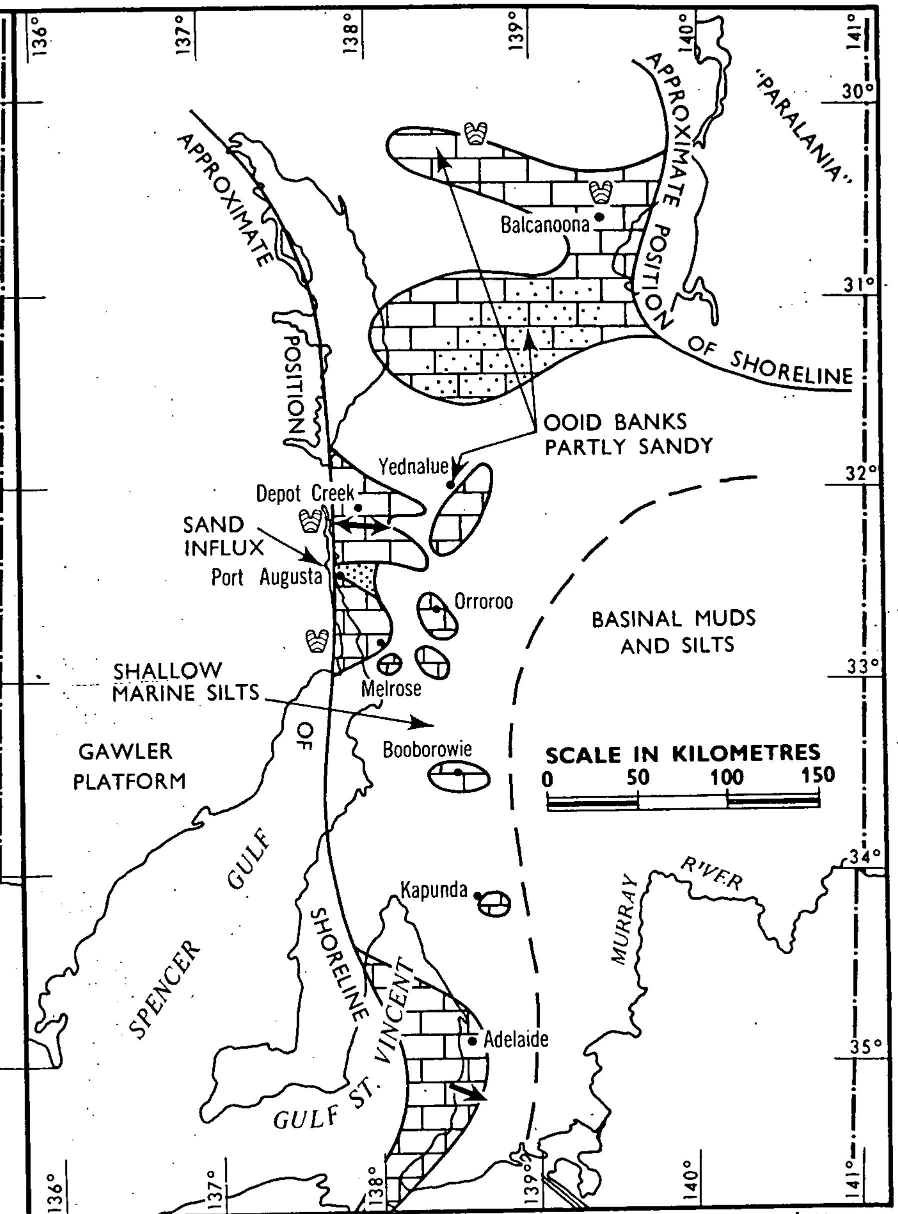
'C' LATE TAPLEY HILL - EARLY BRIGHTON TIME: regressive



'D' MID BRIGHTON TIME: regressive, with intermittent uplift in diapiric areas



