STRATIGRAPHY AND SEDIMENTOLOGY OF THE BILLY CREEK FORMATION (CAMBRIAN, FLINDERS RANGES) AND ITS EQUIVALENTS ON THE NORTHEAST COAST OF KANGAROO ISLAND, SOUTH AUSTRALIA

(VOLUME 2)

BY

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PART THREE

THE STRATIGRAPHY AND SEDIMENTOLOGY OF THE CAMBRIAN OF THE NORTHEAST COAST OF KANGAROO ISLAND, SOUTH AUSTRALIA.

CHAPTER 12

INTRODUCTION TO PART THREE

GENERAL

A relatively unmetamorphosed (greenschist facies) sequence of fossiliferous Cambrian sediment outcrops on the northeast coast of Kangaroo Island, between Middle River and Point Marsden (Fig. 12-2). The sequence is dominated by sandstone, however shale, conglomerate, siltstone and limestone are also present. Unfortunately, no complete stratigraphic section exists because of faulting, however Daily (Fig. 14 *in* Horwitz and Daily, 1958) has established two distinct complementary sequences which together may comprise the complete stratigraphy. Daily (1976b, Fig. 8) has correlated this sequence with the major part of the Kanmantoo Group described by Daily and Milnes (1971, 1973) in its stratotype on southern Fleurieu Peninsula.

In January 1978, the author in conjunction with B. Daily measured detailed stratigraphic sections through the Carrickalinga Head Formation, Smith Bay Shale, White Point Conglomerate, Emu Bay Shale and Boxing Bay Formation. Due to the considerable thickness, lack of appreciable variation in sedimentary structures, and uncertainty of displacement along faults, no section was measured for the Stokes Bay Sandstone. The following chapters are a summary of this work, with additional information based on an unpublished report by Daily (1977).

GEOGRAPHY

The fossiliferous Cambrian sediments of Kangaroo Island are restricted to the region north of the Cygnet-Snelling fault complex (Fig. 12-1). Excellent outcrops occur along the northeast coast between Middle River and Point Marsden, although some intervals are obscured by beaches (eg. Smith Bay, Emu Bay, and west of Pt. Marsden). Cliffs, up to 120m high, are generally flanked by a narrow wavecut platform, parts of which are inaccessible, particularly at high tide. Inland outcrops are sparse, because most of the area is capped by Permian and Quaternary deposits.

The climate of Kangaroo Island is temperate sub-humid, with milder winters and much cooler summers than adjacent regions on the mainland (Baldwin and Crocker, 1941; Bauer, 1959). At Kingscote, the mean maximum in February is 23°C and in August, 15°C. About 65% of the annual precipitation occurs in winter, between May and September. Rainfall generally decreases from west to east across the island, and ranges from over 800mm west of Middle River, to 500mm near Kingscote (Barnett, 1977).

In the western high rainfall areas, the vegetation is dense, and eucalypts are numerous. However, in the eastern areas where this study is concentrated, the dominant natural vegetation is mallee scrub (*Eucalyptus eneorifolia* - *E. rugosa* association of Baldwin and Crocker, 1941). However, extensive development has resulted in much of the land being cleared. In addition, most of the outcrops examined were on the wavecut platform or in adjacent cliffs, so that vegetation cover was no problem.

Field work on Kangaroo Island can be carried out at any time of the year, although the colder, wetter winter months are best avoided if possible, especially if work is being carried out along the potentially dangerous coastal sections.

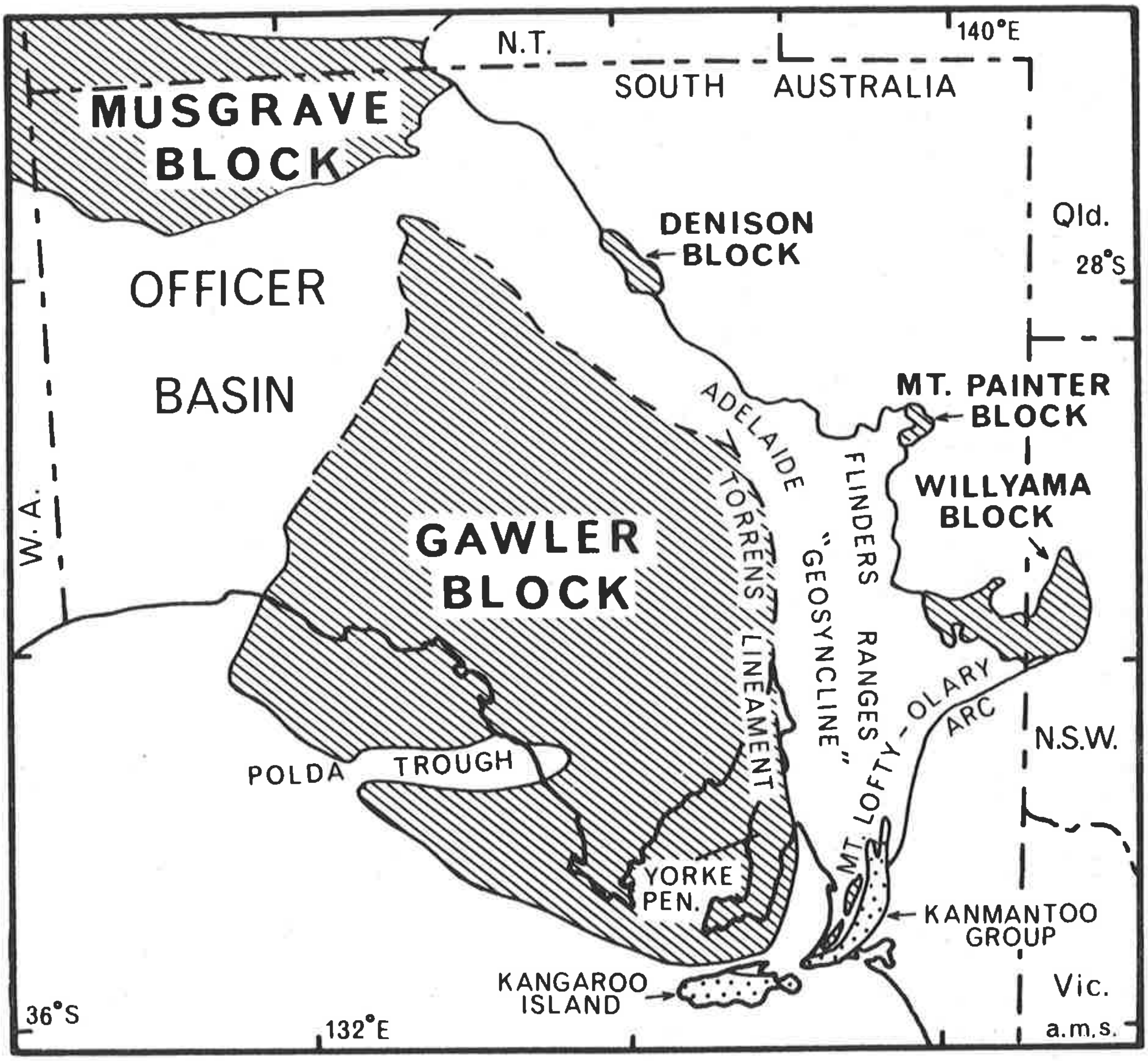

Figure 12-1. Relationship of Kangaroo Island to surrounding tectonic elements.

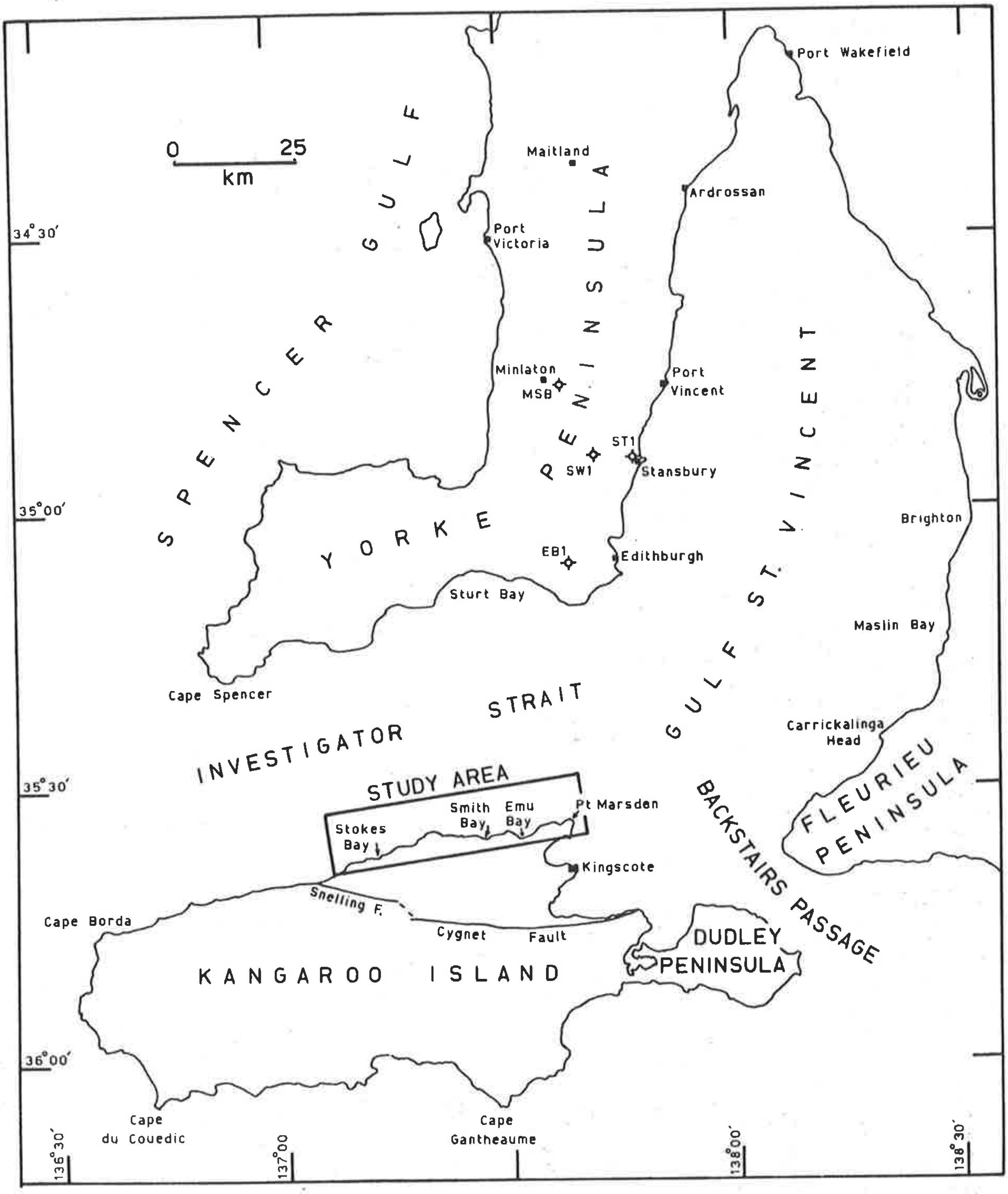

Figure 12-2. Location map of Kangaroo Island and adjacent areas, showing major geographical localities and area of study.

MSB: Minlaton Stratigraphic Bore.

ST1: Stansbury Town No. 1.

SW1: Stansbury West No. 1.

EB1: Edithburgh No. 1.

REGIONAL SETTING

Geologically and structurally, Kangaroo Island is the south-westerly continuation of the Mt. Lofty Ranges. These, together with the Finders Ranges and Olary Arc (Campana, 1954) are merely a small remnant of the Early Palaeozoic fold mountain belt known as the Delamerides (Daily et al., 1976) that was rejuvenated by uplift in the Late Cainozoic to form the present highlands of eastern South Australia.

During the Late Precambrian and Cambrian, a thick, predominantly shallow-water succession was laid down in the Adelaide 'Geosyncline', east and south of the Gawler Block, the latter composed of Archaean-Early Proterozoic crystalline rocks (Fig. 12-1). The Torrens Lineament or Hinge Zone (Sprigg, 1952) separates this block and its platform covering sediments from the much thicker succession laid down contemporaneously in the fold belt. Yorke Peninsula, which is incorporated in the south-eastern portion of the block, has a thin remnant cover of flat-lying to gently folded Cambrian sediments whereas further north thin Adelaidean deposits disconformably intervene between the preserved Cambrian and the basement.

Cambrian rocks outcrop extensively on Kangaroo Island. The bulk of these are metasediments referrable to the Kanmantoo Group except for a small occurrence of basal Cambrian Normanville Group rocks, including marble, on Dudley Peninsula on the eastern end of the island (Daily and Milnes, 1972a). Late Cambrian Encounter Bay Granites intrude the strongly folded metasediments and outcrop intermittently along the southern coast (Milnes et al., 1977). By way of contrast, the remainder of the Kangaroo Island Cambrian, which occurs in the northeast coastal region, is an unmetamorphosed and fossiliferous sequence of largely intertidal to shallow subtidal clastics and interfingering alluvial sands and conglomerates. Daily (1976b, Fig. 8) lithologically correlated this marginal sequence with the much thicker offshore Kanmantoo Group, the stratotype of which was described by Daily and Milnes (1971, 1973) from the southern coastline of Fleurieu Peninsula (Fig. 12-2), opposite Dudley Peninsula where the same stratigraphic succession is found (Fig. 1-3). The basis for this correlation hinges on the fact that as the red and green coloured northeast coast marginal fossiliferous sequence is traced to the west along the northern coastline, it gives way to a progressively metamorphosed sequence of grey coloured metasediments, unfossiliferous apart from trace fossils, and which from their sedimentary structures are interpreted as having been deposited further offshore. Flint (1978) interpreted Kanmantoo Group metasediments on the western end of the island as deep-sea fan deposits. However, there is little justification for such an interpretation, the sequence being a relatively shallow-water offshore succession. This is shown by the abundance of cross-bedded metasandstones outcropping on the western and southern coastlines that are prograded towards the east and which were laid down by offshore marine currents flowing sub-parallel to the southern margin of the Gawler Block which delineated the contemporary shoreline.

The Kangaroo Island fossiliferous Cambrian and Kanmantoo Group rocks were laid down rapidly in an actively subsiding basin in response to widespread marked faulting which commenced in the late Early Cambrian and is known to have extended into the Middle Cambrian on Yorke Peninsula and continued well into the Upper Cambrian in the Flinders Ranges. These movements, both positive (for source areas) and negative (for depositional areas) were episodic and were collectively termed the Kangarooian Movements by Daily and Forbes (1969), the name being derived from Kangaroo Island where evidence for such movements was first established (Daily, 1956). Daily and Milnes (1971, 1973) have discussed the Kangarooian Movements and their effect on contemporary Cambrian sedimentation. The conglomerates and their associated coarse calcareous sandstones that are prominent in the White Point Conglomerate and to a lesser extent in the Boxing Bay Formation were derived from uplifted source areas immediately north of the present coast, and were transported by streams flowing south into the basin. On the other hand the interbedded red-brown feldspathic sandstones and arkoses were derived from more distant sources and were transported by marine currents sub-parallel to the margins of the Gawler Block shorelines which from the time of commencement of Kanmantoo Group sedimentation, were oriented east-west and lay to the north of Kangaroo Island.

Lower Cambrian sedimentary rocks are also present on southern Yorke Peninsula, and are in part older than those of Kangaroo Island (Fig. 1-3). The older rocks include the Winulta and Kulpara Formations, and the Koolywurtie Limestone Member of the Parara Limestone, which contain lithologies identical to clasts in the White Point Conglomerate. However, the nature of the conglomerates, discussed later, indicates an even closer northerly source. Geophysical evidence indicates an Archaean to Proterozoic basement high in Investigator Straight (Fig. 12-2), which Stuart and von Sanden (1972, Fig. 8B) proposed as the source of the White Point conglomerates. This view is supported by the present authors although the abundance of carbonate clasts particularly in the White Point Conglomerate shows that the basement rocks within the source area were largely covered by an Early Cambrian clastic/carbonate shelf sequence (Daily, 1956).

PREVIOUS STUDIES RELATING TO THE FOSSILIFEROUS SEQUENCE OF THE NORTHEAST COAST OF KANGAROO ISLAND : AN HISTORICAL RESUME

The northeast coast Cambrian outcrops were first described by Tate (1883), Brown (1898) and Howchin (1898, 1903). All three workers recognised the individuality of the sequence, and were unable to suggest a correlation with the mainland. Howchin (1898) tentatively suggested a middle or upper Palaeozoic age, based on the lack of significant metamorphism of the sequence and on the presence of reworked boulders of (?)Cambrian limestone in conglomerate beds at Point Marsden. A glacial origin for the sequence now defined as the Boxing Bay Formation was proposed (Howchin, 1898, p.206), however it was noted (p.207) that "these suggestions are only thrown out as possible causes for the peculiar features of these beds rather than any settled conviction as to their origin".

Further descriptions of the northeast coast sequence were presented by Madigan (1928), following a student excursion to the island. Madigan (1928, p.211) recognised the pebbly and arkosic nature of the reddish-brown sandstones, and concluded that "the redness is mainly due to the colour of the orthoclase, which forms a good half of the rock". He also located outcrops of conglomerate on Cape d'Estaing containing boulders of archaeocyathid limestone, and stated (Madigan, 1928, p.212) "it not only indicates the proximity of the Archaeocyathinae limestone, of Middle (?)Cambrian age, but also shows the Point Marsden series to be post-Cambrian, and of an age not hitherto recognised in southern South Australia". Although Madigan's estimate regarding the age of the northeast coast sequence is now known to be too young, his conclusions regarding the origin and depositional environment of the conglomeratic sequence is fairly accurate. Madigan (1928, p.212) considered the sequence "to be of shallow water or even terrestrial origin, derived by torrential streams from neighbouring highlands. These highlands were composed of Cambrian and Pre-Cambrian rocks, which furnished the boulders of Archaeocyathinae limestone and the slate and schist fragments and pebbles of gneissic and granitic rock".

Madigan also reported trace fossils (trilobite tracks) in Freestone Creek, in a shaly sequence which he correctly correlated with the east side of Smith Bay (now defined as the Smith Bay Shale). The whole northeast coast Cambrian sequence, from Middle River to Point Marsden, he called the "Point Marsden series".

Regional geological mapping of Kangaroo Island by the South Australian Geological Survey commenced in 1952. However, an injury to the geologist in charge (R.C. Sprigg) terminated the investigations before the northeast coast succession was mapped or measured in detail. Consequently, the KINGSCOTE 1:250,000 Series Geological Sheet (Sprigg et al., 1954) contains many inaccuracies. Sprigg (1955) defined four formations in the "Point Marsden Group", but failed to recognise major faults and dip reversals in the sequence. Consequently, his stratigraphic succession, from base to top, of Stokes Bay Sandstone, Emu Bay Shale, White Point Limestone and Pt.Marsden conglomerate (Sprigg *et al.*, 1954; Sprigg, 1955) is incorrect.

Sprigg (1955, p.166) suggested that the "Point Marsden beds" accumulated near "the outer edge of a narrowing continental platform". He noted the abundance and considerable magnitude of slump structures within the Stokes Bay Sandstone, and suggested a shallow-water origin for this formation. The conglomerates in the "White Point Limestone" were attributed to erosion of nearby Archaeocyathid reefs, despite the paucity of limestone blocks containing *Archaeocyatha* and the abundance of cobbles and boulders of Precambrian metamorphic basement.

Fossils located by Sprigg's survey group in the Emu Bay Shale at Emu Bay were reported upon by Glaessner (1952). He identified the trilobites *Redlichia* n. sp. and *Lusatiops* n. sp., the brachiopod *Acrothele* sp. and also *Hyolithes* sp. On the basis of the trilobite association of *Redlichia* (Early to Middle Cambrian) and *Lusatiops* (Early Cambrian), Sprigg (1955) suggested an uppermost Early Cambrian age for the Emu Bay Shale.

Daily (1956, p.123) disagreed with the order of succession put forward by Sprigg *et al.* (1954) for the north coast Cambrian sequence, and disregarded the term "Point Marsden Group" because of "ambiguity and evidence indicating a break in its lower part". Daily (1956) recognised at least 5500 feet (1700m) of Cambrian strata, comprising the Stokes Bay Sandstone (1000 ft; 3300m) and the "Kangaroo Island Group" (4500 ft; 1370m). Within the "Kangaroo Island Group", Daily (1956) recognised four formations in continuous stratigraphic section from Bald Rock to White Point. The sequence comprised 100 ft (33m) of unnamed chocolate-coloured micaceous shales, overlain by the White Point Conglomerate (1250 ft; 380m), the Emu Bay Shale (350 ft; 110m) and the Boxing Bay Formation (2500 ft; 770m). Daily (1956) regarded the conglomeratic sequence on Point Marsden as either an upward continuation or a fault repetition of the type Boxing Bay Formation, and thus abandoned the term "Pt. Marsden conglomerates" (Sprigg *et al.*, 1954). He also concluded that the conglomerates near Cape 'Estaing and Hawk Nest are not talus from an archaeocyathid reef as Sprigg (1955) had suggested, but rather, provided evidence of active erosion of an adjacent land mass. Thus, he abandoned the term "White Point Limestone" in favour of "White Point Conglomerate".

Daily (1956) also located opisthoparian trilobites in shale near the top of the White Point Conglomerate, both in the type section near Bald Rock and in a fault-bounded outcrop west of Cape D'Estaing, and thus defined Faunal Assemblage No. 11. In addition to the fauna mentioned by Glaessner (1952), Daily (1956) identified Isoxys n. sp., a crustacean, and annelids in the basal 6m of the Emu Bay Shale. He named this assemblage Faunal Assemblage No. 12. He assigned both faunal assemblages to the upper Lower Cambrian, and suggested that the boundary between the Lower and Middle Cambrian probably lay within the Boxing Bay Formation.

In 1956, the Minlaton No. 1 and Stansbury No. 1 stratigraphic bores were drilled on southern Yorke Peninsula by the South Australian Department of Mines, in conjunction with Beach Petroleum N.L. (Daily, 1957; Ludbrook, 1965). No Early Cambrian strata were identified from the Stansbury No. 1 bore, however a 760m thick Early to Middle Cambrian sequence in the Minlaton bore was correlated in part by Daily (1957) with the Cambrian rocks on north-east Kangaroo Island. A 9m thick conglomeratic unit unconformably overlying the Early Cambrian Parara Limestone in the Minlaton bore (Fig. 12-2) was tentatively correlated on lithological grounds with the White Point Conglomerate (Daily, 1957), thus providing further evidence of a middle Early Cambrian orogeny in the southern portion of the Adelaide 'Geosyncline'. A distinction was made however, between the conglomerates in the Minlaton bore, which were regarded as continental deposits, and the White Point Conglomerate on Kangaroo Island, which was interpreted by Daily (1957) as a marine deposit.

Overlying the conglomerates in the Minlaton bore, there are approximately 110m of red silty clastics, with gypsum and minor carbonate interbeds. This sequence was also interpreted by Daily (1957) as a continental deposit, and together with the underlying 9m of conglomerate, was broadly correlated by Daily (Fig. 14 in Horwitz and Daily, 1958) with the Cambrian sequence on the northeast coast of Kangaroo Island. The stratigraphic column for the Cambrian of Kangaroo Island, shown in Figure 14 of Horwitz and Daily (1958) was a further revision of the stratigraphy of this area, with the definition of the Smith Bay Shale, separating the Stokes Bay Sandstone from the stratigraphically younger White Point Conglomerate. In addition, Daily recognised abundant trilobite tracks and worm burrows in purple and green shales underlying the Stokes Bay Sandstone. This shaly sequence had been mapped by Sprigg et al. (1954) as Adelaidean phyllites, however the presence of these trace fossils established its Cambrian age.

The Cambrian stratigraphy of the northeast coast of Kangaroo Island was summarized by Campana (1958a). Further descriptions of the faunas in the Emu Bay Shale and White Point Conglomerate were published by Pocock (1964, 1970). The trilobite identified by Glaessner (1952) as Lustiops from the Emu Bay Shale was considered by Pocock (1964) to belong to a new genus. Thus, he renamed the trilobite Estaingia bilobata gen. et sp. nov. (Pocock, 1964). In addition, Pocock 1970 recognised a new family of trilobites (the Emuellidae) in the White Point Conglomerate and Emu Bay Shale. From Faunal Assemblage No. 11 (the upper part of the White Point Conglomerate), Pocock (1970) described Balcoracania dailyi and Emuella polymera. In Faunal Assemblage No. 12 (the lower portion of the Emu Bay Shale), Pocock (1970) described Emuella dalgarnoi. Another species of Balcoracania (B. flindersi) was described by Pocock (1970) from the lower portion of the Billy Creek Formation in the Flinders Ranges, and on this basis a late Early Cambrian age was suggested for the White Point Conglomerate.

Further stratigraphic drilling on southern Yorke Peninsula was carried out in 1966 and 1967. Stansbury West No. 1 Well was drilled in mid 1966, approximately 5km west of Stansbury township. It penetrated approximately 1310m of Cambrian strata, including nearly 120m of red-beds and minor interbedded carbonate, resting unconformably on the Early Cambrian Parara Limestone and correlated by Watts and Gausden (1966) with the Minlaton Conglomerate and overlying red-beds in the Minlaton No. 1 bore (Daily, 1957).

Edithburgh No. 1 Well, drilled 24km southwest of Stansbury township (Fig. 12-2) in late 1966, penetrated only 530m of Cambrian strata. A major unconformity separates the Early Cambrian Kulpara Limestone from the Middle Cambrian Dalrymple Limestone (Daily, 1968), indicating that the southern portion of Yorke Peninsula was uplifted and the Cambrian carbonate cover partly eroded during the late Early and (?)early Middle Cambrian.

Further evidence of this orogeny was obtained in 1967, when the Stansbury Town No. 1 Well was drilled (Laws and Heisler, 1967), just 1km south of the earlier and somewhat unsuccessful Stansbury well. The section encountered was similar in many respects to that of Stansbury West No. 1 Well, except for an increased thickness of (?)Middle Cambrian red-beds, and a greatly decreased thickness of Early Cambrian carbonates. The Minlaton Conglomerate, 27m thick rests unconformably on Kulpara Limestone, and comprises pebbles and cobbles of Precambrian crystalline basement at the top, and dolomite clasts at the bottom, indicating complete and progressive stripping of the Early Cambrian carbonate platform cover from adjacent uplifted areas.

Daily (1968) summarized the subsurface stratigraphic data of Yorke Peninsula and concluded (p.5) that "late Lower Cambrian uplifts, along north-south lineaments, took place following the deposition of the Parara Limestone. This initiated erosion which continued well into the Middle Cambrian as in the Edithburgh area, but deposition recommenced earlier elsewhere... The event is of minor significance in the Stansbury West area but assumes major significance in the Stansbury Town and Edithburgh areas". It is this event which gave rise to the thick clastic sequence, especially the White Point Conglomerate, on the northeast coast of Kangaroo Island.

Palaeomagnetic analysis of rock samples from the White Point Conglomerate were published by Briden (1967). The study revealed natural remnant magnetization (NRM) directions consistent with a Mesozoic or early Tertiary age. To explain his results, Briden (1967) suggested that the NRM in the Cambrian of Kangaroo Island was acquired during a period of slightly elevated rock temperature, possibly connected with igneous activity. Briden (1967) postulated that an elevated geothermal gradient would have been associated with extrusion of the basalt which outcrops near Kingscote. The lava flow has been dated as Middle Jurassic by Wellman (1971).

A correlation chart of Cambrian sections in the southern portion of the Adelaide 'Geosyncline' was presented by Daily (1969b, Table 1). In this table Daily (1969b) applied the name Mt. McDonnell Formation to the sequence of purple and green shales and siltstones underlying the Stokes Bay Sandstone near Hummocky Point, on the mid north coast of Kangaroo Island. He correlated the entire Kangaroo Island north coast sequence of six formations with the Kanmantoo Group on Fleurieu Peninsula, and with a thin sequence of conglomerates (the Minlaton Conglomerate) and red-beds in the subsurface on Yorke Peninsula. The basal unit of the Kanmantoo Group (the Carrickalinga Head Formation) was correlated on lithological grounds with the Mt. McDonnell Formation on the north coast of Kangaroo Island. As Daily (1969b, p.52) stated "according to this interpretation the Kanmantoo Group is equated lithologically with the Kangaroo Island sequence of Lower Cambrian age and hence is older than the Middle Cambrian Ramsay Limestone of Yorke Peninsula. The beginning of Kanmantoo Group sedimentation appears to have resulted from widespread movements throughout the region of deposition which allowed a rapid influx of clastics. These Lower Cambrian movements, herein termed the Kangarooian Movements (cf. Kangaroo Island Orogeny of Daily, 1956), are particularly evident in both the Kangaroo Island and Yorke Peninsula regions where vertical uplifts along faults gave rise to impressive conglomerates".

The Handbook of South Australian Geology (Parkin, 1969) presented little new data on the Cambrian sequence of northeast Kangaroo Island, and in some respects (eg. the correlation chart-Fig. 33) was, at that stage, already out of date. Thomson (1969b) introduced the terms "Waitpingan Subsidence" and Cassinian Uplift" to describe the late Early Cambrian orogeny in the southern part of the Adelaide 'Geosyncline'. However, Daily had already termed the orogeny the "Kangaroo Island Orogeny" (Daily, 1956), and had subsequently modified the name to the "Kangarooian Movements" (Daily and Forbes, 1969). Thomson (1969b, Fig. 42) also presented a palaeogeographic map of Early Cambrian sedimentation in the southern portion of the Adelaide 'Geosyncline'. The contour lines, representing original depositional thicknesses for the Early Cambrian, are almost purely speculative for Kangaroo Island, and thus the diagram is misleading and probably quite inaccurate.

Considerable thinning of the Early Cambrian sequence to the west of Kangaroo Island has been inferred by Thomson (1969b, Fig. 42) and more recently by Flint (1978, Fig. 17). However Smith and Kamerling (1969), using refraction seismic and other data in connection with petroleum exploration, considered that the Duntroon Basin, which lies to the west of Kangaroo Island, is floored by an appreciable thickness of Kanmantoo Group metasediments and associated granite. Thus, there is no evidence supporting a land mass to the west of Kangaroo Island in the Early Cambrian. Thomson (1970, p.207) stated that the Torrens Lineament, corresponding to the eastern edge of the Gawler Block, is "truncated in the south by the Cygnet Fault". However, there is little evidence for this interpretation, as the Early Cambrian sediments of the Adelaide 'Geosyncline' continue in an unbroken trend from approximately north-south on Fleurieu Peninsula, turning east-west across Kangaroo Island, and continuing to the northwest beneath the Duntroon Basin (Smith and Kamerling, 1969). Daily et al. (1973, p.63) interpreted this trend as comprising but a small portion of the Cambrian sediments originally circumscribing the Gawler Block, with the "southern section of the arc owing its shape to compression against the virtually unyielding Gawler Block the margin of which, bounded by the Torrens Lineament, is curved in the same sense".

Results of a detailed study of the Kanmantoo Group were published at about this period of time by Daily and Milnes (1971, 1972a, 1972b, 1973). These authors subdivided the Carrickalinga Head Formation on southern

Fleurieu Peninsula into three members known as the Madigan Inlet Member (basal unit), the Blowhole Creek Siltstone Member, and the Campana Creek Member (upper unit). They stated (Daily and Milnes, 1971, p.204) that "the Carrickalinga Head Formation and the Mount McDonnell Formation (Daily, 1969) are synonymous, the two uppermost members of the former being the metamorphic counterparts of the shales, silts and minor coarser clastics found below the Stokes Bay Sandstone along the north coast of Kangaroo Island". Thus, they discarded "Mount McDonnell Formation" as a stratigraphic name, and called the basal formation of the Kangaroo Island northeast coast sequence the "Carrickalinga Head Formation", thus firmly establishing a correlation between Kangaroo Island and Fleurieu Peninsula.

The role of the Kangarooian Movements in Kanmantoo Group sedimentation was discussed by Daily and Milnes (1971, p.209; 1972b, p.232-234), who emphasised the sporadic nature of the tectonism, which delivered immature shales, silts, sands, and gravels into the basin of deposition. They discerned (Daily and Milnes, 1972a) a decrease in pebble size from west to east in the Inman Hill Subgroup, and noted an abundance of current features indicating flow from northwest to southeast in the Brown Hill Subgroup, thus providing further evidence of uplift and erosion of a land mass to the north of Kangaroo Island in the late Early to early Middle Cambrian.

Erosion of the uplifted area produced an unconformity, commonly overlain by the Minlaton Conglomerate. Stuart and von Sanden (1972) reported that the unconformity surface was recognisable on seismic reflection records obtained from the southern portion of Gulf St. Vincent, as far east as the Eden-Burnside Fault Zone (Stuart and von Sanden, 1972, Fig. 5). They also provided a detailed discussion of Late Precambrian-Cambrian tectonism in the southern portion of the Adelaide 'Geosyncline'. Fig. 8b of Stuart and von Sanden (1972) is considered to be an accurate portrail of the late Early Cambrian palaeogeography of the region.

A correlation chart for the Cambrian of the Adelaide 'Geosyncline' and Stuart Shelf was presented by Daily (1976, Fig. 8). In this chart (Fig. 1-3), Daily has clearly illustrated the nature of the late Early Cambrian uplift of Yorke Peninsula, with uplift and erosion in the south-east being much more severe than further north and northwest. Daily et al. (1976, p.17) further suggested that areas lying to the west and southwest of Kangaroo Island may have been uplifted and eroded, however there is little evidence at present to support this view.

A major discussion of the geology of the Cambrian of the northeast coast of Kangaroo Island was produced by Daily (1977), for a Geological Society of Australia (S. Aust. Branch) field conference to Kangaroo Island in October of 1977. New data included the discovery of trilobite fragments in the Carrickalinga Head Formation at Hummocky Point, and a much more detailed discussion of the lithologies, sedimentary structures and palaeocurrents of the sequence than previously available. Daily's (1977) report remains the most up-to-date and comprehensive study of the Kangaroo Island northeast coast Cambrian stratigraphy to date. Daily et al. (in press) has recently prepared a summary of this data for publication in "The Natural History of Kangaroo Island".

CHAPTER 13

STRATIGRAPHY AND ENVIRONMENTAL ANALYSIS OF THE CARRICKALINGA HEAD FORMATION

THE STRATIGRAPHY OF THE CARRICKALINGA HEAD FORMATION

Nomenclature

Beds now assigned to this formation are shown on the KINGSCOTE 1:253,400 map sheet (Sprigg et al., 1954) as belonging to the Late Pre-cambrian Adelaide System. However, abundant arthropod tracks and strongly bioturbated horizons (Campana, 1958a) throughout the sequence, and the presence of Redlichia in the upper part of the formation (Daily, 1977) prove an Early Cambrian age. The base is nowhere exposed along the northeast coast of Kangaroo Island, however 520m of stratigraphic section were measured in the Carrickalinga Head Formation below the Stokes Bay Sandstone near Hummocky Point (Plates 130 and 131) (Figure 13-1, rear pocket).

The sequence was originally named the "Mt. McDonnell Formation" by Daily (1969b, Table 1). However, Daily and Milnes (1971) recognised a marked lithological similarity between the sequence below the Stokes Bay Sandstone on Kangaroo Island and the uppermost two members of the Carrickalinga Head Formation in the type section of the Kanmantoo Group on southern Fleurieu Peninsula. Thus, they discarded the term "Mt. McDonnell Formation" as a stratigraphic name, applying the term "Carrickalinga Head Formation" to both the metamorphosed sequence on Fleurieu Peninsula and its relatively unmetamorphosed counterpart on the northeast coast of Kangaroo Island.

Introduction

The Carrickalinga Head Formation is the oldest Cambrian formation exposed on the northeast coast of Kangaroo Island (Table 13-1). Outcrop of the formation in the vicinity of Hummocky Point and location of the measured stratigraphic section are shown in Figure 13-2. Thickness of the exposed Carrickalinga Head Formation at this locality is 520m. The base is nowhere exposed. The lower 140m near Hummocky Point comprise a fine, silty sequence (Plate 130) correlated with the Blowhole Creek Siltstone Member (Daily and Milnes, 1971) on southern Fleurieu Peninsula. The upper

Table 13-1. Correlations between the Billy Creek Formation and its lateral equivalents on the northeast coast of Kangaroo Island.

	FLINDERS RANGES			NORTHEAST COAST KANGAROO ISLAND
	WIRREALPA BASIN		REAPHOOK HILL	
Middle Cambrian	Wirrealpa Limestone			
Middle Cambrian	Billy Creek Formation	Eregunda Sandstone Member	top not exposed	
Early Cambrian	Billy Creek Formation	Nildottie Siltstone Member	Erudina Siltstone Member	Boxing Bay Formation
Early Cambrian	Billy Creek Formation	Nildottie Siltstone Member	Erudina Siltstone Member	Emu Bay Shale
Early Cambrian	Billy Creek Formation	..... Warragee Member	..... Coads Hill Member	..... White Point Conglomerate
Early Cambrian	Billy Creek Formation	Warragee Member	Coads Hill Member	Smith Bay Shale
Early Cambrian	Billy Creek Formation	Warragee Member	Coads Hill Member	Stokes Bay Sandstone
Early Cambrian	Billy Creek Formation	Warragee Member	Coads Hill Member	Carrickalinga Head Formation base not exposed
Early Cambrian	Oraparinna Shale		Wilkawillina Limestone	

..... Balcoracania horizon

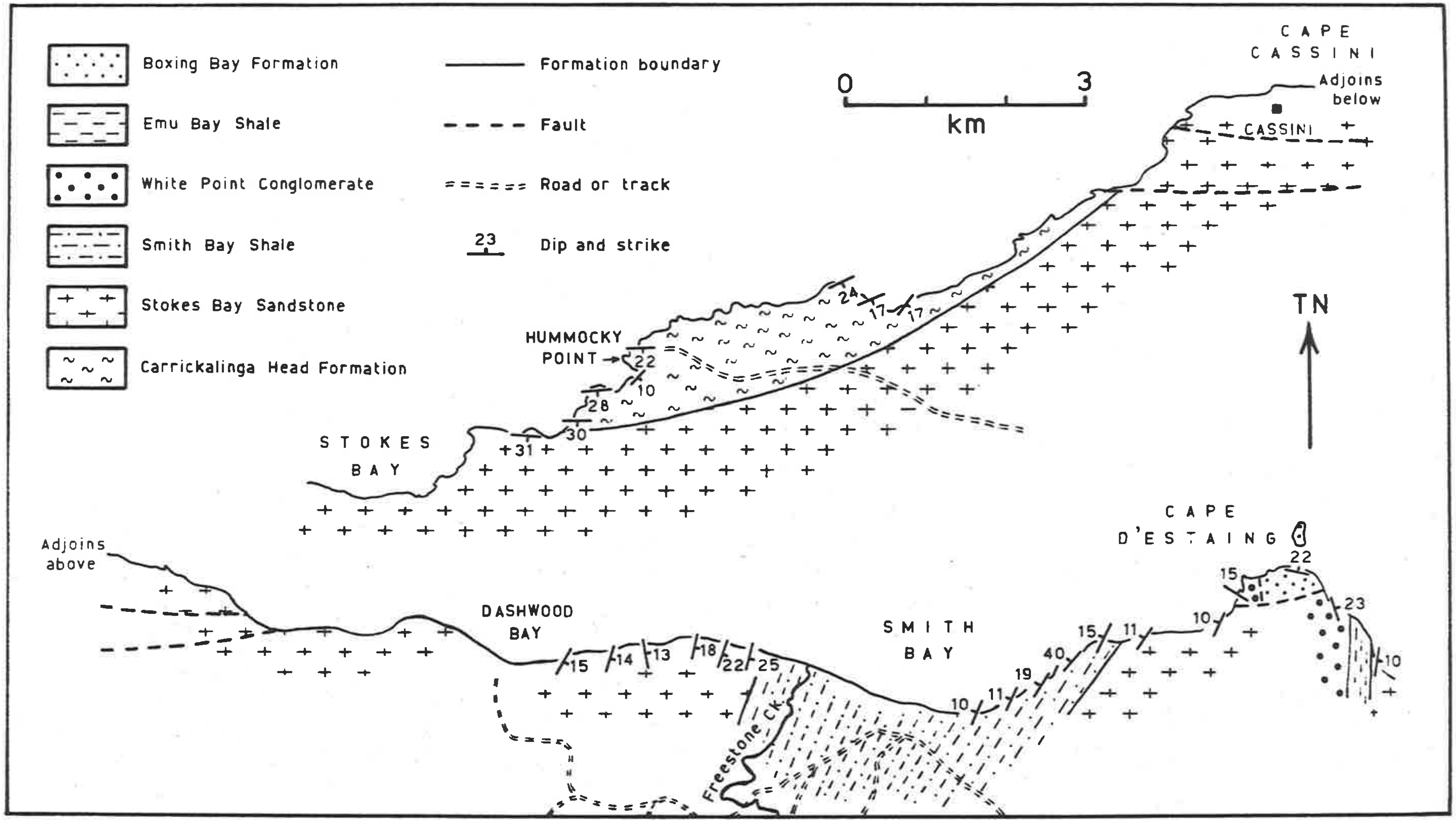

Figure 13-2. Simplified geological map of coastal sections between Stokes Bay and Cape D'Estaing on the northeast coast of Kangaroo Island.

380m are sandier (Plate 131) and are correlated with the Campana Creek Member (Daily and Milnes, 1971). Trough cross stratified and convolute bedded sandstone units are common in the uppermost 100m of the formation, and indicate a gradual transition into the conformably overlying Stokes Bay Sandstone (Plate 132).

Palaeontology

Burrows, trilobite tracks and molluscan trails are abundant throughout the sequence. The only body fossils located to date are fragments of Redlichia, which occur in a thin, yellowish brown calcareous sandstone interbed in the Campana Creek Member at Hummocky Point (234m in the measured section - Fig. 13-1, rear pocket). The trilobite fragments were originally reported by Daily (1977, p.7).

ENVIRONMENTAL ANALYSIS OF THE CARRICKALINGA HEAD FORMATION

Facies Analysis

Introduction

The Carrickalinga Head Formation comprises dominantly greyish green shale, siltstone and fine sandstone, with minor interbeds of red-brown to grey, medium-grained arkosic sandstone. The fine-grained part of the sequence is characterised by a very well-developed facies spectrum. From mud-rich to sand-rich, the spectrum comprises evenly laminated shale (in some cases streaked with silt and sand), through lenticular bedded, linsen bedded and flaser bedded units, into continuously rippled siltstone and fine sandstone. The lower member (the Blowhole Siltstone Member equivalent) is characterised by the muddier facies, whereas the upper member (the Campana Creek Member equivalent) is characterised by the sandier components. In addition, the Campana Creek Member equivalent contains minor interbeds of red-brown arkose, which are typically trough cross-stratified,with minor ripple lamination, planar lamination, and convolute bedding.

Shale and Sand-Streaked Shale

Parallel laminated greyish green shale and fine siltstone, commonly with mm-cm thick coarse siltstone and fine sandstone intercalations, characterises the Blowhole Creek Member equivalent, and occurs sporadically in the Campana Creek Member equivalent (upper and lower portions of Plate 133). The sand-streaked shale is bioturbated, and contain minor arthropod tracks. Common sand-infilled retrusive burrows indicate rapid sedimentation (Plates 134 and 135). This facies is interpreted as having formed in a very low energy subtidal environment, principally by suspension settling. Coarse silt and fine sand intercalations and rare graded bedding represent short periods of higher energy deposition, probably related to suspension settling of coarser material during periods of storm activity (Reineck and Singh, 1972).

Lenticular Bedding

A gradation occurs from the evenly laminated, sand-streaked shale facies into the lenticular bedded facies, which comprises isolated to weakly connected sandstone ripples intercalated with greyish green mudstone (middle portion of Plate 133). The rippled sandstone lenses, commonly referred to as 'starved rippled', indicate minor wave and current activity in a predominantly low energy environment. Worm burrows are common (Plates 136 and 137), and arthropod tracks occur sporadically throughout the facies (Plate 138). DeRaaf et al. (1977) have interpreted similar deposits in the Lower Carboniferous of County Cork, Ireland, as due to thin storm sandlayers which are affected by wave agitation related to the same storm that carried in the sand. However, the marked asymmetry of most of the ripple lenses and the paucity of internally-discordant cross lamination indicate that the thin ripple trains were formed principally by unidirectional currents rather than resulting from wave oscillation.

Linsen Bedding

The linsen bedded facies comprises red and greyish-green, mm-cm thick intercalations of shale and ripple laminated sandstone (Plate 139). The thin, rippled sandstone beds contain both markedly asymmetrical ripple laminae with relatively flat bases, and bundled structures with trough-shaped erosional bases. The latter structures contain minor form-discordant laminae and similar structures are interpreted by DeRaaf et al. (1977) as wave-generated. Worm burrows, arthropod tracks and molluscan trails are abundant in this facies, which contains only rare desiccation cracks.

Exposed bedding surfaces are typically covered with ripples (Plate 140). However, in contrast to the similar looking, linsen-bedded facies described by DeRaaf et al. (1977), the multitude of ripples are predominantly current-formed (linguoid), with only rare, near-symmetrical wave-generated forms (Plate 141). Double crested ripples (Plate 142) indicative of falling water level during deposition (Reineck and Singh, 1975) are rare. Current-ripple orientations are bipolar, and thus the total evidence suggests deposition in a moderate-energy, generally subtidal environment, where tidal currents were relatively strong and wave action subordinate.

Flaser Bedding

With increased sand content, a gradation occurs from the linsen-bedded facies into flaser bedded units, which comprise rippled sandstone with only minor red and green shale drapes (Reineck and Wunderlich, 1968). Worm burrows and trilobite tracks are common, however desiccation cracks are very rare. Internally, the facies comprises both the wave-knit, form-discordant, bundled structures interpreted by DeRaaf et al. (1977) as wave-generated, and strongly asymmetrical ripple laminae, interpreted as current-formed. Bedding surfaces contain both wave and current ripples, although the latter are much more abundant. The facies is interpreted as a predominantly subtidal deposit, formed by tidal current activity on a shallow marine shelf where structures could be partly modified by wave oscillation.

Continuously Rippled Sandstone

Continuously rippled sandstone, devoid of mudstone flasers and shaly interbeds, forms a minor part of the Carrickalinga Head Formation, and unlike the facies described above, is restricted entirely to the upper member of the formation of Kangaroo Island. Although similar to the wave-knitted facies described by Reineck and Singh (1975) and DeRaaf *et al.* (1977), the abundance of 'rib and furrow' structures on bedding surfaces indicates deposition predominantly under the influence of currents. In cross-section, intersecting trough-shaped bundles of ripple-lamination are apparent (Plate 142). However rather than being attributed entirely to wave action, the ripple lamination is partly interpreted as nu cross-stratification (Allen, 1963), formed by the migration of current ripples with highly sinuous crestlines. Worm burrows occur sporadically in the facies, which is interpreted as a moderate-energy, shallow water, subtidal deposit.

Cross-stratified, Horizontally Laminated and Contorted Red-Brown Arkosic Sandstones

These facies are described together, because they constitute only a minor part of the Carrickalinga Head Formation on Kangaroo Island, and are restricted almost entirely to the upper member of the formation. The most common facies is trough cross-stratified, medium-grained sandstone, with multiply intersecting troughs occurring in sets up to 6m in thickness (Plates 144 and 145). Rarely linguoid ripples are preserved on the upper surface of the units, indicating a gradual reduction in the energy of deposition. Minor associated facies are horizontally laminated sandstone commonly with current lineation, and convolute bedded sandstone. The red-brown arkosic sandstones are interpreted as relatively high energy, subtidal deposits, formed by the migration of sandy shoals under the influence of tides and possibly waves. Many of the cross-bedded sandstones are rich in carbonate ooliths and peloids (Plate 146). Similar deposits have been described in the modern environment by Curray (1960), Emery (1966), Uchupi (1968), Stride (1963) and Belderson and Stride (1966). Convolute bedded sandstones are characterized by approximate subvertical symmetry of the slumps, which are attributed to dewatering of loose-packed sediment (Allen and Banks, 1972;

Brenchley and Newall, 1977).