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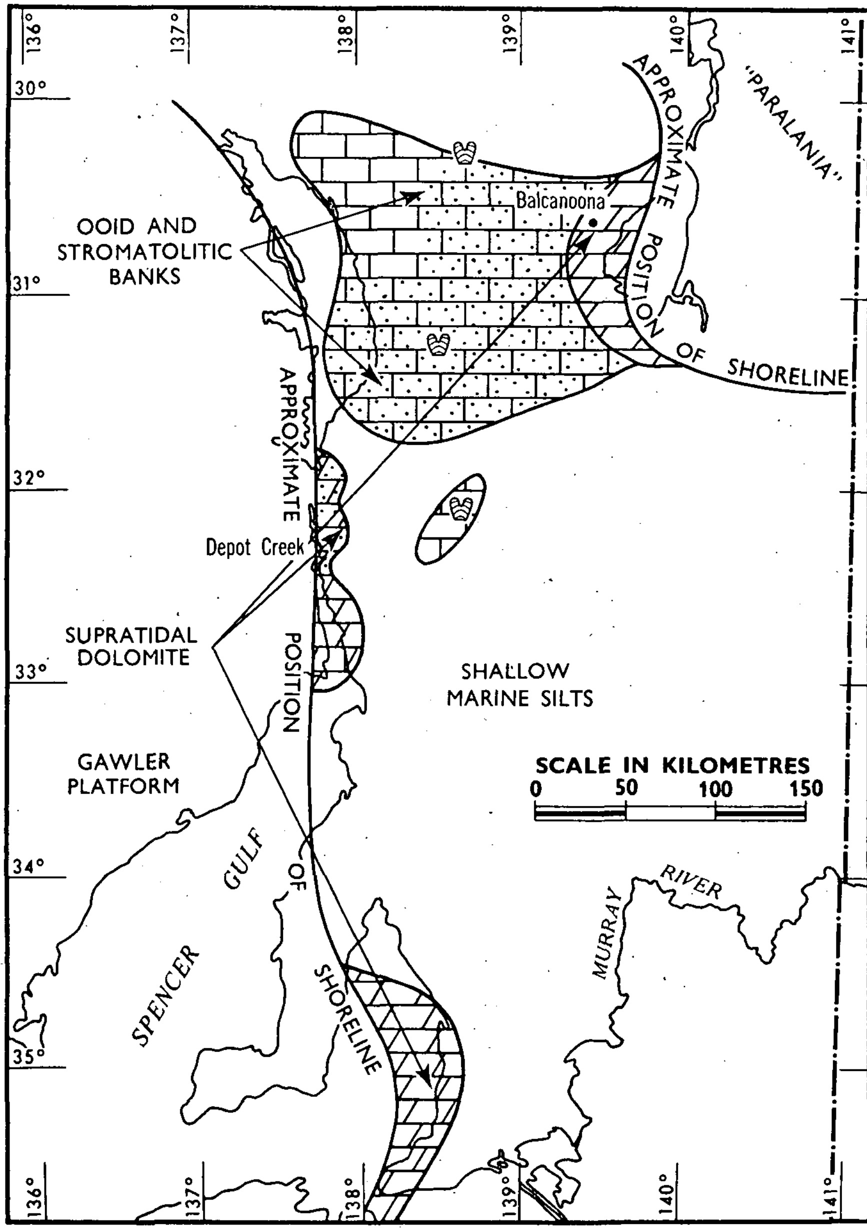
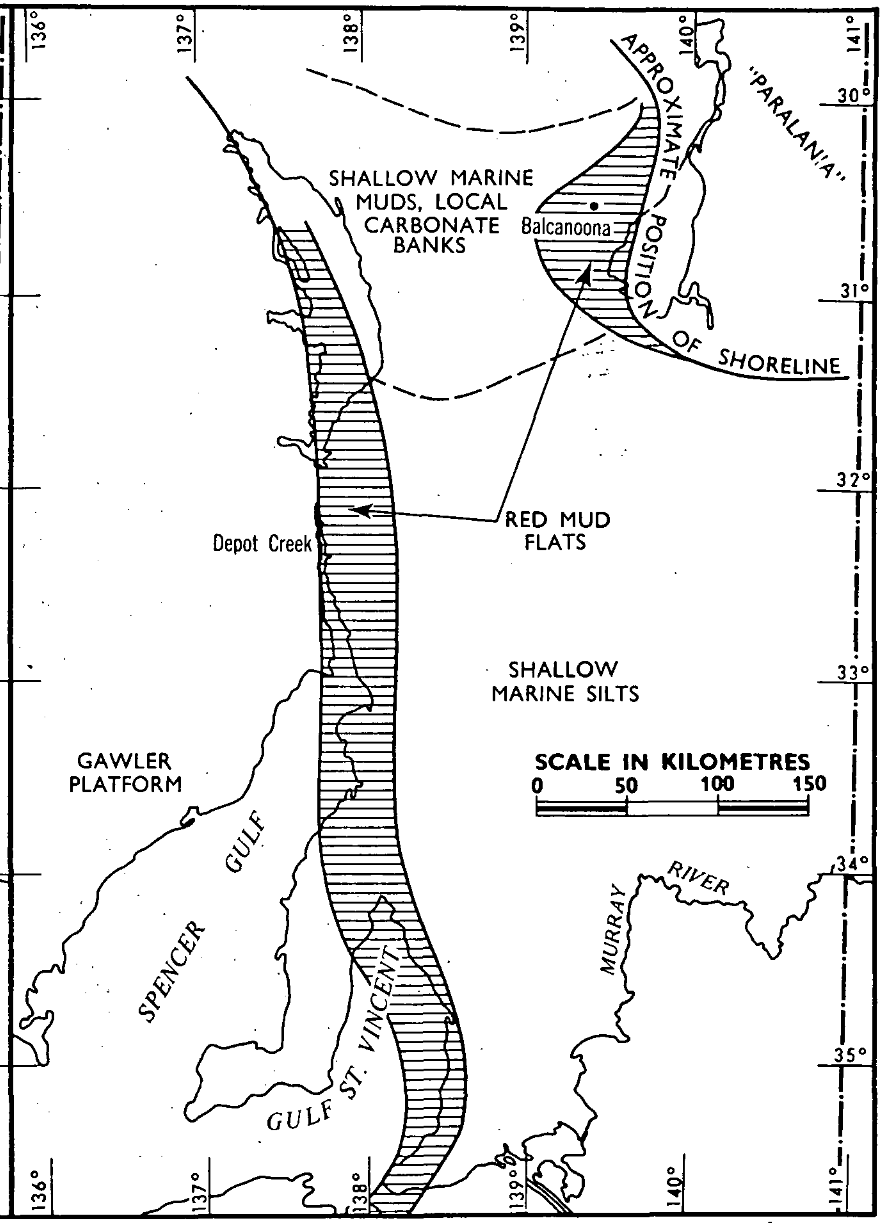