Facies Associations and their Interpretation

Coarsening-upward (CU), fining-upward (FU), and coarsening then fining-upward (CUFU) sequences, as described by DeRaaf et al. (1977) are all present in the Carrickalinga Head Formation. CU sequences average about 10m in thickness, however considerable variation occurs about this mean. The CU sequences vary from shale or linsen bedded shaly sandstone, through flaser bedding, into large scale cross-stratified or ripple laminated sandstone. FU sequences are generally thinner (average 5-7m), but otherwise are the reverse of the CU sequences described above. CUFU sequences are most abundant, and this feature further emphasises the paucity of distinctive basal surfaces in the sequence. Instead, the sequence comprises an alternation of coarse and fine elements, in which the fine elements predominate.

The Carrickalinga Head Formation is interpreted as representing the migration of sandy shoals in a shallow subtidal environment. The shoals develop in the highest energy environments, where tidal and minor wave energy was most concentrated. Flaser bedded and linsen bedded units were deposited on adjacent, lower energy parts of the tidal flat. Sand-streaked shales represent the lowest energy deposits, and accumulated in a protected, low energy, probably deeper water, subtidal environment. Large-scale alternations of coarse and fine elements in the sequence are interpreted as resulting from minor transgressions and regressions. In addition, some alternations may be due to the lateral migration of the sandy shoals in the shallow marine environment.

Palaeocurrent Analysis

Palaeocurrent data for the Carrickalinga Head Formation is presented in Figure 13-3. Current ripples and trough cross-stratification orientations are bipolar, WNW-ESE. Current lineations have similar orientations, with current crescents indicating upper regime flow from WNW to

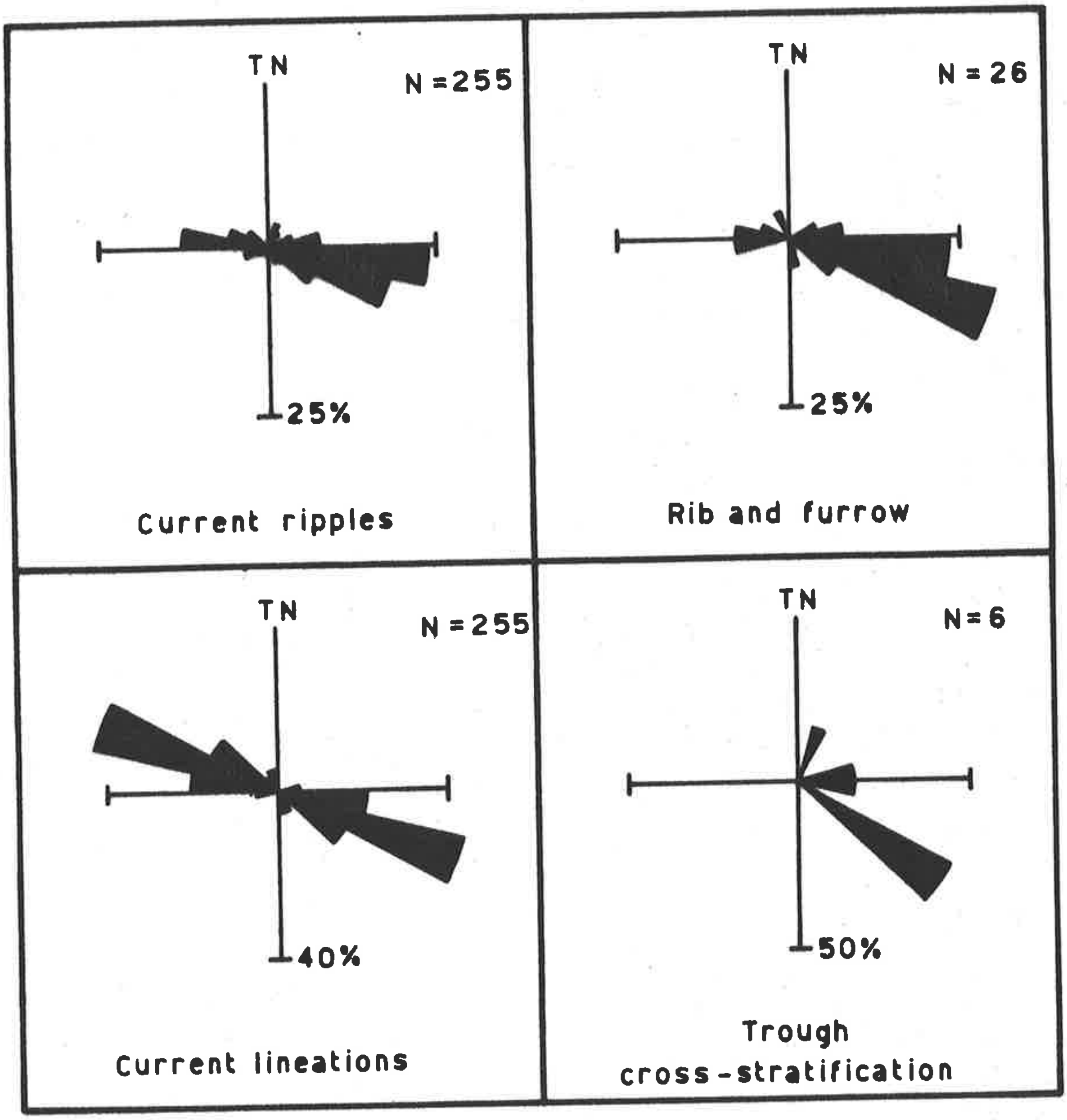

Figure 13-3. Palaeocurrent rose diagrams, Carrickalinga Head Formation. N = number of data.

ESE. By analogy with the upper part of the Kangaroo Island northeast coast Cambrian sequence (Chapter 16) and on the basis of the abundant tidal influence in the Carrickalinga Head Formation (reflected in the type of bedding structures and the bipolar palaeocurrent orientations), the sequence is interpreted as having been formed by tidal currents which flowed subparallel to a WNW - ESE striking coastline. The absence of symmetrical ripples, the paucity of wave-ripple cross lamination (as described by Reineck and Singh, 1975 and DeRaaf *et al.*, 1977), and the paucity of north-south palaeocurrents indicates that wave activity was minor.

Conclusions

The Carrickalinga Head Formation is similar to modern tidal deposits, as described by Reineck (1967), Reineck and Singh (1975) and Ginsburg (1975). However, notable features of the sequence are the paucity of well-developed tidal channels and the near-absence of desiccation cracks. Paucity of tidal channels has been noted by Walker and Harms (1975) as evidence of low palaeotidal range. The lack of desiccation cracks in most of the sequence is considered to be the result of deposition in a predominantly subtidal environment. Evans (1965) notes that in the lower, subtidal flats of the Wash, England, sediment transport is by reversing longshore currents which flow parallel to the shoreline. Thus, a close similarity is noted between the submerged, outer portions of the Wash, and the sequence in the Carrickalinga Head Formation, as exposed of the northeast coast of Kangaroo Island.

CHAPTER 14

STRATIGRAPHY AND ENVIRONMENTAL ANALYSIS OF THE STOKES BAY SANDSTONE

THE STRATIGRAPHY OF THE STOKES BAY SANDSTONE

The Stokes Bay Sandstone was originally defined by Sprigg et al. (1954) and Sprigg (1955). However, much of the area shown of the KINGSCOTE 1:253,400 map sheet (Sprigg et al., 1954) as Stokes Bay Sandstone is of uncertain affinity, and may belong to the sandy portions of other formations within the northeast coast Cambrian sequence.

The Stokes Bay Sandstone is dominated by trough cross stratified, evenly bedded and slumped reddish brown arkose. It rests conformably on the Carrickalinga Head Formation and is overlain conformably by the Smith Bay Shale (Table 13-1). The basal contact with the Carrickalinga Head Formation is gradational, and is clearly observed in the cliffs approximately 1km west of Hummocky Point (Fig. 13-2). The upper contact with the Smith Bay Shale is exposed in Smith Bay and also along Freestone Creek (Madigan, 1928; Daily, 1977). No stratigraphic section was measured for the Stokes Bay Sandstone, which Daily (1977) considers may attain a thickness of 700m. No fossils have been found in the formation to date.

ENVIRONMENTAL ANALYSIS OF THE STOKES BAY SANDSTONE

Facies Analysis

Introduction

The Stokes Bay Sandstone comprises approximately 700m of red-brown, medium-grained arkose. The sandstones are commonly trough cross-stratified, plane laminated and convolute bedded. Indeed, the convolute intervals are so common and so distinctive that they have attracted the attention of geologists over many years (Howchin, 1898; Madigan, 1928; Sprigg, 1955; Daily, 1956, 1977).

Trough Cross-Stratified Sandstone

Medium-grained, trough cross-stratified red-brown arkose with rare crystalline basement pebbles is the most abundant facies in the Stokes Bay Sandstone (Plate 147). The trough cross-sets average 20-40cm in thickness and 1-3m in width, and are commonly arranged in cosets up to 4m in thickness. They are interpreted as having resulted from the migration of dunes (megaripples) in a moderate to high energy, shallow marine environment (Clifton et al., 1971; Harms et al., 1975). Synsedimentary deformation down the direction of cross-bedding is uncommon, and in the absence of other features indicative of a moderate to high palaeoslope, is attributed to current drag on the unconsolidated bed (Allen and Banks, 1972) rather than gravity slumping.

Contorted Sandstone

Contorted and convolute layers up to 1.5m in thickness, and averaging about 50-80cm thick are common in the red-brown, medium-grained arkose of the Stokes Bay Sandstone (Plates 148 and 149). Folded structures generally have subvertical symmetry, suggesting that deformation took place by predominantly vertical movement (water escape) rather than lateral displacement. Contorted layers commonly continue to the limits of the outcrop (maximum of 40m), and are overlain by undeformed strata without truncation.

The common occurrence of contorted structures in the Stokes Bay Sandstone is interpreted as largely a feature of rapid deposition of loose-packed sand (Allen, 1972). Brenchley and Newall (1977) have noted that the expulsion of water and the resulting deformation of the strata can be triggered by seismic shock. Another possible trigger mechanism is fluid pressure fluctuations due to wave surge (Lowe, 1975), however in the case of the Stokes Bay Sandstone this is a less likely mechanism, considering the considerable thickness of the deformed layers.

Plane Laminated Sandstone

Plane laminated, fine to medium-grained, red-brown sandstone, with heavy mineral concentrations along clay laminae and containing rare granules and pebbles of crystalline basement is a minor facies in the Stokes Bay Sandstone. Primary current lineation is very common, with rare current crescents indicating upper flow regime transport from west to east. The plane laminated sandstones occur in units up to 1.5m in thickness (average 0.5-0.7m) and are overlain by contorted or trough cross-stratified sandstone.

Channel Sandstone

Poorly defined scours or shallow channels, generally 5-20m in width and 0.5-1.5m in depth, are very uncommon in the Stokes Bay Sandstone. The scours are infilled with poorly bedded or trough cross-stratified, medium-grained red-brown arkose (cf. Plate 132). Basal channel-lag conglomerates are absent. The paucity of channels, and their poor definition where present is a feature of the sequence and is further evidence of a shallow marine origin for the sandstone.

Facies Associations and their Interpretation

The Stokes Bay Sandstone generally comprises a random alternation of cross-bedded, plane laminated and contorted medium-grained arkose. In rare cases, a weak cyclicity is recognised where broad shallow channels are overlain by trough cross-stratified sandstone, in which the cross-stratification becomes better defined and smaller scale upwards, before passing into plane laminated, contorted, or rarely, ripple laminated sandstone. Such sequences are interpreted as the product of strong unidirectional currents, and a large supply of clastic detritus, which produced minor scouring followed by the migration of meggaripples in broad shallow channels. Plane laminated sandstones were deposited by strong currents during periods of reduced sediment supply.

Palaeocurrent Analysis

Palaeocurrent data for the Stokes Bay Sandstone is presented in Figure 14-1. Channels, trough cross-stratification, current ripples, slumps down cross-sets and current crescents all indicate current flow from west to east. These observations are in agreement with data presented by Stuart and Johnson (1970). Two interpretations of the data are possible: either the

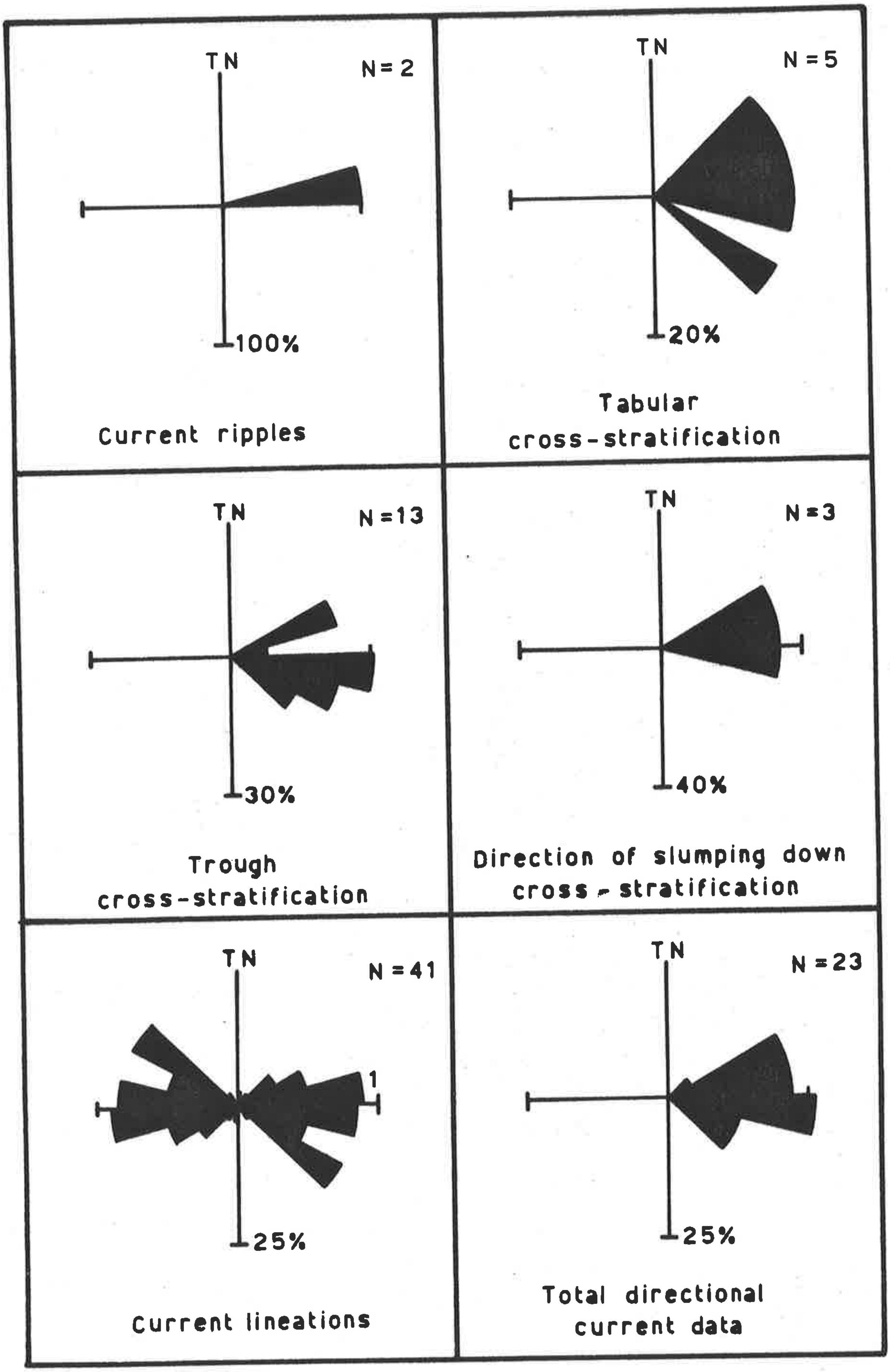

Figure 14-1. Palaeocurrent rose diagrams, Stokes Bay Sandstone.
N = number of data.

palaeocurrents represent transport down a depositional slope (i.e. off-shore transport), or they represent longshore migration on a shallow marine shelf.

The lack of well-defined channels, the paucity of cyclicity in the sequence and the considerable lateral extent of beds in the Stokes Bay Sandstone suggests that deposition took place on a gentle palaeoslope such as a shallow marine shelf. An east-west shoreline was influential throughout the deposition of the overlying sequence (Chapter 16), and the shoreline was probably similarly orientated during the deposition of the underlying Carrickalinga Head Formation (Chapter 13). Thus, it is concluded that the Stokes Bay Sandstone was most probably deposited on a shallow marine shelf by strong, generally unidirectional currents, flowing from west to east parallel to the ancient shoreline.

Conclusions

It appears that the Stokes Bay Sandstone was deposited by strong, unidirectional currents, flowing from west to east, parallel to the strandline. The arkosic nature and only moderate sorting and rounding of the sediment, combined with the paucity of herringbone cross-stratification indicates that the terrigenous detritus underwent only minor sorting and abrasion in the marine environment, and may also indicate that sediment supply was considerable and deposition relatively rapid. Several models for sediment dispersal on continental shelves have been proposed. The model of random dispersal suggested by Swift (1970) and Swift et al. (1971) is obviously not applicable to the Stokes Bay Sandstone, and the wind-drift transport recognised by Sternberg and McManus (1972) is probably not a powerful enough mechanism to produce the structures observed in the present example. However, as noted by Pettijohn et al. (1973), tidal currents may play a significant role in the distribution of sediment on shallow marine shelves. They may concentrate sand into 'windrows' or ribbons parallel to current direction, with large scale cross-stratification generally indicating flow parallel to the strandline. For example, in the North Sea, sediment transport is principally by tidal currents which parallel the shoreline and produce both sand ribbons and sand wave systems or 'shoals' (Stride, 1963, 1970; Houbolt, 1968, Kenyon and Stride, 1970). On the continental shelf of southeast Africa, Flemming (1978) has observed large dunes migrating parallel to the shoreline in response to a unidirectional ocean current (the Agnlhas Current). The current velocities recorded by Flemming (1978) are high enough to produce upper flow regime plane lamination (see Harms et al., 1975, Fig. 2-5), even at depths in excess of 50m.

Thus, the Stokes Bay Sandstone is interpreted as having resulted from uplift and erosion of the Gawler Block (to the northwest of Kangaroo Island) and dispersal of the arkosic sediment by strong unidirectional longshore currents flowing across the shallow marine shelf which flanked the southern margin of the Gawler Craton. Thus, the currents were either tide-induced (as for the North Sea) or were oceanic currents, such as those produced by the Coriolis force or by temperature/density variations in the ocean waters. However, there is no evidence to support a deep water origin for the Stokes Bay Sandstone since the formation is contained in a very thick sequence of sediment which show abundant evidence of deposition in a shallow water shoreline environment. Furthermore, evidence of strong tidal activity is present throughout the Kangaroo Island northeast coast Cambrian sequence, and thus it is suggested that the Stokes Bay Sandstone was most probably deposited in moderately shallow water under the influence of strong, tide-generated currents which swept the coastline.

CHAPTER 15

STRATIGRAPHY AND ENVIRONMENTAL ANALYSIS OF THE SMITH BAY SHALE

THE STRATIGRAPHY OF THE SMITH BAY SHALE

The Smith Bay Shale comprises a fine-grained, grey, green and red, shaly and silty sequence with minor reddish brown sandstone interbeds and rare carbonates. The formation was originally named and defined by Daily (Fig. 14 in Horwitz and Daily, 1958), who linked a 120m thick, fine-grained sequence conformably overlying the Stokes Bay Sandstone in Smith Bay and along Freestone Creek with an 88m thick silty and sandy sequence below the White Point Conglomerate west of Bald Rock. These two sections are considered by Daily (1976b, Fig. 8) as belonging to the same formation, although no overlap has been recognised. Thus, the original stratigraphic thickness of the Smith Bay Shale remains unknown. Stratigraphic sections were measured in both parts of the formation, and are summarized in Figure 13-1 (rear pocket). In Freestone Creek, Madigan (1928) reported arthropod tracks in shales, and Daily (in Parkin and Glaessner, 1958; Daily, 1977) reported *Redlichia* fragments in an argillaceous limestone which may correlate with the dark grey shaly limestone in the coastal section. Trilobite tracks and worm burrows are common throughout the formation.

ENVIRONMENTAL ANALYSIS OF THE SMITH BAY SHALE

Facies Analysis

Introduction

The lower portion of the Smith Bay Shale rests conformably on the Stokes Bay Sandstone near Smith Bay. The sequence comprises approximately 120m of red, green and grey shales and siltstones, with minor red-brown and grey sandstone interbeds. The combination of abundant desiccation cracks and rare arthropod tracks and bioturbated intervals indicates that the sequence is predominantly upper intertidal in origin. The upper portion of the Smith Bay Shale, outcropping below the White Point Conglomerate west of Bald Rock comprises approximately 88m of red siltstone and sandstone, with marine trace fossils and minor desiccation cracks. Interpretation of this upper sequence is discussed in more general terms in Chapter 16.

Red Shale

Evenly laminated to poorly bedded red and minor greyish green shale, containing rare arthropod tracks, occurs sporadically throughout the Smith Bay Shale at Smith Bay. It is typically desiccation cracked, with large, sandstone-infilled polygons up to 1.5m across, opening 10cm at the top and tapering downwards for distances of over 0.4m (Plates 150 and 151). The shale is interpreted as very low energy, uppermost intertidal to supratidal deposits.

Sand-Streaked Shale

Evenly laminated, red and minor green shale with thin, evenly bedded to weakly ripple laminated sandstone interbeds, is common in the Smith Bay Shale at Smith Bay. The shale is generally desiccation cracked and contain trilobite tracks and minor bioturbated intervals. The facies is interpreted as due to low energy suspension settling of muds in an upper intertidal environment, with only minor sandy incursions, probably related to storms and unusual high tides.

Linsen Bedding

Linsen bedded units in the Smith Bay Shale are similar to those observed in the Carrickalinga Head Formation and are common in the upper portion of the Smith Bay Shale, near Bald Rock. They comprise red and greyish green, mm-cm thick intercalations of shale and ripple laminated sandstone. Bedding surfaces are commonly covered with current ripples with bipolar palaeocurrents. However, a distinguishing feature is the abundance of desiccation cracks in the linsen beds of the Smith Bay Shale. Minor worm burrows (Plate 152) and arthropod tracks are recorded from this facies, which is interpreted as a moderate to low energy intertidal, tide-dominated deposit.

Flaser Bedding

Fine to medium-grained sandstone, with thin mudstone flasers and rare mudstone intraclasts is a minor facies in the Smith Bay Shale, being restricted mainly to the upper part of the formation near Bald Rock. The units are generally 20-40cm in thickness and grade upwards into linsen bedded shaly sandstone and sandy shale. Desiccation cracks are rare and the facies is interpreted as a shallow subtidal to lower intertidal deposit, formed during periods of moderate tidal activity.

Red-Brown Sandstone

Red-brown, medium-grained arkosic sandstone, occurring in sets up to 7m in thickness, occurs sporadically throughout the Smith Bay Shale, especially in the upper portion, where a passage into the White Point Conglomerate is indicated. The sandstone is typically horizontally laminated, commonly with primary current lineation. Thicker units are trough cross-stratified and convolute bedded (Plate 153). Current rippled intervals are uncommon. In rare instances, the sandstone is loaded (Plate 154) or form small scours on the underlying shale. In the uppermost portion of the Smith Bay Shale west of Bald Rock cross-bedded oolitic grainstones are present in the sequence (Plate 155).

The subvertical symmetry of folds in the contorted sandstones indicates that they formed primarily by water escape, and are not related to gravity slumping (Allen and Banks, 1972). As for similar deposits in the Carrickalinga Head Formation, Stokes Bay Sandstone, White Point Conglomerate and Boxing Bay Formation, the sandstones of the Smith Bay Shale are interpreted as shallow marine tidal deposits. Evidence of tidal activity includes the bipolar orientation of current ripples and current lineations, and their association with fine-grained deposits containing bipolar palaeocurrents and well developed tidal stratification. The presence of upper flow regime, plane laminated, current lineated sandstone and the paucity of distinctive wave-formed structures indicates that tides were strong and wave activity subordinate. A more detailed discussion of the origin of upper flow regime plane lamination in tidal deposits is presented in Chapter 16, and shall not be repeated here.

Facies Associations and their Interpretation

Fining-upward cycles, 0.5-13m in thickness (average 5m) are common in the Smith Bay Shale, particularly at Smith Bay. The cycles have a sharp, generally non-erosional base. A thin unit of plane laminated or flaser bedded sandstone is typically overlain by linsen bedded shale/sandstone, then sand-streaked shales, and finally laminated to poorly bedded shales containing abundant desiccation cracks. The cycles are interpreted as tidalites (cf. Klein, 1971) formed by progradation of the tidal flat, with subtidal sand flats and sandy shoals overlain by lower intertidal mixed flat sediments and finally upper intertidal mudflat deposits. New cycles are initiated by sudden basin subsidence and the desiccation cracks at the top of the fining-upward cycles are infilled with sands of the succeeding cycle. Klein (1971) has suggested that the thickness of the fining-upward sequences (5m in the case of the Smith Bay Shale) is related directly to the palaeotidal range. However, since the thickness of the cycles must partly be controlled by the rate of basinal subsidence during their formation, it is concluded that the 5m figure represents an absolute upper limit to the palaeotidal range during the deposition of the Smith Bay Shale.

Only one other type of cycle was noted in the Smith Bay Shale. It comprises a coarsening-then-fining upward (CUFU) sequence, with evenly laminated silty shale with thin sandstone interbeds at the base, which grades upwards into red-brown plane laminated, trough cross-stratified, contorted and rippled sandstone. The sandstones pass eventually back into sand-streaked shales. Desiccation cracks are absent. By analogy with similar cycles described by DeRaaf et al. (1977), the sequence is interpreted as the result of either lateral migration, or construction then destruction of a sandy shoal or bar, in the shallow subtidal zone of a predominantly muddy tidal flat. Random sequences in the Smith Bay Shale are common and are interpreted as resulting from random events, such as storms, unusual high tides, and possibly minor tectonic activity.

Palaeocurrent Analysis

Palaeocurrents for the lower part of the Smith Bay Shale (Smith Bay section) are shown in Figure 15-1. Upper Smith Bay Shale palaeocurrents are presented in Figure 16-11. The extreme predominance of current ripples over wave-generated ripples is interpreted as the result of a combination of strong tides and only minor wave activity. Current ripples are bipolar east-west, with the majority of ripples indicating flow to the west. Similarly, current lineations are orientated east-west, with current crescents indicating flow in both directions. By analogy with a great number of modern tidal flats (eg. Evans, 1965; Hobday and Eriksson, 1977), and by analogy with the rest of the Kangaroo Island northeast coast Cambrian sequence, the palaeocurrents are interpreted as representing longshore transport of sand by strong, at times reversing, tidal currents.

Conclusions

The Smith Bay Shale was deposited in a shallow subtidal to intertidal environment, subject to shore-parallel tides, but with only minor onshore wave activity. The fine-grained, muddy facies are similar to those described by Reineck and Wunderlich (1968), Reineck (1967) and Reineck and Singh (1975) and interpreted by these workers as tidal deposits. Red-brown arkosic sandstone interbeds also contain many features typical of shallow marine tidalites, and in most cases their bipolar palaeocurrent distribution pattern confirms this interpretation.

The variation in sandstone content between the Smith Bay Shale and the adjacent formations is partly related to water depth, with the sand bodies being confined largely to the subtidal environment. However, the variation in sandstone content was probably largely determined by the nature and rate of sediment supply. Thus, the Smith Bay Shale represents a brief period of relatively stable conditions following the rapid deposition of

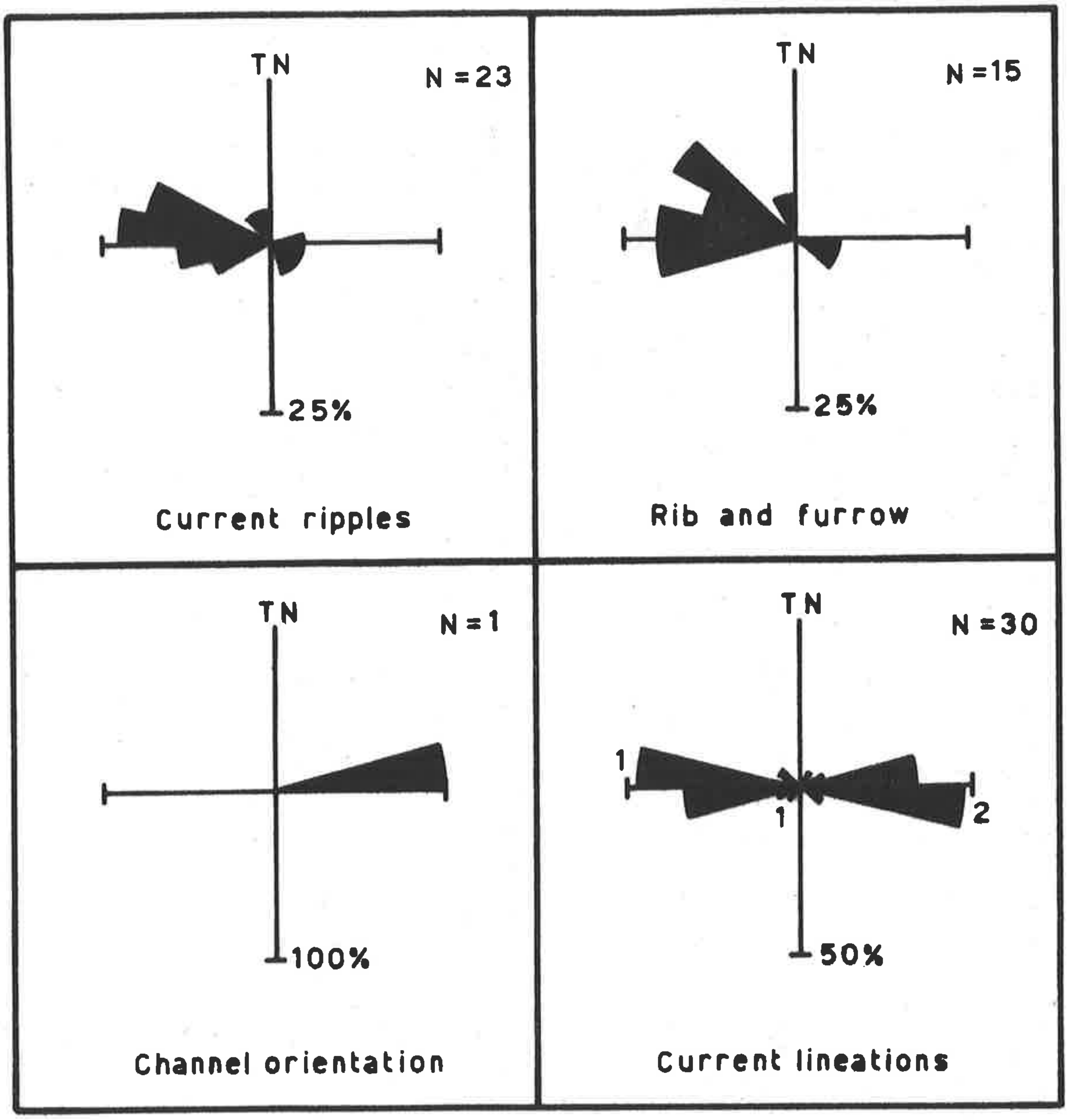

Figure 15-1. Palaeocurrent rose diagrams, lower part of the Smith Bay Shale in Smith Bay. N = number of data.

the Stokes Bay Sandstone, and preceding the main sequence of uplifts which produced the overlying White Point Conglomerate.

CHAPTER 16

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE UPPER SMITH BAY SHALE, WHITE POINT CONGLOMERATE, EMU BAY SHALE, AND BOXING BAY FORMATION.

Modified from the paper titled

"Terrestrial-marine transition in the Cambrian rocks of Kangaroo Island, South Australia"

and submitted to Sedimentology by

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INTRODUCTION

An approximately 2700m thick succession of Early Cambrian sedimentary rocks exposed on the north coast of Kangaroo Island, South Australia (Figs. 16-1 and 16-2) was mapped and briefly described by Sprigg (Sprigg et al., 1954; Sprigg, 1955). Daily (1956) gave a more detailed account of the rocks and their trilobite faunas, which were described systematically by Pocock (1964, 1967, 1970). The succession comprises six conformable formations (Daily, in Glaessner & Parkin, 1958, Fig. 14), of which this chapter discusses the upper four, namely in ascending order the upper part of the Smith Bay Shale, the White Point Conglomerate, the Emu Bay Shale and the Boxing Bay Formation. The stratigraphy of the latter three formations is discussed below, and the stratigraphy of the Smith Bay Shale is presented in Chapter 15.

The present work is based on measured sections of the four formations which occur in virtually continuous succession between Bald Rock and The Big Gully (Fig. 16-2A), and in fault-bounded sections near Cape D'Estaing (Fig. 16-2B). The Bald Rock section is nearly 1300m thick (Fig. 16-3), and has the advantage of stratigraphic continuity through all four formations, with minor gaps due to beach development. The Bald Rock and Cape D'Estaing sections (Figs. 16-3 and 16-4) are regarded as lateral, essentially time-stratigraphic equivalents, because they both contain a distinctive mottled limestone unit (665m, 160m and 42m respectively on Figs. 16-3, 16-4B and 16-4C), and the same trilobite faunas in conformably overlying and underlying rocks.

THE STRATIGRAPHY OF THE WHITE POINT CONGLOMERATE

Originally named the White Point Limestone by Sprigg (Sprigg et al., 1954; Sprigg, 1955), this 600m thick sequence of polymictic conglomerates (Plate 156) and interbedded shales (Plate 157) and sandstones (Plate 158) was renamed the White Point Conglomerate by Daily (1956), who defined a type section in the vicinity of Bald Rock.

In the type section (Fig. 13-1 in rear pocket, Fig. 16-3), the White

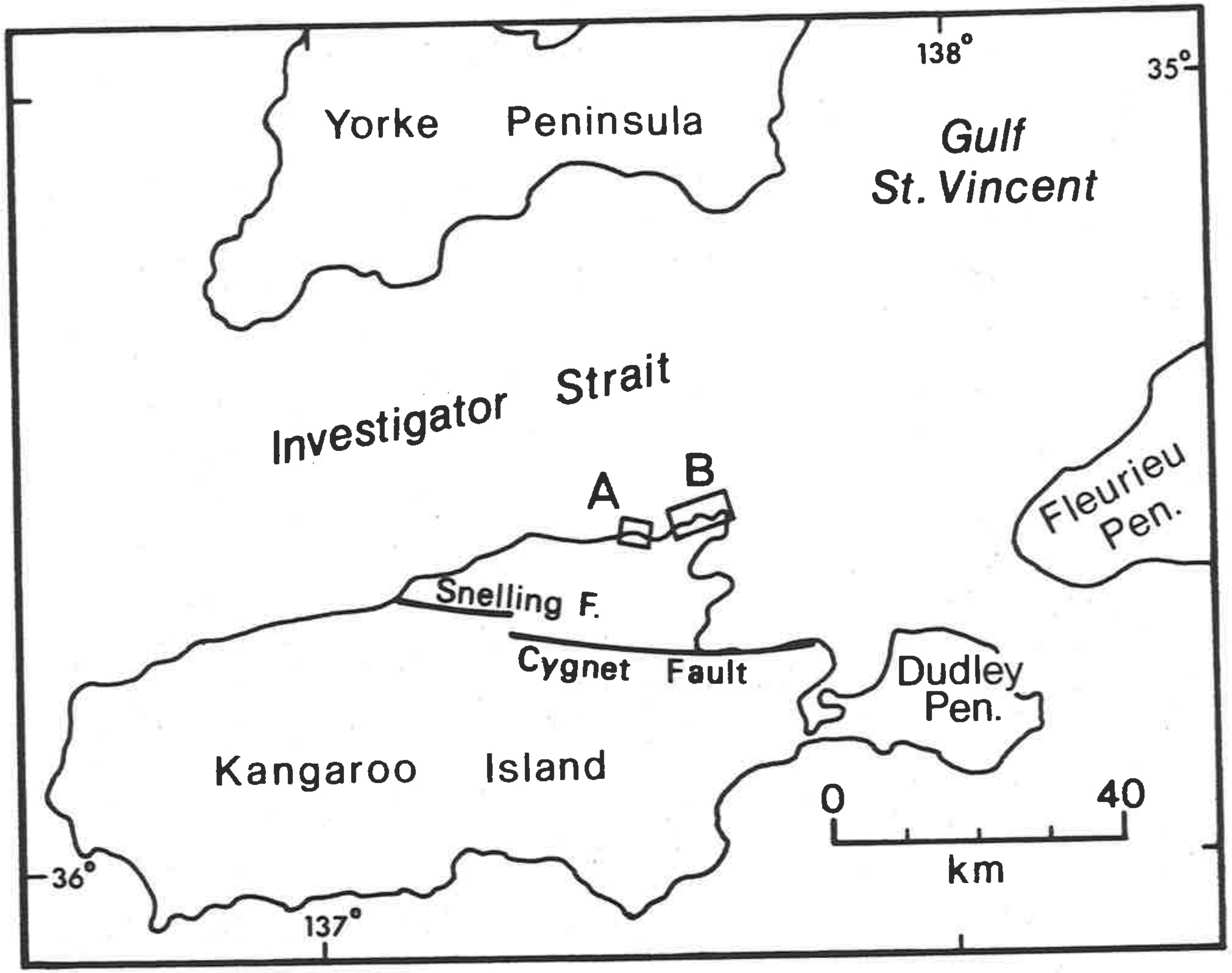

Figure 16-1. Location map of Kangaroo Island, showing location of measured sections between Cape D'Estaing and Pt. Marsden.

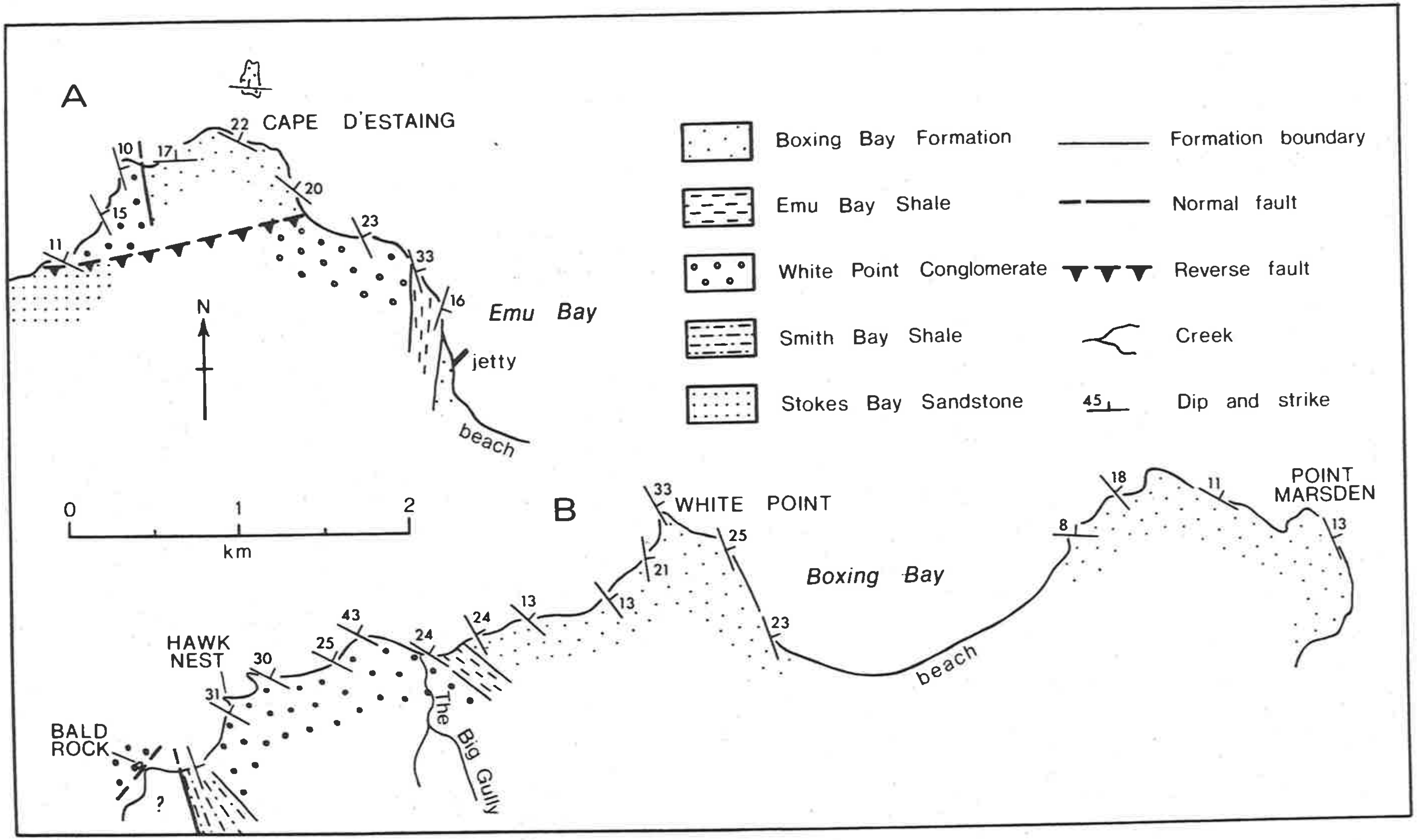

Figure 16-2. Simplified geological maps of coastal sections. A: Cape D'Estaing.
B = Bald Rock to Pt. Marsden.

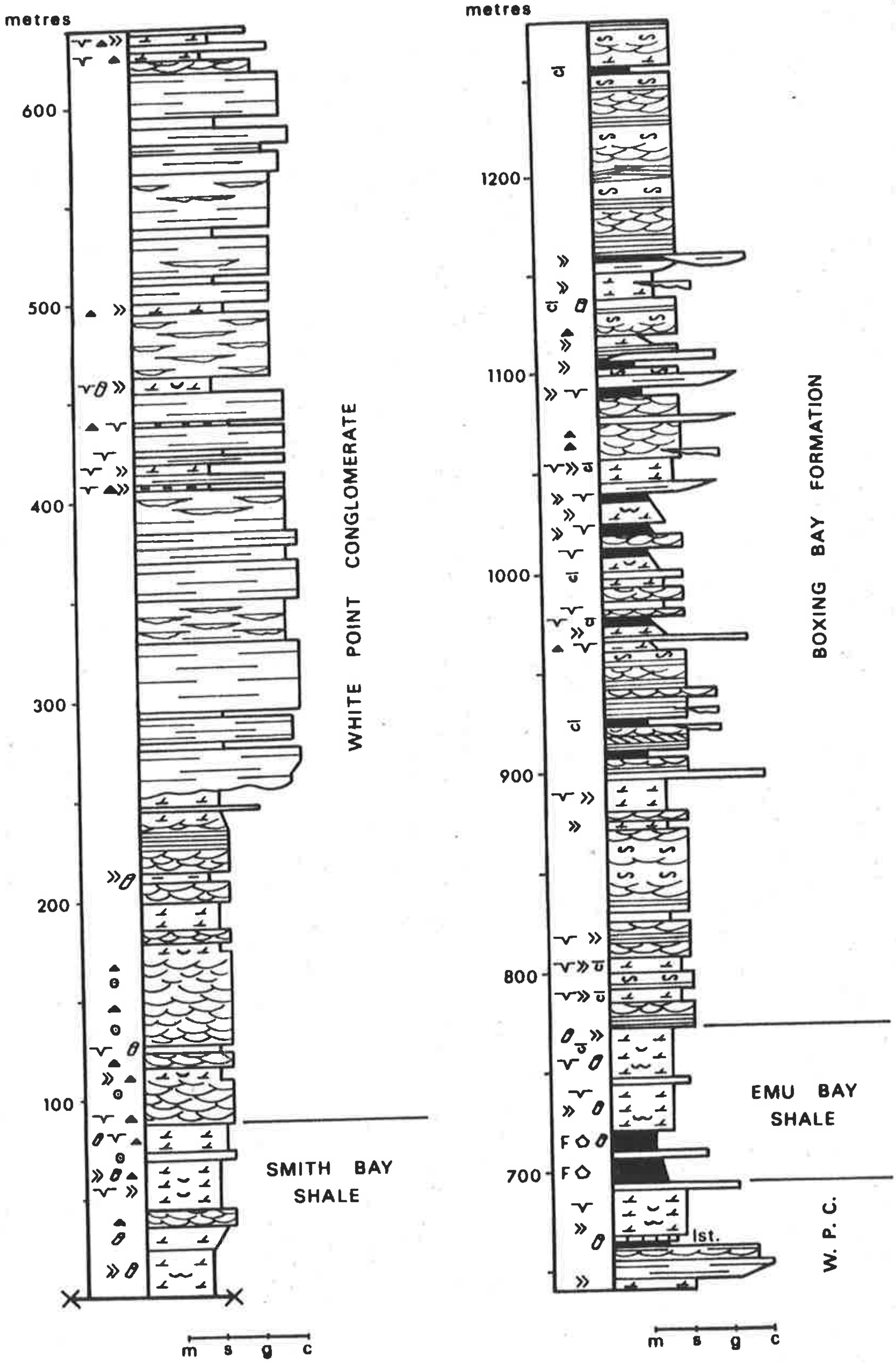

Figure 16-3. Generalised stratigraphic column of the section between Bald Rock and Boxing Bay, showing part of the Smith Bay Shale, the White Point Conglomerate, the Emu Bay Shale and the Boxing Bay Formation. m, s, g and c on scale bar indicate mudstone, sandstone, granule conglomerate and cobble/boulder conglomerate in the figured stratigraphic columns. See Fig. 16-4 for explanation of other symbols.

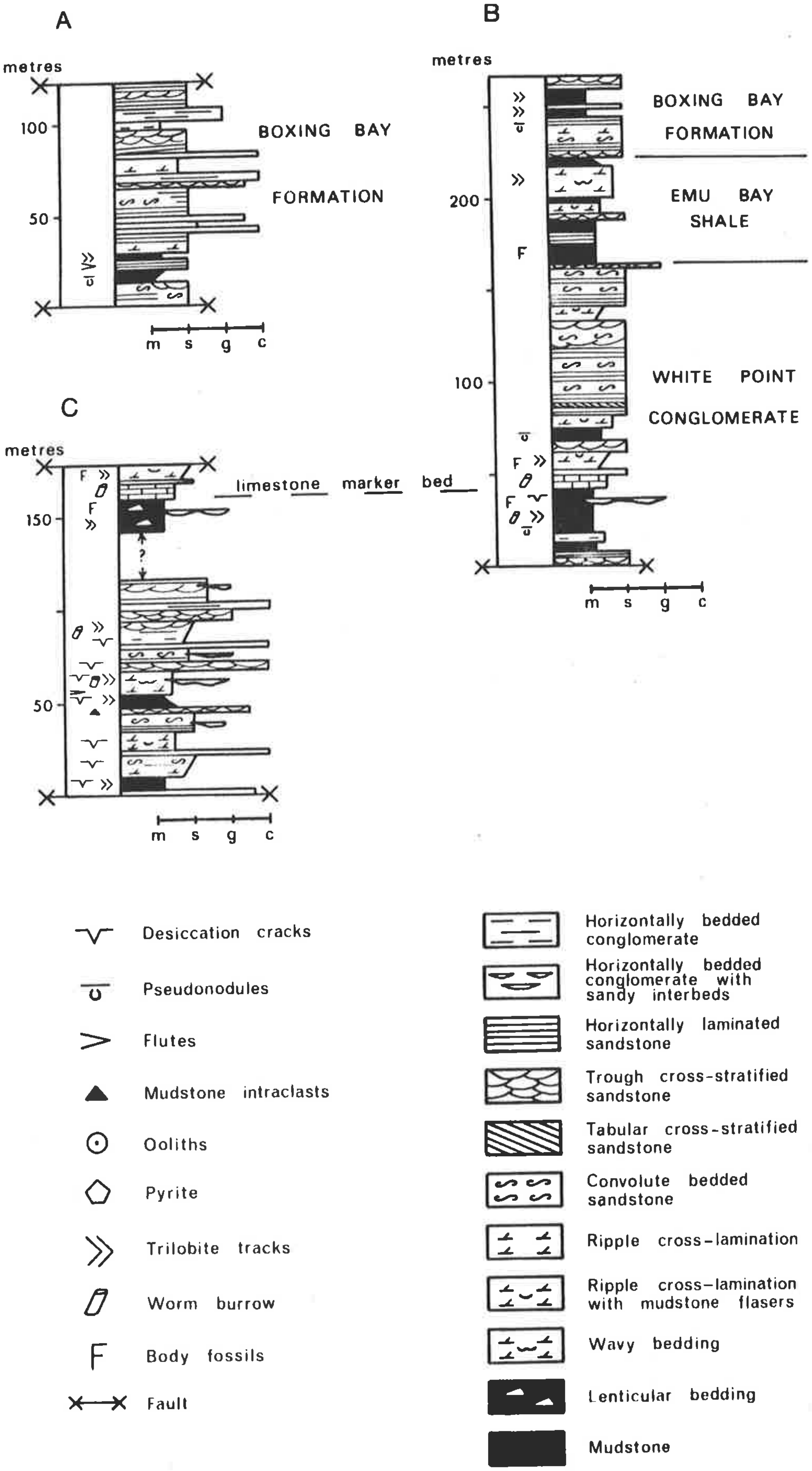

Figure 16-4. Stratigraphic columns of fault-bounded sections of the Boxing Bay Formation at Cape D'Estaing (A), and the White Point Conglomerate west (C) and east (B) of Cape D'Estaing.