'E' LATE BRIGHTON TIME: regressive



'F' EARLY WILLOCHRA TIME



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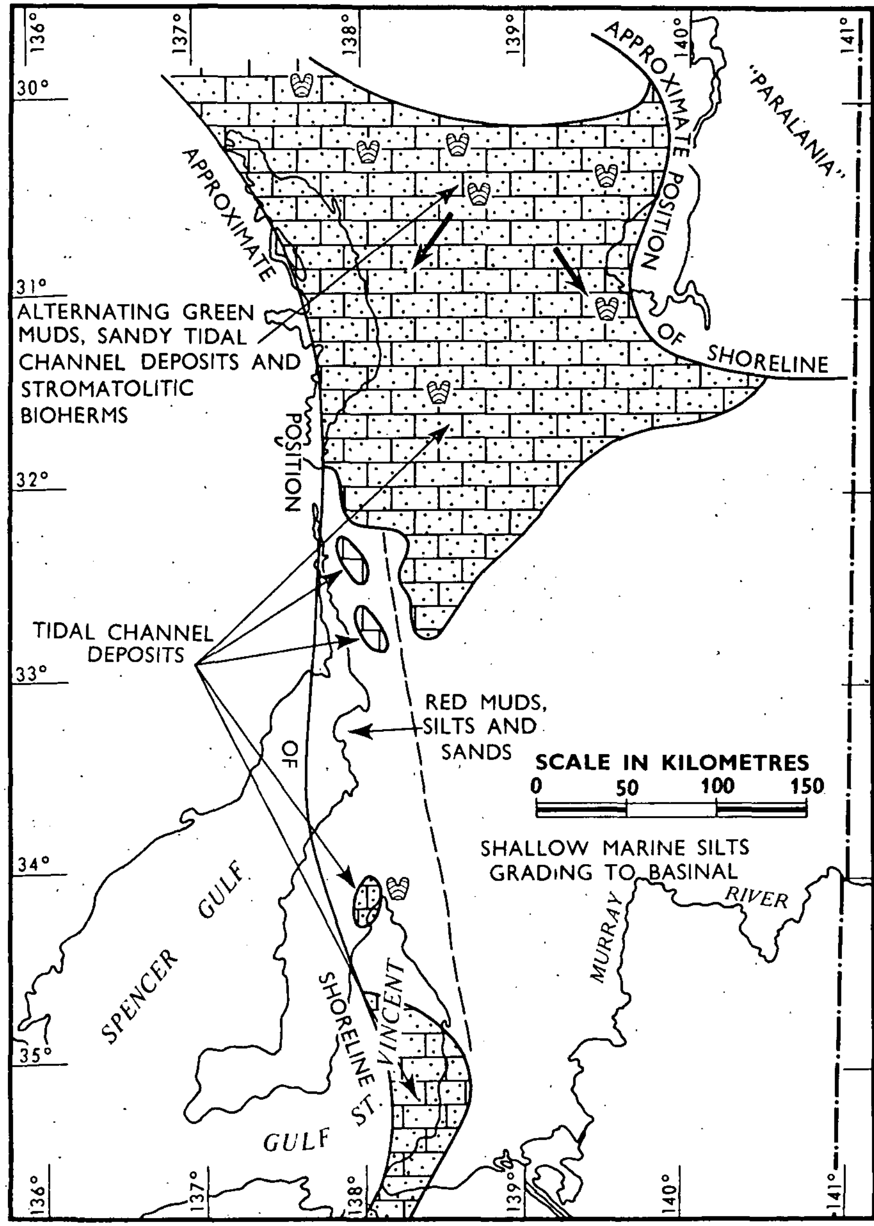