Point Conglomerate rests conformably on rippled silty sandstones of the Smith Bay Shale and is overlain conformably by grey shale and fine siltstone of the Emu Bay Shale. The upper part of the White Point Conglomerate is also present on the east side of Cape D'Estaing, adjacent to Emu Bay, where it is overlain conformably by greyish green siltstones of the Emu Bay Shale (Fig. 13-1 in rear pocket, Fig. 16-4). A third outcrop of White Point Conglomerate occurs on the west side of Cape D'Estaing (Fig. 16-2). This section is fault bounded, however it can be correlated with the two sections discussed above on the basis of a distinctive burrow mottled limestone unit and an adjacent trilobite fauna which occur in all three outcrops (Fig. 16-4).

The trilobite Balcoracania dailyi Pocock occurs in a thin burrow-mottled limestone and associated shales near the top of the formation (Pocock, 1970). The trilobites Emuella polymera Pocock, Estaingia bilobata Pocock and Redlichia and other fossils including tubes and opercula of hyolithids occur in shales and siltstones in the White Point Conglomerate west of Cape D'Estaing (Pocock, 1964, 1967; Daily, 1977). Arthropod tracks, worm burrows and minor molluscan trails occur in fine-grained intervals throughout the formation.

THE STRATIGRAPHY OF THE EMU BAY SHALE

The Emu Bay Shale was defined by Sprigg (Sprigg et al., 1954; Sprigg, 1955). The stratotype is located on a wave-cut platform between Cape D'Estaing and Emu Bay, west of the Emu Bay Jetty (Fig. 16-2A).

The Emu Bay Shale comprises a dominantly fine-grained, shaly and silty sequence (Plate 159), with minor interbeds of sandstone and conglomerate up to 1m in thickness. In both sections, the sequence generally coarsens upwards, with evenly laminated grey to black shale near the base, giving way to grey-green and red, flaser bedded, linsen bedded, continuously rippled and minor planar laminated siltstone in the upper portion. Red-brown to grey, medium-grained, arkosic sandstone interbeds are typically trough cross-bedded, occurring in sets of multiple intersecting troughs up to 1m in thickness. Granule to cobble conglomerate beds are rare, and were not noted in the type section. The conglomerates are lenticular, and some have markedly channeled bases (Plate 160). The finer, granule conglomerates are internally trough cross-stratified.

In the type section (Fig. 16-4), the basal 20m of dark grey shale and siltstone are slightly calcareous and contain the trilobites Estaingia bilobata Pocock, Redlichia, Emuella dalgarnoi Pocock and a species of Hyolithes (Pocock, 1964, 1970; Daily, 1977). The interval is infrequently bioturbated. The overlying silty sequence is also bioturbated and arthropod tracks are abundant (Plate 161). Interference ripples were noted in the siltstones in several outcrops.

In The Big Gully section (Fig. 16-3), the basal 12m of the Emu Bay Shale comprise grey-black to black shale and fine siltstone. This unit contains, in addition to the fauna cited above, phyllocarids and other crustaceans and annelids. According to Daily (1977, p.10), "the excellent preservation and articulated nature of most of the fossils is indicative of a strongly reducing bottom environment (stagnant) generally free of current activity". Complete specimens of Redlichia up to 35cm in length occur at this locality. The black shales are devoid of arthropod tracks, and are only sparsely burrowed. However, the overlying sequence contains abundant burrows and trilobite tracks, in association with red and red-brown, ripple-laminated and desiccation cracked siltstone.

THE STRATIGRAPHY OF THE BOXING BAY FORMATION

Strata now comprising part of the Boxing Bay Formation were originally termed "Pt. Marsden series" by Madigan (1928) and the "Pt. Marsden conglomerates" by Sprigg et al. (1954). However, since the conglomeratic outcrops on Point Marsden are isolated from the rest of the sequence by a long stretch of beach devoid of outcrop (Fig. 16-2B), Daily (1956) abandoned this nomenclature and named the sequence overlying the Emu Bay Shale between

Big Gully and White Point the "Boxing Bay Formation". The 350m thick sequence of sandstones and conglomerates on Pt. Marsden are considered by Daily (1956, 1977) to represent either an upward continuation of the Boxing Bay Formation or, less likely, a faulted repetition of that formation. Recently, Daily et al. (in press) attributed a fault bounded section of sandstone, shale and interbedded conglomerate on the tip of Cape D'Estaing to the Boxing Bay Formation on lithological, sedimentological and structural grounds. The sequence had formerly been considered as part of the White Point Conglomerate.

Outcrops of the Boxing Bay Formation in the type section, at Pt. Marsden and in the vicinity of Cape D'Estaing are shown in Figure 16-2. Stratigraphic sections were measured for all these outcrops with the exception of the Point Marsden beds. The Point Marsden stratigraphy is complicated by several small beach-covered intervals and by several faults of unknown displacement.

In the type section, the Boxing Bay Formation comprises 500m of reddish brown sandstone (Plate 162), with common shale, siltstone and thin, lenticular conglomerate interbeds (Plate 163) (Fig. 16-3). The sequence rests conformably on the Emu Bay Shale. The contact can be seen near The Big Gully and also about 100m west of the Emu Bay Jetty, where the base of the Boxing Bay Formation is defined as the first major red-brown sandstone interval (Fig. 16-4). The top of the Boxing Bay Formation is nowhere exposed, and thus the total stratigraphic thickness of this formation remains unknown. Daily (1977, p.11) reported that "beds younger than the Boxing Bay Formation" are unknown along the north coast of Kangaroo Island". However, a fault bounded outcrop of conglomerate adjacent to Bald Rock, to the west of the Smith Bay Shale outcrop, contains clasts of Kanmantoo Group metasandstone and metasiltstone, and thus may be late Middle Cambrian, Late Cambrian, or even post-Cambrian in age. Unfortunately, its relationship to the rest of the sequence is unknown.

The type section of the Boxing Bay Formation can be divided into three units (Fig. 13-1, rear pocket), comprising a lower sandy sequence (with minor siltstone and rare shale), a middle mixed sequence (which contains most of the shale and conglomerate beds) and an upper sandstone sequence (devoid of shaly or conglomeratic intervals). The fault bounded section of the Boxing Bay Formation on Cape D'Estaing is considerably more conglomeratic than any of these three members, however it is best related on lithological grounds to the middle mixed member of the type Boxing Bay Formation. The Point Marsden outcrops are somewhat different again, with their prominent channels, well-developed cross-stratification and abundance of coarse grey, calcareous sandstones associated with the conglomerates (Plate 164). On this basis, the author supports Daily's (1956, 1977) view that these beds probably represent an upward continuation of the type Boxing Bay Formation. No body fossils have been found in the formation to date, although shaly intervals commonly contain arthropod tracks and worm burrows (including Skolithos). Molluscan trails are rare.

ENVIRONMENTAL ANALYSIS OF THE UPPER SMITH BAY SHALE, WHITE POINT CONGLOMERATE, EMU BAY SHALE AND BOXING BAY FORMATION.

Facies Associations

Three clastic facies associations and a minor limestone facies association have been recognised in the four formations under discussion. Variation in the proportions of the clastic associations is the main basis for distinguishing between the formations.

Conglomerate Facies Association

The conglomerate facies association is restricted almost entirely to the White Point Conglomerate and the Boxing Bay Formation (Figs. 16-3 to 16-6) and comprises two facies defined on the basis of grain size and structure. The predominant facies is horizontally bedded cobble to boulder conglomerate (Plate 165), while trough cross-stratified (Plate 166) and plane stratified fine conglomerate to coarse sandstone is less abundant.

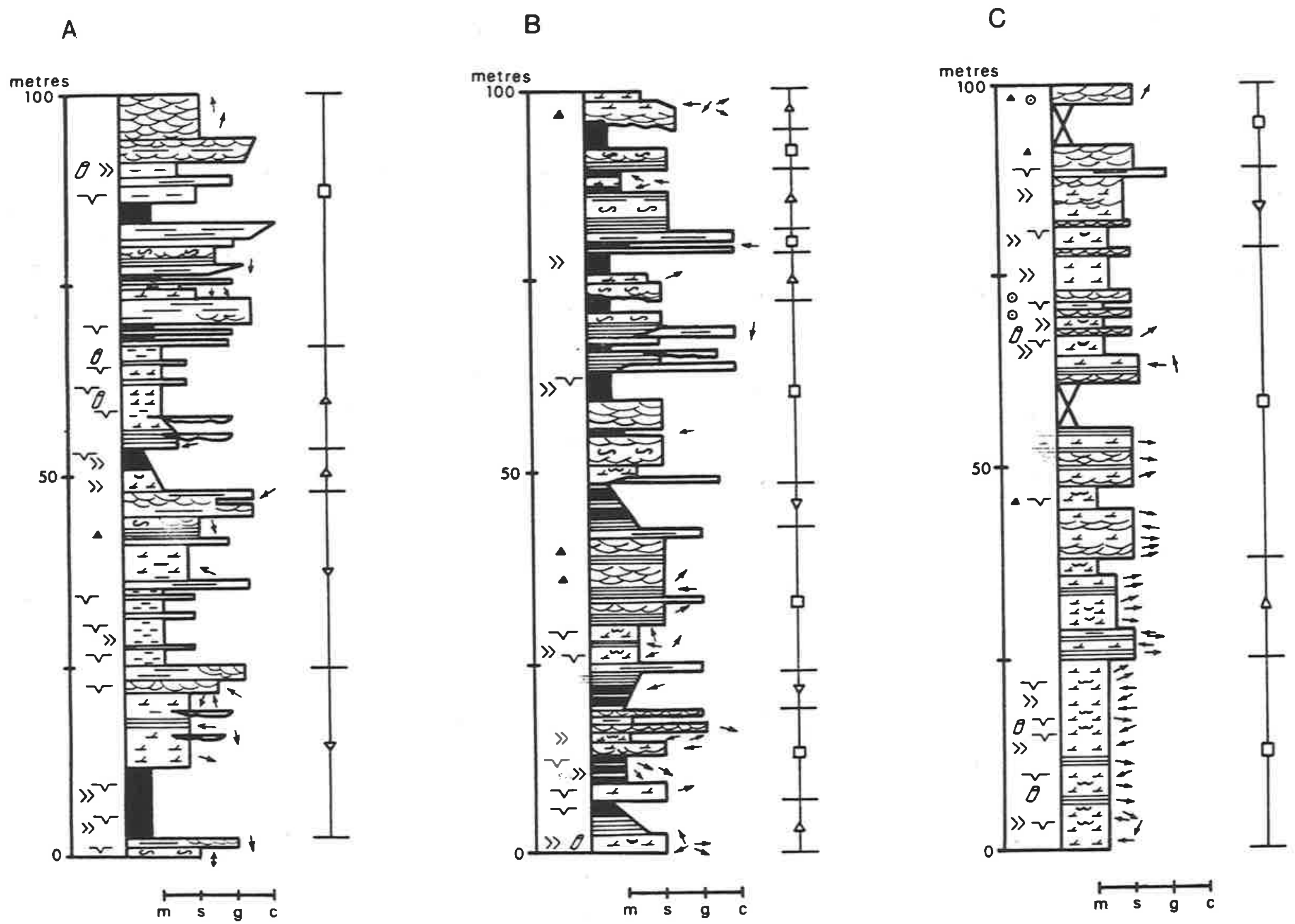

Figure 16-5. Stratigraphic columns of A: White Point Conglomerate west of Cape D'Estaing, B: Boxing Bay Formation at White Point, C: Smith Bay Shale at Bald Rock. Triangle with apex up indicates fining-upward sequence; apex down is the reverse; square indicates random intercalation. See Fig. 16-4 for explanation of other symbols.

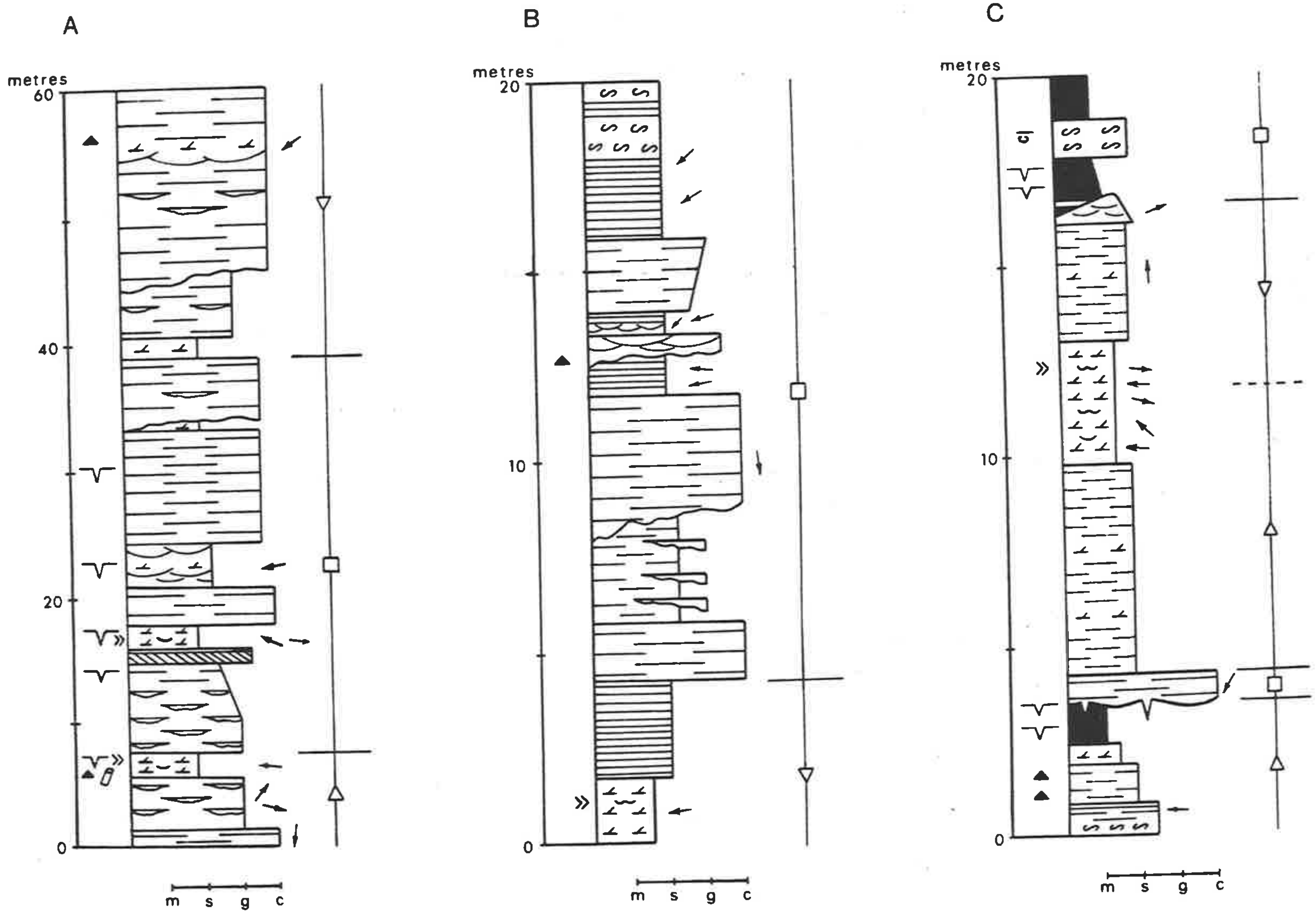

Figure 16-6. Stratigraphic columns of A: White Point Conglomerate west of The Big Gully, B: Boxing Bay Formation at Cape D'Estaing, C: Boxing Bay Formation at White Point. Triangle with apex up indicates fining-upward sequence; apex down is the reverse; square indicates random intercalation. See Fig. 16-4 for explanation of other symbols.

These facies are interbedded, and show strong petrographic affinity. For example, the White Point conglomerates contain abundant carbonate clasts, which are also present in their associated sandstones, but in reduced amounts. In contrast, the Boxing Bay Formation conglomerates are characterised by a greater proportion of gneissic and granitic clasts, while their associated sandstones are generally richer in feldspar, mica and quartz (Fig. 16-7A and Appendix D).

A. Clasts in the coarse conglomerate facies are predominantly subrounded to subangular (Plate 167), as determined by visual comparison (Powers, 1953). Maximum particle size is commonly 50cm in the White Point Conglomerate although clasts up to 1m are present and reach a maximum diameter of 1.5m at Bald Rock. Maximum clast size in the Boxing Bay Formation conglomerates is commonly 10-20cm, but reaches 50cm.

Most of the coarse conglomerates are framework-supported, but some are characterised by matrix-support. Clast orientation was measured for conglomerates in which clasts stood out from the matrix, and showed that some units, principally those that are matrix-supported have poorly defined clast orientation, with weak concentrations of ab dips around 70° (Fig. 16-8B, C). Most however, are clast-supported and imbricate, with dips of the ab plane at angles of 10-40°, and a axes sub-parallel to ab strike (Fig. 16-8A, C). In some cases, mostly at Cape D'Estaing, imbrication is visually apparent (Plate 168). As discussed lated, many of the conglomerates are interpreted as alluvial deposits, for which clast imbrication is an excellent palaeoslope indicator, because the larger clasts imbricate only at flood stage when flow departs little from the downslope direction (Bluck, 1974; Rust, 1978). Imbrication thus defines a consistent southward palaeoslope for the White Point and Boxing Bay conglomerates (Fig. 16-9a, e).

Bed thickness is variable in the horizontally bedded coarse conglomerates, and shows a rough correlation with maximum clast size. In the Boxing Bay Formation and in the Cape D'Estaing section of the White Point

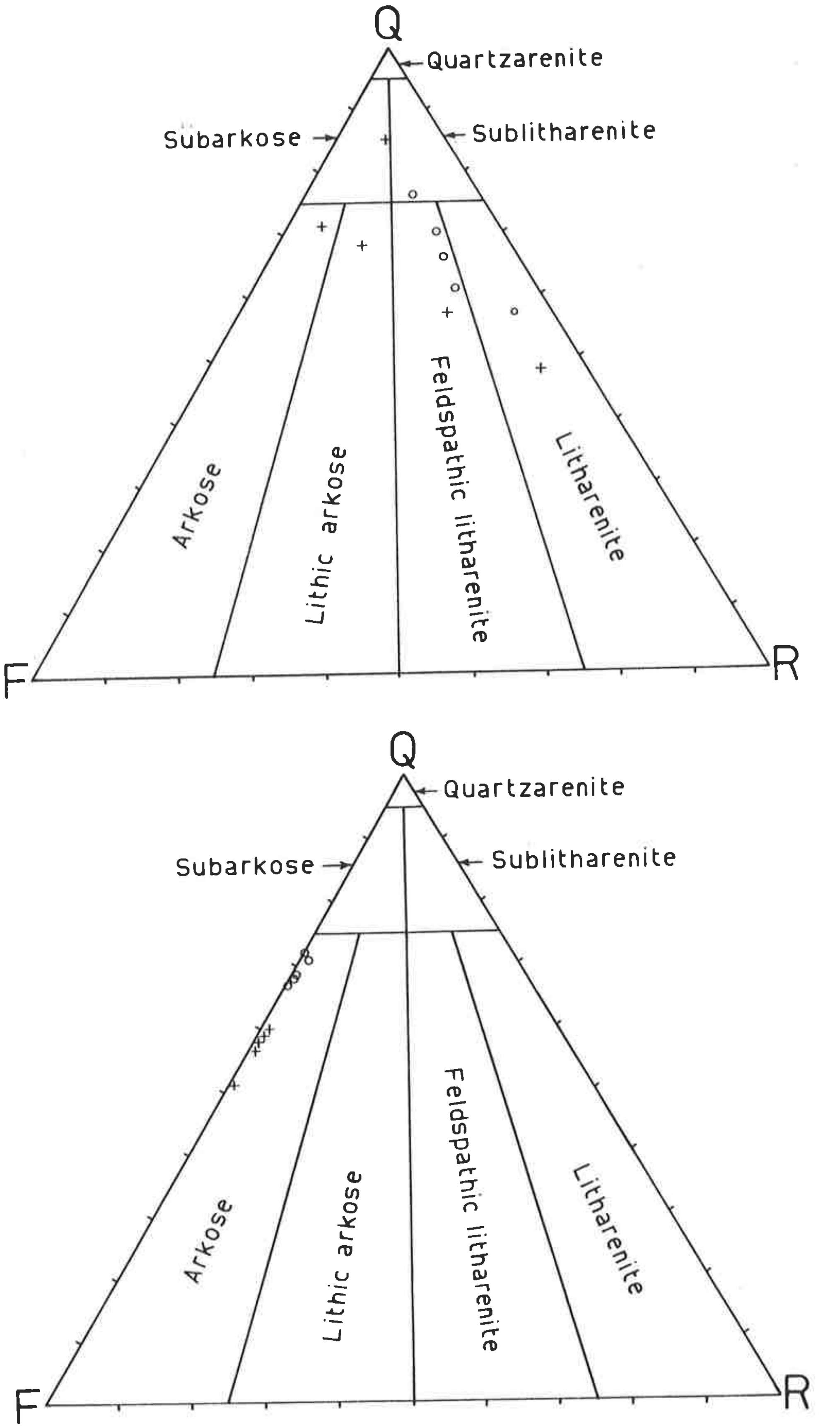

Figure 16-7. Sandstone compositions, northeast coast Cambrian of Kangaroo Island. A: Conglomerate facies association, B: Sandstone facies association. Circles are White Point Conglomerate sandstones, crosses are Boxing Bay Formation sandstones.

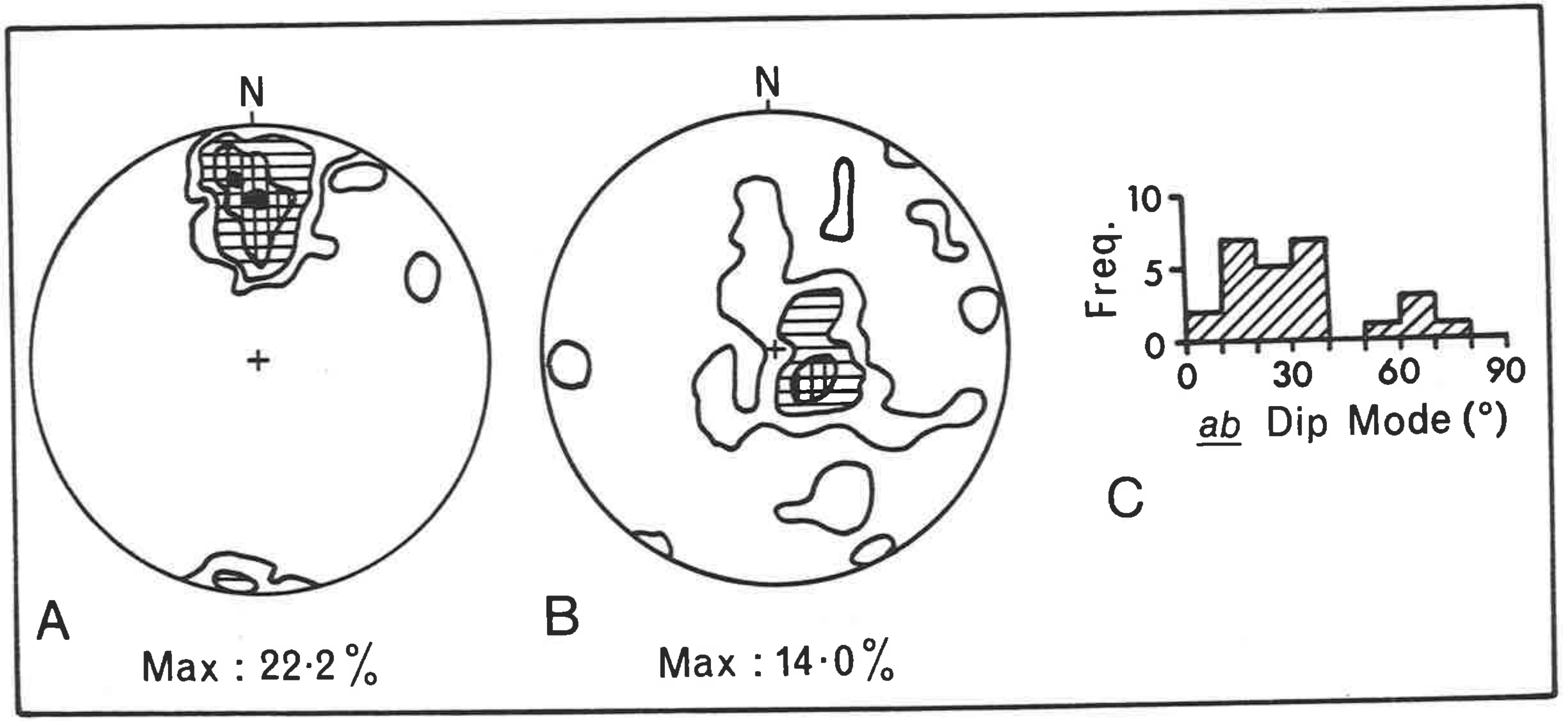

Figure 16-8. Fabric plots showing dips of ab planes of discoidal clasts in conglomerate units. A: White Point Conglomerate with well developed imbricate fabric at 270m on Fig. 16-3. B: Boxing Bay Conglomerate unit with dispersed fabric, at 1107m on Fig. 16-3 and also illustrated in Plate 183. C: Modal values of ab dip for White Point and Boxing Bay conglomerate fabrics.

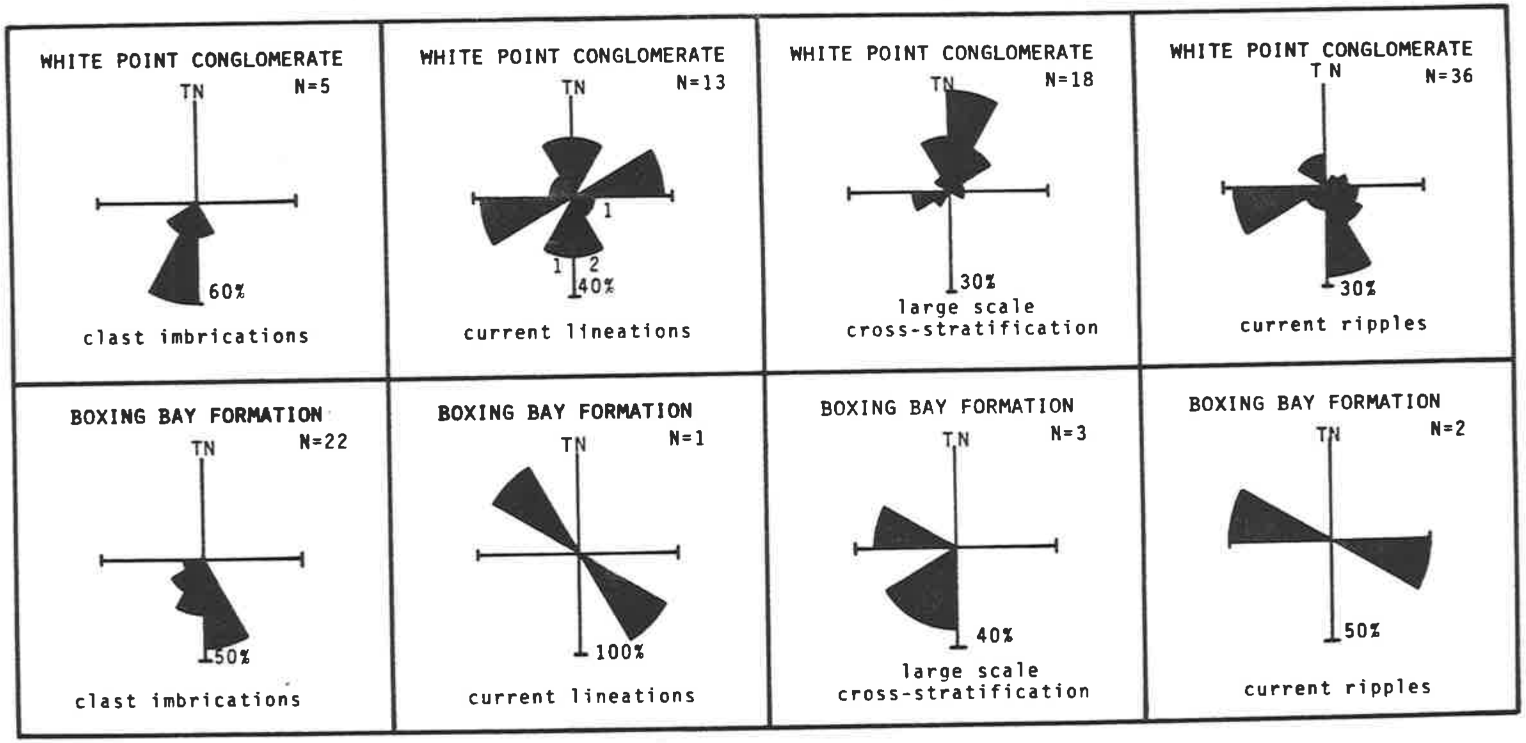

Figure 16-9. Palaeocurrent rose diagrams, conglomerate facies association. 30° intervals. N = number of data. Numbers on rose diagrams for current lineations indicate the number of lineations in each sector which have known direction (from scours, current crescnets etc.).

Conglomerate bedding is between 0.2m and 4, commonly 0.5-1m thick. Thicker conglomerate beds (up to about 10m) are present in the White Point Conglomerate east of Hawk Nest (Fig. 16-2B), where they alternate with sequences of relatively thin bedded conglomerate on scale of up to 50m thick. Normal and reverse grading are both present in the coarse conglomerates. In the reverse graded conglomerates, the larger clasts commonly extend 1-20cm above the upper surface of the bed. Most conglomerate units have parallel bounding surfaces, but a few have channeled bases (Plate 169), often irregular.

B. The fine conglomerate and coarse sandstone facies consists mainly of trough cross-stratified units of granule/pebble conglomerate to coarse calcareous sandstone (Plate 170). The units comprise multiple intersecting sets of shallow troughs, commonly about 10cm thick. In many instances they are interbedded with and may show lateral transition to horizontally stratified coarse sandstone, which is generally too coarse to show current lineation. However current lineations, where present, are generally directed either east-west or to the south (Fig. 16-9b,f). The modal palaeocurrent direction for the trough cross-strata in this facies is predominantly northward, although other trends were measured (Fig. 16-9c,g). Current ripples are not abundant in this facies, and have a variety of orientations (Fig. 16-9d,h). However, in the White Point Conglomerate, prominent modes to the south and west are present (Fig. 16-9d).

Sandstone Facies Association

The sandstone facies association is present in all four formations, but is most abundant in the Boxing Bay Formation, followed by the White Point Conglomerate. It mostly comprises reddish brown, moderately well sorted, fine- to medium-grained feldspathic sandstones. Petrographically they differ from the sandstones of the conglomerate association in having much higher feldspar and mica contents, whereas carbonate clasts are virtually absent. These characteristics distinguish them readily from the coarse grey calcareous sandstones associated with the White Point conglomerates, although distinction is more difficult in the Boxing Bay Formation.

A. The most abundant facies is fine to medium-grained, trough cross-stratified sandstone (Plates 171 and 172) with scattered siltstone or mudstone intraclasts. The trough sets are low-angled, average 50-10cm in thickness, and are arranged in cosets commonly 1-3m thick, which in many cases show upward decrease in set thickness. Palaeocurrent directions tend to be bipolar: approximately east-west for the White Point Conglomerate and Boxing Bay Formation, although some northwesterly trends were noted (Fig. 16-10a,b,c). Contorted layers are relatively common (Plates 173 and 174), and mostly comprise folded structures up to 1.5m in amplitude with subvertical symmetry. This suggests that deformation took place by predominantly vertical movement (probably related to liquefaction and water escape) rather than by lateral displacement. Contorted layers commonly continue to the limits of outcrop (maximum of 35m), and are overlain by undeformed strata without truncation.

B. Plane laminated sandstone with heavy mineral concentrations along laminae is a less abundant facies. It is fine- to medium-grained and moderately well sorted, except for occasional gneissic or granitic pebbles. Primary current lineation is common, and has a predominantly east-west orientation in the Smith Bay Shale, White Point Conglomerate and Boxing Bay Formations (Fig. 16-10d,e,f). Plane laminated sandstone (Plate 175) is commonly interbedded with cross-stratified sandstone or units of the conglomerate facies association. Units vary in thickness from approximately 10cm to 1.5m.

C. Ripple laminated sandstone (Plate 176) is a very minor facies within the sandstone facies association. It is fine- to medium-grained, and generally overlies or is interbedded with plane laminated and trough cross-stratified sandstone. Ripple laminated intervals are rarely greater than 20cm in thickness. Ripples are typically linguoid in form, with average crest spacing of 12cm and ripple height of approximately 3cm.

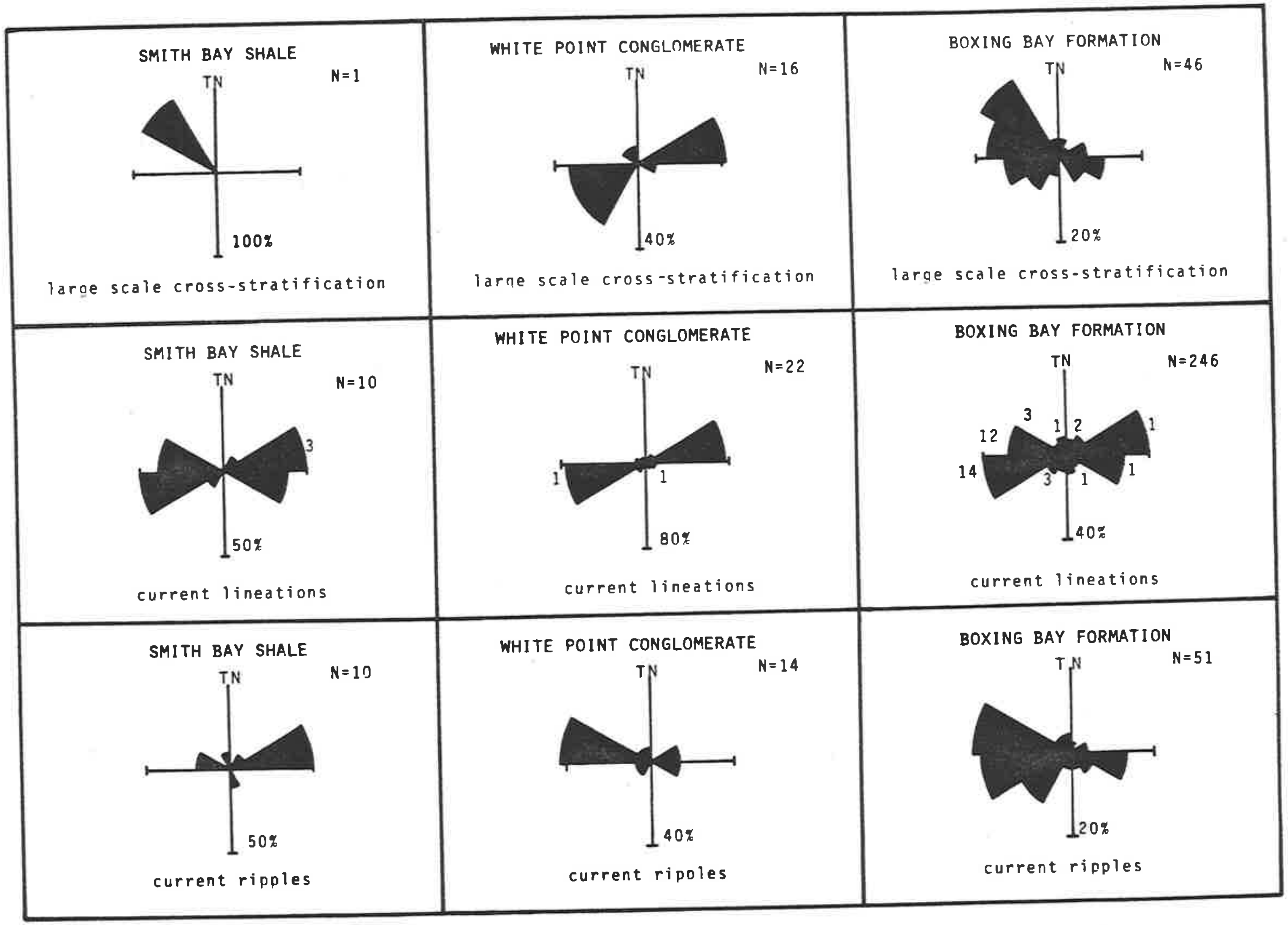

Figure 16-10. Palaeocurrent rose diagrams, sandstone facies association. 30^{o} intervals. N: number of data. Numbers on rose diagrams for current lineations indicate the number of lineations in each sector which have known direction (from scours, current crescents etc.).

Ripple orientations are bipolar east-west (Fig. 16-10g,h,i).

Fine-grained Facies Association

This association comprises a spectrum of interbedded siltstone, mudstone and minor sandstone ranging from continuously rippled very fine sandstone with rare, thin, current lineated intervals, through flaser bedding, wavy bedding, lenticular bedding to evenly laminated shale and massive mudstone (Reineck and Wunderlich, 1968; Reineck and Singh, 1975, Fig. 164). The association is most abundant in the Emu Bay and Smith Bay Shales, but it is also present in the White Point Conglomerate and Boxing Bay Formation. The latter two formations contain a greater proportion of the sandier members of the facies spectrum, whereas the Emu Bay and Smith Bay Shales are characterised by its muddier constituents. For the sake of simplicity, the spectrum is divided arbitrarily into three facies, one with sandy layers, the others in which sandstones are rare.

A. Rippled sandstone, commonly associated with mudstone flasers, is the predominant facies of the fine-grained association; it is present in all four formations, but particularly characterises the Smith Bay Shale and the upper part of the Emu Bay Shale. It consists of red to greenish-grey wavy and lenticular beds (Plate 177) with minor simple flaser bedding and rare, continuously rippled (Plate 178) and plane laminated sandstones. The ripples commonly have amplitudes of 1-2cm and include highly asymmetrical, symmetrical (Plate 179) and interference forms, with crest lines varying from straight to highly sinuous (linguoid). Vertically adjacent rippled sets with opposed dips are common; double-crested ripples (Reineck and Singh, 1975, p.368) are present, but not abundant. The palaeocurrent directions indicated by ripples and current lineations are mainly bipolar and are essentially the same for all four formations: east-west, with minor variations (Fig. 16-11). North-south current lineations in the Emu Bay Shale (Fig. 16-11c) were collected over a very small stratigraphic interval in one area only, and thus may not be representative of the formation as a whole.

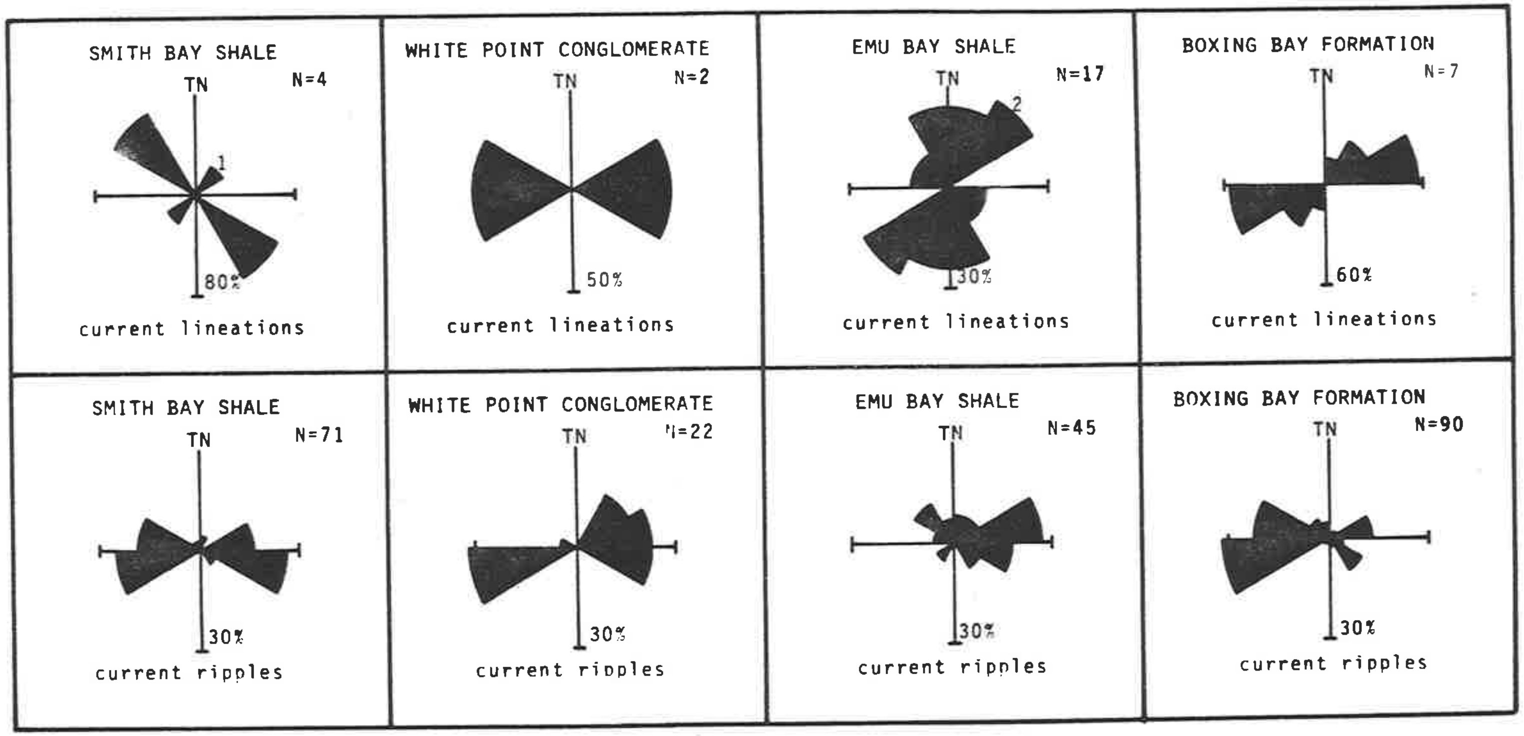

Figure 16-11. Palaeocurrent rose diagrams, fine-grained facies association. 30^{o} intervals. N: number of data. Numbers on rose diagrams for current lineations indicate the number of lineations in each sector which have known direction (from scours, current crescents etc.).

Shrinkage cracks are common in the mudstones of this facies and in many cases are associated with trilobite tracks (Plate 180), horizontal and subvertical burrows and molluscan trails (Plate 179). The cracks are mainly of regular, random, nonorthogonal type (Kahle and Floyd, 1971, Fig. 7F), a form characteristically developed during subaerial desiccation. Plate 181 illustrates a large downward-tapering desiccation crack in mudstone filled by gravels.

B. The laminated to massive mudrock facies makes up a minor part of the succession, occurring in the middle of the Boxing Bay Formation and in the upper part of the White Point Conglomerate. It comprises grey-green and red, evenly laminated shale and massive mudstone, commonly with abundant desiccation cracks. Trilobite tracks are fairly common, whereas burrows and molluscan trails are rare. Pocock (1970) described the trilobites Emuella and Balcoracania from shales in the White Point Conglomerate. The same beds also contain the trilobites Redlichia and Estangia.

C. Dark grey to black shale is a distinctive minor facies, restricted to the Emu Bay and Smith Bay Shales, and transitional vertically to the other fine-grained facies described above. The shale is partly calcareous, with rare streaks of siltstone or fine sandstone, and contains sparse burrows but lacks desiccation cracks. In the lower part of the Emu Bay Shale near Bald Rock the facies is black and pyritic; bioturbated intervals are rare, but a well preserved itinerant marine fauna, dominated by the articulated remains of the trilobites Redlichia and Estaingia bilobata, is present.

Limestone Facies Association

A. A grey mottled argillaceous limestone (Plate 182) averaging 3m in thickness is a significant stratigraphic marker within the White Point Conglomerate, in the Cape D'Estaing section (165m, Fig. 16-4C), Big Gully section (665m, Fig. 16-3) and between Cape D'Estaing and Emu Bay Jetty (45m, Fig. 16-4B). The mottles, due to bioturbation, are outlined by argillaceous sediment. It is underlain by fossiliferous grey-green calcareous shales, and overlain by laminated or flaser-bedded sandstones of the fine-grained facies association.

B. A cross-stratified ooid grainstone unit (Plate 154) about 1.5m thick is present in the Smith Bay Shale at 70m in the Bald Rock Section (Fig. 16-3), while scattered carbonate ooids occur in siliclastic cross-stratal sets within the succeeding 100m of section.

Reconstruction of Palaeoenvironments

Introduction

The combination of trilobite tracks and desiccation cracks in the fine-grained facies association in all four formations indicates recurrence throughout this dominantly shallow marine succession of upper intertidal conditions. The facies of this association resemble modern and ancient tidal deposits (Reineck and Singh, 1975; Ginsburgh, 1975) with evidence for both current and limited wave activity.

The presence of extrabasinal conglomerates in a tidal succession points to a nearby high-relief source of terrestrial detritus. Two alternative modes of deposition are as beach gravels eroded from cliffs by high-energy waves, or as alluvium transported a short distance to the coast. As discussed below, the second hypothesis is favoured because of abundant alluvial features and the absence of high-energy beach deposits.

Conglomerate Facies Association

The coarse conglomerates of the White Point Conglomerate and Boxing Bay Formation are unlike beach deposits. Beach gravels are typically well sorted and rounded, with an imbricate fabric of ab planes dipping seaward at low angles (Cailleux, 1945). Wave-worked pebbles tend to be better segregated into discrete beds of greater lateral extent than those deposited by alluvial processes (Clifton, 1973). Most of the White Point and Boxing Bay Conglomerate beds grade vertically into sandstone, or show vertical and lateral variation in degree of matrix support; in other words they show poor bedding segregation. The imbricate conglomerates have a mean ab dip of 24^{o}, which is consistent with alluvial transport (Rust, 1975), but is significantly higher than the 12° mean imbrication angles observed in beach gravels by Cäilleux (1945). As discussed previously, the regional geology points to a northern source, which is consistent with fabric development by alluvial transport, whereas the same imbrication formed on a beach would indicate land to the south. More importantly, the subrounded to subangular shape of the limestone megaclasts in the White Point conglomerates mitigates against a beach environment and indicates short alluvial transport together with minimal reworking in the tidal-flat environment.

Many other features of the Boxing Bay and White Point conglomerates are compatible with alluvial transport. Some of the conglomerates are matrix-supported, and have a poorly defined clast orientation, with high dips of ab planes (Fig. 16-8B,C). These units commonly show reverse grading, with some of the larger clasts extending above the general surface of the bed. Plate 183 shows a conglomerate unit in the Boxing Bay Formation which has a dispersed fabric (Fig. 16-8B), grades inversely up to a boulder layer along the convex upper surface, and shows abrupt lateral termination. Stratification in the overlying sandstone overlaps the conglomerate unit and is parallel to its base. The conglomerate unit is interpreted as the edge of a debris flow lobe, similar in form to that illustrated by Curry (1966, Plate 1). This was the only observed example with preserved surface relief, and to the best of our knowledge no other cases have been reported from ancient rocks interpreted as debris flow deposits. However, other characteristics of this unit, namely matrix support, inverse grading and poorly defined, subvertical megaclast fabric are more common in this and other ancient successions, and are equally indicative of debris flow deposition (Johnson, 1970; Fisher, 1971; Enos, 1977). The interbedding of debris flow layers with imbricate stream flow gravels is typical of alluvial fans (Bull, 1972; Rust, 1978). The conglomerate facies association is therefore ascribed to progradation of alluvial outwash, including in part alluvial fans, across the tidal flats.