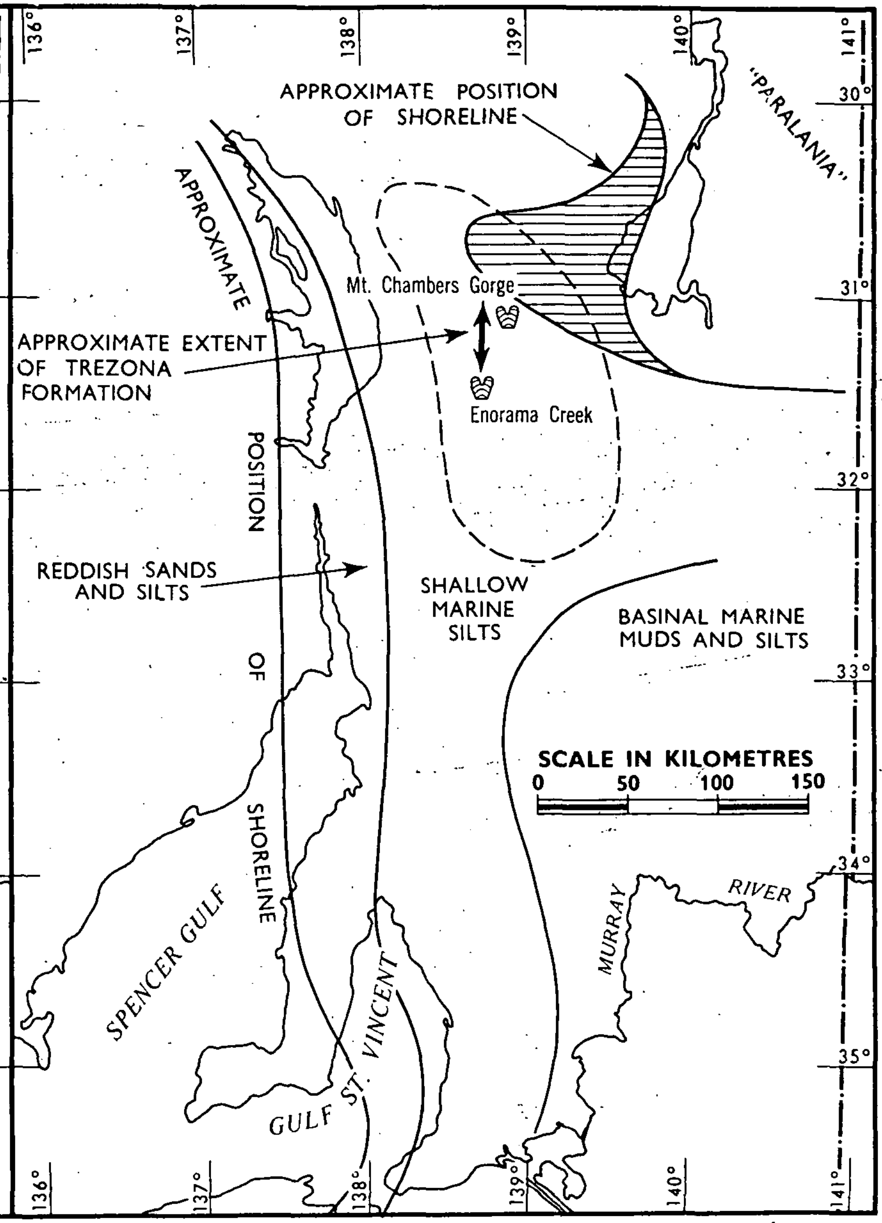
'G' MID WILLOCHRA TIME



'H' LATE WILLOCHRA TIME: minor transgression



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