The widespread occurrence of conglomerate outcrops normal to the palaeoslope along the north-east coast of the island suggests that alluvial fans formed a laterally coalescing complex between a mountain front and the sea. A similar modern environment in the Gulf of California was described by Walker (1967) and Meckel (1975); alluvial fans also reach the coast of the Gulf of Elat, where their deposits interfinger with sabkhas and coral reefs (Gvirtzman and Buchbinder, 1978). McGowen (1971) termed an individual fan that prograded into the sea a fan delta, but in the present case many fans were involved, and "coastal fan complex" seems a more appropriate designation. A more basic objection to a deltaic connotation is that it implies deposition related to the base level of the sea, with distinctly different subaerial and submarine parts. In contrast, terrestrial relief is the major control on alluvial fan sedimentation, including shallow submerged parts, for modification by wave action and dilution of debris flows are likely to be relatively minor influences. In the Kangaroo Island succession there is no evidence that the coarse conglomerates were reworked by waves, nor could we detect differences between debris flow conglomerates isolated within a sequence bearing trilobite tracks (presumably subaqueous), and those in thick conglomerate sequences, probably deposited subaerially. Shoreline orientation was controlled by the east-west strike of the uplifted mountain front and as the marine palaeocurrents are similar for most of the sequence it is concluded that an east-west shoreline was influential throughout.

Apart from paraglacial environments (Ryder 1971), the sharp relief required to form alluvial fans is commonly due to fault uplift. This is appropriate in the present case, because dip-slip faults are prominent in the Delamerian fold-belt and especially along the Torrens Lineament (Fig. 12-2) (Daily et al., 1973, Fig. 2). The recurrence of tidal deposits throughout the succession indicates that rates of subsidence and sedimentation maintained approximate balance, despite periodic alluvial influx in response to faulting. The thick conglomerate section east of Hawk Nest (Figs. 16-2 and 16-3) implies very rapid accumulation, which at times probably exceeded the rate of subsidence, but terrestrial deposition cannot be proved conclusively, because land plants did not evolve until the mid-Palaeozoic. In addition, sedimentation was too coarse and rapid for soil to develop.

The large size and moderate rounding of limestone clasts in the White Point conglomerates implies a source within a few kilometres. Sneed and Folk (1958) showed that limestone pebbles in the Colorado River, Texas achieved maximum rounding in about 16km of transport. The partial rounding of limestone clasts suggests that the escarpments from which they came probably lay 5-10km north of the present north coast of Kangaroo Island, up a relatively steep palaeoslope (Fig. 16-12).

The conglomerate succession east of Hawk Nest shows an alternation of thick bedded coarse conglomerate and thin bedded finer conglomerate with sandstone interbeds. Sequences that coarsen upward, fine upward, or coarsen then fine are all present. However, in most cases, it is hard to define cycles because of the lack of well-defined starting horizons; the section is described more realistically in terms of alternation of the two facies rather than cyclicity. Alternations are commonly on a 20m scale, but reach up to 50m in thickness. In terms of facies types the succession resembles the upward-coarsening cycles recognised by Steel et al. (1977) in Devonian alluvial fan deposits in Norway. These authors attributed their cycles to lowering of the basin floor by marginal faulting, which increased local relief and stimulated fan progradation. Distal deposits were overlain by more proximal detritus, and an upward-coarsening cycle resulted. However, one would expect the complete sedimentary response to fault uplift to be an initial fan progradation causing upward coarsening, followed by gradual return to equilibrium, resulting in upward fining. Coarsening-then-fining cycles can therefore be attributed to sufficient time lapse between fault movements to allow completion of the sedimentary response, whereas upward coarsening cycles indicate interruption by renewed faulting. Alternation of coarse and fine deposits can result from sedimentary mechanisms such as lateral migration of fans, or progradation of active fans over inactive neighbours. Variation in the White Point conglomerates in the vicinity of

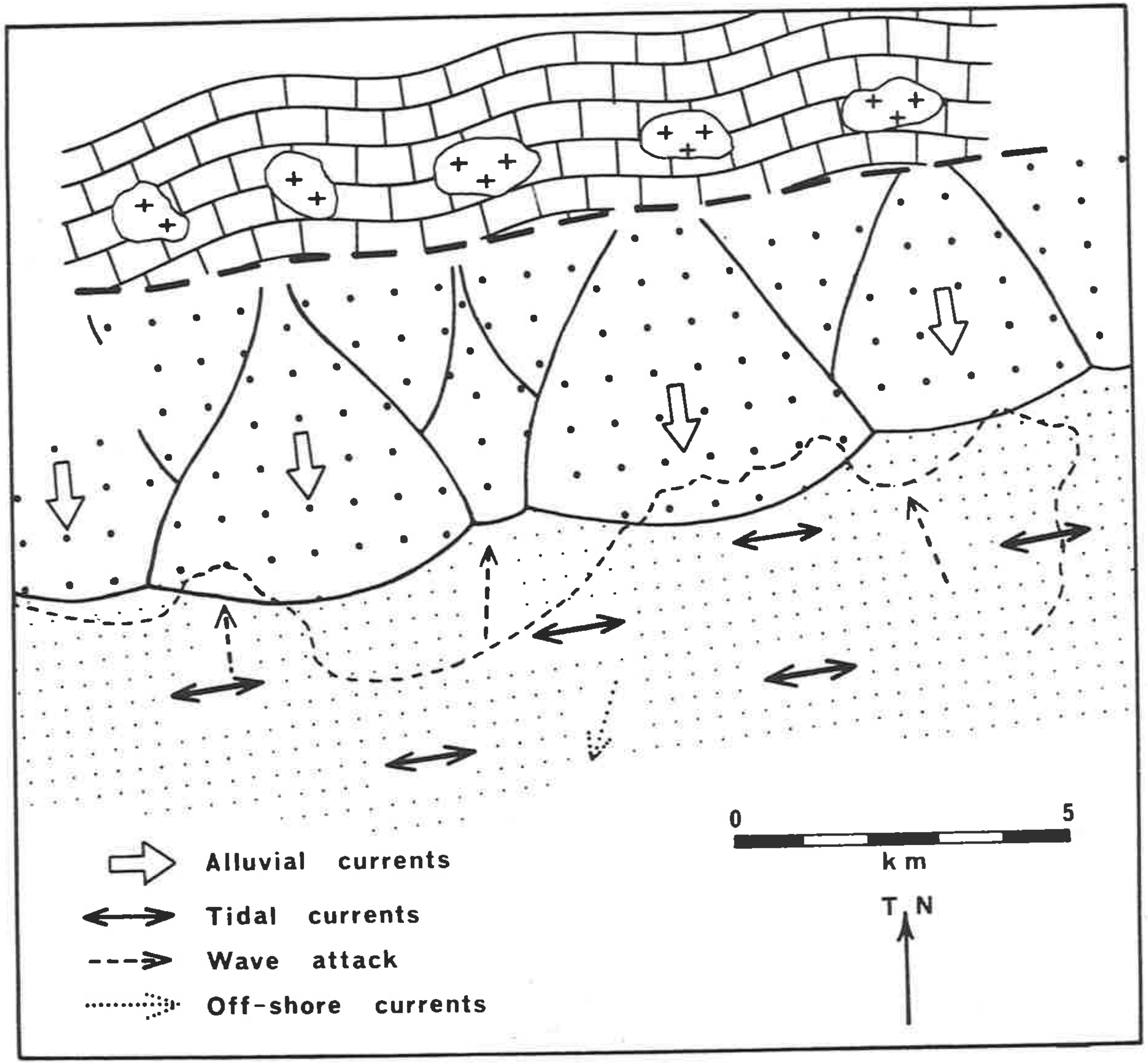

Figure 16-12. Proposed Early Cambrian palaeogeography of northeast Kangaroo Island, during maximum progradation of alluvial outwash (time of deposition of the White Point Conglomerate). Crosses; basement source rocks. Bricks; Early Cambrian sedimentary source rocks. Heavy dashed line; fault scarp zone. Heavy dots; coastal alluvial fan complex. Light dots; tidal flats. Light dashed line; present northern coast of Kangaroo Island.

Hawk Nest is therefore attributed to sporadic uplift along the east-west oriented fault escarpments, and varied sedimentary responses in neighbouring fans along the complex.

Trough cross-bedding in the fine conglomerate and coarse sandstone facies of the conglomerate association indicates predominantly northward transport (Fig. 16-9c,g). This is incompatible with alluvial deposition, and is attributed to the action of onshore waves, by analogy with shoreward-dipping cross-strata formed by lunate megaripples in the outer rough zone of a non-barred coast (Clifton et al., 1971). The north-south current lineations in the plane laminated sandstones of the conglomerate association (Fig. 16-9b) could also be wave-worked deposits, representative of one of the plane bed zones of the nearshore (Clifton et al., 1971). However, in this case, there is no evidence to distinguish plane lamination formed by wave, alluvial or combined processes. Current crescents, indicating flow to the south, may have formed either by alluvial processes or by backwash on the shoreface.

Sandstone Facies Association

Modal orientations of trough cross-beds in the sandstone facies association, although variable, are mainly towards the east, west and north-west (Fig. 16-10). With a dominant southward palaeoslope these cannot be attributed to alluvial deposition, and they are therefore ascribed to marine processes. As with the fine conglomerates discussed above, northerly and northwesterly dipping cross-beds are attributed to oblique, onshore wave action (Plate 184).

The east-west palaeocurrent modes for trough cross-beds in the White Point Conglomerate and Boxing Bay Formation are interpreted together with their respective lineated sandstones because of similar orientation (Fig. 16-10). The lineated sandstones can be assigned palaeocurrent directions where they have current crescents, or where they form scours and drapes around boulders at the top of an underlying conglomerate bed (Plate 185).

On this basis (Fig. 16-10d,e,f), the lineations indicate bipolar (upper flow regime), east-west transport, with the predominant mode to the west, at least for the Boxing Bay Formation. It is concluded that the trough cross-bedded and current lineated sandstone facies were transported by shore-parallel currents, which is consistent with their abundant feldspars and lack of carbonate clasts, indicating that they were not derived from the carbonate source rocks to the north. Clifton et al. (1971, p.657) observed that cross-strata in the inner rough zone of the nearshore have a pronounced longshore component when influenced by longshore currents. However, there is no evidence that wave-induced longshore currents alone can form plane laminated, lineated sands although they have been reported from numerous tidal deposits, both modern and ancient. Modern examples include those described by Dörjes et al. (1970), Howard and Reineck (1972, p.110), Kumar and Sanders (1974), Knight and Dalrymple (1975, p.54), Wunderlich (1970) and Terwindt (1971). Most authors did not indicate whether the plane laminae were also lineated, probably because lineation is hard to observe in sections of modern sediments. However, Kumar and Sanders (1974, p.514) reported plane laminated sand formed by upper regime flow in shallow tidal channels, and both Wunderlich (1970, p.111) and Terwindt (1971, p.519) regarded their plane laminated sands as deposits of high velocity, highly turbulent flows, conditions which are incompatible with planar beds of the lower flow regime. Klein (1970, Table 2) listed examples of supposed ancient tidal deposits, many of which contain plane laminated sandstone. Allen and Tarlo (1963) demonstrated the similarity between a Devonian tidal deposit and modern equivalents in the Wilhelmshaven area, both containing a plane laminated sand facies. Barnes and Klein (1975) used modern tide-dominated sand bodies in the North Sea to interpret plane-laminated sandstones in the Zabriskie Quartzite as tidal current bedload deposits. Plane laminated sandstones with lineations were reported from ancient tidal successions by Ireland et al. (1978), Tankard and Hobday (1977) and Hobday and Horne (1977), while Sellwood (1972) interpreted plane laminated sands as an upper flow regime structure formed on tidal flats. Like the Kangaroo Island case, the lineations discussed by Tankard and Hobday (1977, p.140) were parallel to the inferred shoreline.

In the case of Kangaroo Island, shore-parallel orientation of lineations, and association with similarly oriented bipolar cross-beds and ripples suggest that the structures were mainly formed by tidal currents. A possible explanation for the essentially unidirectional paleocurrents of the lineated sandstones may be that they only formed when storm surge (and perhaps wave-induced longshore drift) augmented the tidal currents. Sellwood (1972, p.103-4) proposed a similar explanation (formation by wind-tides and hurricanes) for plane laminated sands formed on tidal flats of a Liassic eipcontinental sea. Shaw (1964) and Mazzullo and Friedman (1975) argued against tidal influence in epicontinental seas, but Johnson and Belderson (1969) and Klein and Ryer (1978) produced abundant evidence for tidal deposition in at least some ancient seas of this type. Several of the modern and ancient examples cited above are from epicontinental seas, indicating that the necessary velocity/depth conditions of tidal flow to form lineated, plane laminated sand can occur within this environment.

The common occurrence of contorted structures in the trough cross-stratified sandstone (Plates 173 and 174) is interpreted as largely due to rapid deposition in a loose-packed state (Allen, 1972). Allen and Banks (1972) showed that loose-packed sands are easily liquified in response to sudden shock, and the resultant movement may deform primary structures. In the present case, the cross-beds were evidently deposited in a relatively loose-packed state, and the proximity to active faults makes seismic shock a likely trigger mechanism (Brenchley and Newall, 1977). Dalrymple (in press) suggested that the depth of deformation within a unit may be taken as indicative of the depth of liquefaction of the original sediment.

Synsedimentary deformation down the direction of cross-bedding is rare in the sandstones of this sequence. By comparison, it is a major feature in the cross-bedded metasandstones of the Kanmantoo Group further south on Kangaroo Island, which were deposited further offshore (Flint, 1978). The passage of a wave or current may exert a horizontal drag on the under-consolidated bed, and deform the cross-strata into features like recumbent folds (Allen and Banks, 1972; Dalrymple _in press_). This mechanism is invoked to explain the relatively rare contorted structures in the north coast succession with sub-horizontal symmetry, for the slope was probably too gentle to initiate slumping.

Fine-grained Facies Association

The spectrum of facies in this association is similar to that observed in many ancient and modern tidal deposits (Reineck and Singh, 1975, p.355-372; Ginsburg, 1975). Characteristic features are the association of desiccation cracks with a marine infauna and epifauna, and the interbedding of ripple laminated marine sandstone and coarse siltstone with varying proportions of mudstone (Plates 177 and 178). In most cases desiccation cracks are associated with red rocks, and indicate temporary emergence of the tidal flat. The cracks are absent from a minor part of the succession, which is commonly greenish-grey to dark grey in colour, and is interpreted as lower intertidal to subtidal.

The palaeocurrent patterns for ripples and current lineations in most of the sequences are essentially bipolar parallel to the shore, with minor onshore and offshore modes (Fig. 16-11). Sandstones with north-south lineations are prominent in the upper Emu Bay Shale and basal Boxing Bay Formation at Emu Bay, and are interpreted as backwash lineations formed on a shoreface (Hantzschel, 1939, Fig. 9 and p.48). Thus, onshore/offshore modes result principally from wave action, whereas shore-parallel modes are due to tidal currents flowing along the shore, as observed by Evans (1965) on the lower flats of the Wash, England. The Kangaroo Island tidal flats are therefore interpreted as an environment in which tidal currents predominated over wave action.

DeRaaf, Boersma and van Gelder (1977) described a Carboniferous succession in southern Ireland that is similar to the fine-grained facies association of the Kangaroo Island rocks but shows a sharper separation of coarse and fine elements. They recognised four types of sequence: those that fine upward, coarsen upward, coarsen then fine upward (CUFU), and sequences that are random intercalations. We have recognised similar sequences (Figs. 16-5 and 16-6) but the relative proportions differ: random intercalations and fining-upward sequences are more abundant, while CUFU sequences are rare.

DeRaaf et al. (1977) interpreted their succession as almost entirely wave generated. This conclusion was based largely on the recognition of wave-formed ripples, for which several criteria were listed. We also recognise distinctive wave-generated features, such as symmetrical ripples and form-discordant cross-lamination but see wave action as moderate and accompanied by relatively strong tidal currents. Apart from this distinction, the interpretation of deRaaf et al. (1977) for coarsening upward and random sequences appears to be applicable to the Kangaroo Island succession (Figs. 16-5 and 16-6). Upward coarsening within the sandy units of the fine-grained facies association (Figs. 16-5b,c, and 16-6b,c) probably indicates shoaling on the outer part of the tidal flat, thereby intensifying wave and current activity. Random sequences can be attributed to storms, which increase wave energy and augment tidal and other currents through storm surge effects. Random sequences could also result from another storm effect: increased terrestrial runoff influencing tidal flat sedimentation through a rapid influx of terrigenous detritus. There is no evidence that individual tectonic movements influenced tidal flat sedimentation, for one would expect the terrigenous influx to give rise to upward coarsening then upward fining (the CUFU sequence of deRaaf et al., 1977). This type of sequence is rare in the fine-grained association on Kangaroo Island despite the fact that alternations in the conglomerate facies association indicate recurring tectonic influence.

DeRaaf et al. (1977) had only one independent fining-upward sequence in their succession, and did not attempt a full explanation. Such sequences are more common in the Kangaroo Island rocks (Figs. 16-5 and 16-6), and are of two types. One type leads to the development of dark shales which lack desiccation cracks, and in some cases contain pyrite, articulated trilobites and annelid impressions with preservation almost comparable to that of the Burgess Shale (Whittington, 1971). Fining-upward sequences of this sort are attributed to transgressive events in which the rate of subsidence exceeded that of sedimentation. The depth of water (subtidal) and partial isolation tended to cause stagnation of bottom waters and the reducing conditions favoured preservation of body fossils. In the second (more common) type of fining-upward sequence grey-green siltstones commonly with worm burrows and abundant trilobite tracks pass up into red mudstones with desiccation cracks and rarer occurrences of such traces (Fig. 16-6c, base of section). This is interpreted as a regressive sequence in which conditions on the inner part of the tidal flat changed from a dominantly subtidal to an upper intertidal to supratidal environment. Deposition of finer sediment in the shallower environment was due to frictional loss of wave and current energy during passage into a relatively sheltered part of the tidal flat. This is in contrast to the effect of shoaling on outer parts of the tidally-dominated areas, which were interpreted above as resulting in coarsening-upward sequences.

Evolution of the Alluvial-Tidal Complex

The upper four formations in the Cambrian succession of northeast Kangaroo Island show an alternation of fine and coarse deposits which reflects temporal changes in the coastal environment. The fine-grained facies association is dominant in the Smith Bay Shale, and includes a minor part interpreted here as subtidal to lower intertidal. Evidentally there was a tendency for subsidence to exceed sedimentation on the tidal flat during deposition of the Smith Bay Shale. There is no direct evidence of terrestrial influence on the Smith Bay Shale, but the fact that its palaeocurrent pattern is similar to that of fine-grained facies in the overlying White

Point Conglomerate indicates a similar pattern of waves and currents. It is therefore concluded that shoreline orientation was similar for the two formations, with a subdued northern landmass during Smith Bay Shale sedimentation.

During deposition of the White Point Conglomerate uplift occurred in the northern landmass, from which fossiliferous Early Cambrian and Precambrian crystalline rocks were eroded. Uplift probably occurred along dip-slip faults located in what is now Investigator Straight, adjacent to Kangaroo Island, as part of the fault-dominated tectonics of the region. Uplift and the resulting fan progradation were not uniform in time and space: thick, coarse fan deposits accumulated east of Bald Rock, while west of Cape D'Estaing gravel beds, commonly lenticular, alternated with shallow marine deposits. Tidal flat sedimentation persisted over much of the study area, and throughout the greater part of White Point Conglomerate deposition, but it was considerably influenced by alluvial influx from the north. This interfingering of alluvial fan and tidal flat complexes is relatively unusual in the geological record; more commonly alluvial fans were entirely terrestrial (eg. Steel et al., 1977), or low-slope, high sinuosity rivers intervened between the fan complex and the sea (Miall, 1970; Tankard and Hobday, 1977).

The section east of Bald Rock shows a general fining upwards in the upper part of the White Point Conglomerate, terminating in a thin conglomerate at its top. This suggests that the northern source was gradually worn down after uplift ceased. The contact between the White Point Conglomerate and the Emu Bay Shale is sharp and represents a sudden deepening possibly associated with a transgression: a strongly reducing environment pertained which gradually became dominantly oxidising with shallowing and upward coarsening of the sediment. Thus, the upper part of the Emu Bay Shale represents a return to dominant tidal flat deposition, with very few conglomerate beds indicative of coarse terrigenous influx. With the exception of north-south lineated sandstones, palaeocurrent directions for the

Emu Bay Shale are similar to the other formations, suggesting maintenance of the east-west shoreline. The two sections of the Emu Bay Shale (Cape D'Estaing and Bald Rock, Figs. 16-3 and 16-4) do not reveal significant lateral variation along the tidal flats at that time, although the dark pyritic shale facies is present only in the Bald Rock section. The terrestrial relief which had developed and persisted during White Point times had been largely eliminated, but some erosion evidently continued in the source area, for when the alluvial fan complex prograded southward again in Boxing Bay times as a result of further tectonic uplift, the clast assemblage was enriched in gneiss and granite. This shows that basement rocks had become extensively exposed in the source area during the intervening period. Although mainly composed of more resistant lithologies, the clasts of the Boxing Bay Formation conglomerates are significantly smaller than those of the White Point Conglomerate. This indicates either that the terrestrial source was less elevated in Boxing Bay Formation times, or that the uplifted area was further north than during White Point Conglomerate deposition. However, conglomerate imbrication and palaeocurrents of the sandstone and fine-grained facies associations show that the east-west strike of the source terrane and of the shoreline was maintained.

CONCLUSIONS

The uppermost Lower Cambrian succession of northeast Kangaroo Island was formed along an ancient shoreline subject to strong tidal, minor wave and at times alluvial influence. The fauna and sedimentary structures of the fine-grained sediments indicate that deposition was mainly intertidal while alluvial influence is represented by conglomerates and coarse sandstones with stratification, textures and fabrics in some cases comparable to those of alluvial fans. The restriction of wave-worked deposits to cross-stratified fine conglomerates and associated sandstones suggests that wave energy was moderate. Likewise the absence of well-rounded clasts is similarly significant. Plane laminated sandstones with current lineation subparallel to the shoreline cannot be explained by direct wave action. By analogy with similar sands in modern environments, they are attributed to tidal currents, probably augmented by wave-induced longshore drift and storm surge effects. Other indications of tidal current activity are the bipolar longshore palaeocurrents for ripples and cross-strata.

The palaeoenvironment is interpreted as a shoreline along which alluvial deposits, including alluvial fan complexes, interfingered with tidal deposits. Shoreline migration was in response to the interplay of fault uplift of the northern source area and basinal subsidence, which determined the nature and amount of coarse alluvial detritus shed southwards into the basin.

PART 4 AND

CHAPTER 17

CONCLUSIONS - LATE EARLY AND EARLY MIDDLE CAMBRIAN SEDIMENTATION IN THE ADELAIDE 'GEOSYNCLINE'

INTRODUCTION

The preceding study comprises a detailed examination of the stratigraphy and sedimentology of the Billy Creek Formation (Flinders Ranges) and its lateral equivalents on the northeast coast of Kangaroo Island, South Australia. The study concentrates on the Billy Creek Formation (Chapters 2 to 11), and detailed conclusions regarding the depositional history of this predominantly fine-grained,red-bed sequence are presented in Chapter 11. Unfortunately, no outcrops of late Early Cambrian strata occur in the southern Flinders Ranges, and thus a zone of no outcrop, several hundred kilometres long, separates the Billy Creek Formation from its lateral equivalents on Kangaroo Island. This chapter presents some tentative correlations between the two sequences, and briefly discusses the nature of late Early and early Middle Cambrian sedimentation in South Australia, with particular emphasis on sedimentation in the Adelaide 'Geosyncline'.

THE KANGAROOIAN MOVEMENTS AND LATE EARLY - EARLY MIDDLE CAMBRIAN SEDIMENTATION IN SOUTH AUSTRALIA

Sedimentation in the Adelaide 'Geosyncline' in the late Early and early Middle Cambrian was largely controlled by the Kangarooian Movements (Daily and Forbes, 1969); a complex and persistent tectonism which was most pronounced in the southern portion of the geosyncline. The Kangarooian Movements were responsible for:

(a) fault-controlled uplift of the Gawler Block in the Yorke Peninsula - Investigator Strait area (particularly the latter), and subsequent erosion of the thin Early Cambrian platform cover and underlying basement metamorphics;

(b) formation of the Kanmantoo Trough through fault-controlled collapse of the sea floor to the south and southeast of the uplifted Gawler Block, and deposition of a thick sequence of flysch-like sediments in the rapidly subsiding basin;

(c) formation of a shallow marine platform to the south of the Gawler Block in the vicinity of northeastern Kangaroo Island. This platform probably intervened between deeper water Kanmantoo Group sediments which lay to the south, and the uplifted areas (eg. the Investigator Strait High) which lay to the north;

(d) deposition of (?)continental gravels and marginal marine red-beds adjacent to the uplifted areas on Yorke Peninsula (the Minlaton Conglomerate);

(e) deposition of coarse alluvial detritus and formation of alluvial fan complexes which intertongued with the intertidal and shallow marine shelf sediments in the vicinity of northeastern Kangaroo Island. The conglomerates and associated coarse calcareous sand-stones were shed southwards from the Investigator Strait High and adjacent uplands, whereas the shallow marine and intertidal shelf sediments were derived from a more distant basement source, and transported to the site of deposition by longshore tidal currents, flowing east-west;

(f) gentle but persistent uplift and erosion of the Broken Hill-Olary region, causing a coarsening-upward sequence of arkosic clastics (the Billy Creek Formation) to be deposited in the northern Adelaide 'Geosyncline';

(g) strong, but short-lived uplift of the area between the Broken Hill-Olary Block and Reaphook Hill in the Flinders Ranges,causing erosion of the Adelaidean and Early Cambrian cover rocks, and their subsequent deposition in a local, probably fault-controlled depression at Reaphook Hill (the Coads Hill Member of the Billy Creek Formation).

In addition, the Kangarooian Movements may have been responsible for the widespread regression that is indicated in late Early Cambrian sequences throughout South Australia. Apart from the Kanmantoo Group, the sediments are all very shallow water deposits, and indicate at least partial derivation from the crystalline basement of either the Gawler Block or the Willyama Complex. To the east of the Gawler Block in the late Early - early Middle Cambrian, fine-grained sediments of the Yarrawurta Shale (Johns, 1968) accumulated in a very low energy environment on a broad intertidal shelf (the Stuart Shelf). Further east, coarser-grained sediments of the Billy Creek Formation were deposited in a shallow epicontinental sea (the northern Adelaide 'Geosyncline'). South of the Gawler Block, tidal deposits accumulated on a shallow tide-swept shelf flanking the Investigator Strait High while further offshore, to the south and east of the uplifted area, deeper water, flysch-like sediments accumulated in the rapidly subsiding Kanmantoo Trough. Geophysical evidence suggests that the east-west trending belt of Kanmantoo Group rocks on Kangaroo Island swings to the northwest beneath the floor of the offshore Duntroon Basin, and thus follows the southern and southwestern margins of the Gawler Block (Smith and Kamerling, 1969). Further west, gently dipping sandstones and conglomerates of unknown age occur at Mt. Wedge on the eastern margin of the Polda Trough, and according to Daily et al. (1973, p.62) "are lithologically similar to Cambrian rocks on the north coast of Kangaroo Island and Yorke Peninsula" and thus may indicate continuity of late Early Cambrian sedimentation in this area. To the west of the Gawler Block, a thick sequence of fine-grained, arkosic red-beds (the Observatory Hill Beds; Wopfner, 1969c), lithologically similar to the lower and middle portions of the Billy Creek Formation, has been tentatively correlated with the Billy Creek Formation by Gatehouse (1976). Recent drilling in the Officer Basin has confirmed the widespread extent of the red-beds, with sequences similar to the Observatory Hill Beds intersected in Emu No. 1 (Grasso, 1963), Mallabie No. 1 (Daily et al., 1973), Murnaroo No. 1 (Gatehouse, in prep.,a) and Wilkinson No. 1 (Gatehouse, in prep.,b). Kreig (1969) correlated the Observatory Hill Beds at Wallatinna with a sequence of red-beds in the Mt. John area. Thus, it is concluded that Cambrian (and probably more specifically, late Early Cambrian) clastics were deposited in a more or less continuous belt around the Gawler Block.

Thin beds of halite occur in the lower portion of the red-bed sequence in Wilkinson No. 1 bore, together with the presence of thin micritic and oolitic carbonate interbeds (many of which are dark and foetid) suggests that the sequence at this locality was deposited in a very shallow and very restricted marine embayment, flanked on the north by the Musgrave Block and on the south by the Gawler Block. By comparison, the sediments of the Billy Creek Formation were deposited under less restricted conditions, where the precipitation of halite was confined to the ephemeral growth of isolated hopper crystals on upper intertidal and supratidal mudflats. Also, the sediments of the Billy Creek Formation are much better sorted and winnowed than those in the Wilkinson No. 1 bore, which show minimal reworking by marine processes. On the northeast coast of Kangaroo Island, the late Early Cambrian sediments are quite different again, and contain abundant evidence of reworking by waves and especially tides on a moderate energy, shallow marine to intertidal shelf. Major differences between the Billy Creek Formation and the Cambrian succession on the northeast coast of Kangaroo Island are discussed below.

COMPARISON BETWEEN THE STYLES OF SEDIMENTATION IN THE NORTHERN AND SOUTHERN PARTS OF THE ADELAIDE 'GEOSYNCLINE'

Both the Billy Creek Formation and its lateral equivalents on the northeast coast of Kangaroo Island comprise complex sequences with a great deal of internal variability. However, due to their different sites of deposition, there are some gross differences which are summarized below.

A. The Billy Creek Formation was deposited in response to relatively mild uplift of the Broken Hill-Olary Block and mild subsidence in the basin of deposition. The formation has a maximum measured thickness of approximately 930m, and averages 500m in thickness. By comparison, uplift of the Yorke Peninsula-Investigator Strait region and subsidence of the areas to the south were much more pronounced, with the deposition of a thick sequence of shelf sediments, presently exposed on the northeast coast of Kangaroo

Island. The northeast coast sequence is incomplete, however total measured stratigraphic thickness is approximately 2700m. Thus, the rates of subsidence and sedimentation in the southern portion of the Adelaide 'Geosyncline' were many times greater than in the northern part of the geosyncline.

B. The more pronounced tectonism in the southern portion of the geosyncline, and the close proximity of the northern source area (the fault escarpment from which the conglomerates were eroded lay only 5-10km north of the present north coast of Kangaroo Island) were responsible for the development of a relatively coarse-grained sequence of clastics by comparison with those of the Billy Creek Formation.

C. Petrological studies indicate that the source areas for both sequences were mainly Precambrian crystalline basement rocks. However, the interpreted source area for the Kangaroo Island sequence is the Gawler Block, whereas the source area for the Billy Creek Formation was the Broken Hill-Olary Block.

D. For both sequences, older, relatively unmetamorphosed cover rocks provided a minor source of clastic detritus. In the Billy Creek Formation, Early Cambrian limestones contributed the bulk of the detritus for the conglomerate in the basal part of the Coads Hill Member (Unit A), and are also represented as scattered pebbles in Unit C of the same member. However, most of the detritus comprising the Coads Hill Member at Reaphook Hill was derived from the erosion of submature sandstones attributed to the older Cambrian (Bunkers Sandstone equivalents) or possibly Adelaidean cover rocks. In the Kangaroo Island sequence, the conglomerates and coarse calcareous sandstones indicate derivation from Early Cambrian strata and Precambrian crystalline basement rocks. There is no evidence that Adelaidean sediments were available as a source of detritus for the Kangaroo Island northeast coast Cambrian sequence.

E. The muddy nature of the Billy Creek Formation, and the relatively poor sorting of the sediment into coarse and fine elements indicates that wave and tidal activity were limited in the northern part of the geosyncline.

By comparison, the Kangaroo Island sequence is well sorted and the abundance of current lineated, plane laminated sandstones and large scale cross-stratification indicates relatively strong reworking by waves and tides.

F. The very small lateral and vertical variability in the Billy Creek Formation and the predominance of intertidal conditions (indicated by the association of desiccation features and trace fossils) throughout much of the basin of deposition indicates that the sequence accumulated in a very low energy epeiric sea, characterised by restricted circulation and by a very low palaeoslope. By comparison, the northeast coast Kangaroo Island sequence shows much greater lateral and vertical variability and was deposited in relatively open water, on a moderate slope, shallow marine shelf.

G. The Billy Creek Formation is characterised by an abundance of symmetrical and near-symmetrical, wave-formed ripples. Highly asymmetrical current ripples are present, but not abundant, indicating that wave oscillation predominated over tidal current activity. In the Kangaroo Island sequence however, the vast majority of ripples are of the highly asymmetrical form, indicating strong tides and subordinate wave oscillation. This observation is consistent with Shaw's (1964) hypothesis of very limited tidal activity in shallow epeiric seas.

H. Crests of wave ripples in the Billy Creek Formation are generally aligned north-south, sub-parallel to the inferred margins of the basin of deposition. Slight asymmetry in the ripples indicates bipolar transport up and down the palaeoslope, although shoreward transport was dominant. On Kangaroo Island however, current ripples, current lineations and much of the large-scale cross-stratification is directed east-west, parallel to the inferred shoreline. This feature reflects a basic difference in the environments of deposition, with longshore tidal currents developing on the relatively open marine shelf, south of the Investigator Strait High, but not being able to develop in the shallow epeiric conditions of the northern Adelaide 'Geosyncline' presumably because of frictional loss on the very shallow tidal flats. As noted in Chapter 16, longshore tidal activity in the Kangaroo Island succession was probably augmented, and may have been originally generated, by oblique wave attack. In the Billy Creek Formation, there is no evidence of strong wave activity. The very small wavelengths of the oscillation ripples is partly a reflection of the fine grain-size of the available detritus, however it probably also indicates that wave fetch was limited and thus the driving mechanism behind pronounced longshore transport was absent. A further factor is the depth of water at the site of deposition, for Evans (1965) has shown that on the tidal flats of the Wash, longshore tidal transport is predominant in the offshore, subtidal zone whereas currents move up and down the tidal flats in the intertidal zone. Since the Billy Creek Formation was largely deposited in the intertidal or very shallow subtidal environment, it is to be expected that longshore transport was minimal.

I. The restricted nature of the northern Adelaide 'Geosyncline' is further indicated by the presence of evaporites in the sequence. Anhydrite, although mainly restricted to borecore samples, has been identified from thin-sections of weathered surface outcrops, indicating its extensive original distribution. Halite pseudomorph casts are abundant throughout the Billy Creek Formation outcrops, and also occur in the subsurface. By comparison, there is no evidence of evaporite formation in the Kangaroo Island sequence.

J. The restricted conditions of deposition in the northern Adelaide 'Geosyncline' were apparently unfavourable for the proliferation of marine organisms, and thus body fossils are rare in the Billy Creek Formation, being restricted to small trilobites, which lived in the deeper water environments (eg. Reaphook Hill and Wirrealpa Basin outcrops). In addition, trace fossils comprise minor arthropod tracks and worm burrows and rare molluscan trails. In the northeast coast, Kangaroo Island sequence however, trilobites are recorded from four of the six formations, and in addition, a variety of other fossils are preserved in the Emu Bay Shale. The fossils are also larger, and specimens up to 35cm long of the open-water trilobite *Redlichia* are reported from the Emu Bay Shale. Trace fossils are also abundant, with a rich array of arthropod and molluscan traces, and worm burrows.

K. Penecontemporaneous dolomite is the predominant carbonate in the Billy Creek Formation, further indicating restricted water circulation. The sabkha model of early dolomitization is invoked to explain the dolomites, although the high salinity of the water and removal of Ca^{++} ions by precipitation of gypsum may have been a contributing factor. By comparison, the Kangaroo Island carbonates are all limestones. Furthermore, carbonate mudstones are abundant in the Billy Creek Formation, indicating very quiet water deposition whereas oolitic limestones, indicating moderate agitation by waves and tides, are present in the Carrickalinga Head Formation, Smith Bay Shale and White Point Conglomerate on Kangaroo Island.

In summary, the Billy Creek Formation indicates very restricted, very shallow water deposition in an epeiric sea where wave and tidal activity were limited, whereas the Kangaroo Island northeast coast Cambrian sequence indicates deposition on a relatively open, shallow marine shelf, subject to moderate wave attack and swept by strong tides.

SOME TENTATIVE CORRELATIONS BETWEEN THE BILLY CREEK FORMATION AND THE CAMBRIAN SEQUENCE ON THE NORTHEAST COAST OF KANGAROO ISLAND

Introduction

The six Cambrian formations on the northeast coast of Kangaroo Island have been correlated by Daily (1976b, Fig. 8) with the Billy Creek Formation in the Flinders Ranges. In this thesis and elsewhere (Moore, 1979 and *in press*), the Billy Creek Formation has been subdivided into five members. Tentative correlations between these five members and the six formations on Kangaroo Island are discussed below.

The Age of the Cambrian Sequence on the Northeast Coast of Kangaroo Island

The presence of *Redlichia* in the Carrickalinga Head Formation, and the identification of *Redlichia*, *Isoxyx* and *Hyolithes* in the Emu Bay Shale fauna serve to establish a Cambrian age for these and the intervening formations. The trilobite Estaingia bilobata, which occurs near the top of the White Point Conglomerate and in the basal portion of the Emu Bay Shale, also occurs towards the top of the Cymbric Vale Formation in northwestern New South Wales (Warris, 1967), where it is assigned a late Early Cambrian age (Öpik, 1968, 1976). More specific ages for the rest of the northeast coast Kangaroo Island sequence are based on lithological correlation with the Kanmantoo Group metasediments, because the base of the Carrickalinga Head Formation on Kangaroo Island and the top of the Boxing Bay Formation are not exposed. The Carrickalinga Head Formation is recognised in the Kanmantoo Group on southern Fleurieu Peninsula (Daily and Milnes, 1971) where it conformably overlies the middle to late Early Cambrian Heatherdale Shale (Daily, 1976b, Fig. 8). Thus, the Carrickalinga Head Formation is considered to be late Early Cambrian in age. The Boxing Bay Formation is lithologically correlated with the Balquhidder Formation in the Kanmantoo Group, which is overlain by the Wattaberri Sub-Group (Petrel Cove Formation and Middleton Sandstone). The Middleton Sandstone is intruded by Late Cambrian granites and must have been overlain by 5-10km of sediment at the time of intrusion. Thus a late Early to early Middle Cambrian age is suggested for the entire Kanmantoo Group and its lateral equivalents on the northeast coast of Kangaroo Island (Table 13-1).

The Correlation between Kangaroo Island and the Flinders Ranges

A tentative correlation chart for the Billy Creek Formation and its lateral equivalents on the northeast coast of Kangaroo Island is presented in Table 13.1. The Early-Middle Cambrian boundary occurs at an unknown position in the upper portion of the Billy Creek Formation (Daily, 1956) and its location in the left hand (Flinders Ranges) side of Table 13.1 is somewhat arbitrary. However, since the Eregunda Sandstone Member is comparatively thin and was deposited quite rapidly, it is probable that it is largely, if not entirely, Middle Cambrian in age.

As shown in the correlation chart, there is little evidence of any lithological correlation between the Billy Creek Formation and its equivalents on Kangaroo Island, as might be expected. Thus, as the very low energy, muddy tidal flat deposits of the Warragee Member developed over much of the northern part of the Adelaide 'Geosyncline', a complex sequence of shales, sandstones and interbedded conglomerates was being deposited in a relatively high energy, shoreline environment south of the Investigator Strait High. A short period of low energy deposition, represented by the lower portion of the Emu Bay Shale and to a lesser extent by the uppermost portion of the White Point Conglomerate on Kangaroo Island, may signify a minor late Early Cambrian transgression. This interval is richly fossiliferous and can be traced into the northern part of the Adelaide 'Geosyncline' on the basis of the trilobite genus Balcoracania. Specimens of Balcoracania occur in the upper portions of the Coads Hill and Warragee Members of the Billy Creek Formation (Table 13.1) and in the upper portion of the White Point Conglomerate on Kangaroo Island. More specifically, Balcoracania dailyi is common to both the White Point Conglomerate and the Coads Hill Member. The specimens of Balcoacania in the Flinders Ranges are associated with predominantly green shales with common interbeds of limestone or dolomite.

The Boxing Bay Formation, which overlies the Emu Bay Shale on Kangaroo Island, signifies a return to higher energy conditions, with renewed uplift in the source area. The same tectonic event may be recorded in the Flinders Ranges, where the Erudina and Nildottie Siltstone Members developed in response to increased sediment input, presumably due to more pronounced uplift of the Broken Hill-Olary Block.

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STRATIGRAPHY OF THE EARLY CAMBRIAN EDEOWIE LIMESTONE MEMBER, FLINDERS RANGES, SOUTH AUSTRALIA

By P. S. MOORE

ADELAIDE
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APPENDIX B

Estimates of Ancient Waves, Water Depth and Fetch during Nildottie Sedimentation

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Estimates of Ancient Waves, Water Depth and Fetch During Nildottie Sedimentation

The following calculations are based on the work of Tanner (1971), with supplementary data derived from Harms (1969), Komar (1974), and Bretschneider (1966).

Symmetrical Ripples

From Table 5-1 (Chapter 5):

s = mean ripple spacing = 2.53cm

s_{max} = 4.5cm

s_{min} = 0.9cm

RSI = 1.0

g = average grainsize = 60μm

$\ln g = 4.1$

Step 1:

$0.97s - 3.72 \ln g = -12.8$

From Figure 1 of Tanner (1971), we get the following limits:

(a) water depth $h \geqslant 15$cm (average value 40-50cm)

(b) fetch f = 3-500km (average value about 200km)

(c) wave height H = 7-17cm (average value 15cm)

Step 2:

On the basis of $s < 5$cm, we can assume that deposition occurred in a small, shallow body of water. An abundance of desiccation features supports this view.

Step 3:

Water wave height $H = 38.52 + 1.89s - 7.11 \ln g$

$= 14.2$cm

Step 4:

Water depth: $\ln h = 22.74 + 0.97s - 3.72 \ln g - 0.41H$

$= 4.1201$

APPENDIX B (cont'd)

Step 4: (cont'd)

Water depth h = 62cm

Step 5:

A recheck with Tanner's Figure 1 shows that the above values are hydrodynamically acceptable.

Step 6:

Wave fetch: $\ln f = 2.2968 \ln H - 0.583 \ln h - 0.731$

$= 2.96$

Wave fetch f = 19.3km

Additional calculations:

From Komar (1974),

E_{max} = horizontal particle displacement d_o

= (ripple spacing)/0.8

= 3.16cm

and $E_{max} = \frac{-H}{\text{Sinh}(2\pi\ h/L)}$

For H = 14.2cm and h = 62cm,

Wave length L = 3.99m

Also from Komar (1974), and Komar and Miller (1973),

$L = L_\infty \left| \tanh(2\pi\ h/L_\infty) \right|^{\frac{1}{2}}$

L_∞ = 4.85m (deep water wave length).

and $T^2 = L_\infty \cdot \frac{2\pi}{G}$ where G = acceleration due to gravity

Wave period T = 1.76 secs

N.B. This is a very short period oscillation. Based on shallow water empirical tables (Fig. IV-B of Bretschneider, 1966) water depth of less than about 1m should be expected. Even allowing for winds of up to 50km/hr., waves should rarely exceed 30cm in height.

APPENDIX B (cont'd)

Near-Symmetrical Ripples

From Table 5-3 (Chapter 5):

s = mean ripple spacing = 2.25cm

s_{max} = 4.0cm

s_{min} = 1.3cm

RSI = 1.5

g = average grainsize = 60μm

$\ln g = 4.1$

Step 1:

$0.97s - 3.72 \ln g = -13.1$

From Figure 1 of Tanner (1971), we get the following limits:

(a) water depth $h \geqslant 15$cm (average value 40cm)

(b) fetch $f = 2 - 500$km (average value 150-200km)

(c) wave height $H = 7$-17cm (average value 15cm)

Step 2:

On the basis of $s < 5$cm, we can assume that deposition occurred in a small, shallow body of water. An abundance of desiccation features supports this view.

Step 3:

Water wave height $H = 38.52 + 1.89s - 7.11 \ln g$

$= 13.6$cm

Step 4:

Water depth: $\ln h = 22.74 + 0.97s - 3.72 \ln g - 0.41H$
$= 4.0945$

Water depth h = 60cm

Step 5:

A recheck with Tanner's Figure 1 shows that the above values are hydrodynamically acceptable.

APPENDIX B (cont'd)

Step 6:

Wave fetch: $\ln f = 2.2968 \ln H - 0.583 \ln h - 0.731$

Wave fetch $f = 17.8$km

Additional calculations:

From Komar (1974),

E_{max} = horizontal particle displacement d_o

= (ripple spacing)/0.8

= 2.81cm

and $E_{max} = \dfrac{-H}{\sinh(2\pi\ h/L)}$

For H = 13.6cm and h = 60cm,

Wave Length L = 3.80m

Also from Komar (1974), and Komar and Miller (1973),

$$L = L_\infty \left| \tanh(2\pi\ h/L_\infty) \right|^{\frac{1}{2}}$$

L_∞ = 4.58m (deep water wave length)

and $T^2 = L_\infty \cdot \dfrac{2\pi}{G}$ where G = acceleration due to gravity

Wave period T = 1.71secs

N.B. This is a very short period oscillation. Based on shallow water empirical tables (Fig. IV-B of Bretschneider, 1966) water depth of less than about 1m should be expected. Even allowing for winds of up to 50km/hr, waves should rarely exceed 30cm in height.

APPENDIX C

Petrographic Data,

Billy Creek Formation

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Petrographic Data, Billy Creek Formation

THIN SECTION LISTING

Four lithological associations are recognised in the Billy Creek Formation (Chapter 10). They are:

(a) Association 1: Red and minor green shales, siltstones and sandstones all of which are rich in feldspars and micas.

(b) Association 2: Red, brown and green shales, siltstones and sandstones characterized by a paucity of feldspars and micas, and containing a very mature heavy mineral suite.

(c) Association 3: Carbonates.

(d) Association 4: Tuffs and tuffaceous sediments.

In the course of this study, nearly 1000 thin sections were prepared and the various rock-types identified. Thin-section listings are presented below, and are grouped into the four major lithological associations. Identification numbers on the thin sections follow the format 530-X-Y17, where:

530 is the author's identification number in the collections of the Geology Department at the University of Adelaide.

X is the locality prefix. Localities referred to are:

BC - Wirrealpa Basin (Mt. Billy Creek - Balcoracana Ck.)

BU - Bunyeroo

BR - Brachina

MS - Mount Scott Range

MF - Mount Frome

CG - Chambers Gorge

RH - Reaphook Hill

LF1 - Delhi-Santos Lake Frome No. 1 Stratigraphic Well

LF2 - Delhi-Santos Lake Frome No. 2 Stratigraphic Well

YL2 - S.A.M.D. Yalkalpo No. 2 Stratigraphic Well

Y17 is the sample number. For example, generally Y17 refers to the seventeenth sample collected in Section Y.

In the following listing, the author's identification number (530) is omitted (ie. X-Y17 not 530-X-Y17), since it is invariable. Sample heights are given in brackets: the height refers to the stratigraphic distance in metres above the base of the relevant member. Exceptions are noted in the text.

For borecore samples, the code number is either:

(a) YL2-X meaning Yalkalpo 2 borecore, X metres below ground level;

or (b) LF1-X, meaning Lake Frome No. 1 borecore, X feet below ground level. These figures are given in feet for quick and easy access to the original borecore which was logged in feet and inches.

There are several additional symbols:

* calcareous

\+ anhydrite present

ss sandy

s shaly

vs very shaly

d dolomitic

ds domal stromatolites (generally dolomitic).

LITHOLOGICAL ASSOCIATION 1

Red Sandstones

Nildottie Siltstone Member

Mount Scott Range: Section MS-B

MS-B11 (1m), MS-B12 (8m).

Mount Frome: Section MF-A

MF-A16 (101m)

Chambers Gorge: Section CG-B

CG-B5*(5m), CG-B6*(27m), CG-B7*(44m), CG-BG*(75m),

Red Sandstones (cont'd)

Eregunda Sandstone Member

Wirrealpa Basin: Section BC-B (Type Section)

BC-E13 (1m), BC-12 (2m), BC-L3 (6m).

Wirrealpa Basin: Section BC-K (Ten Mile Creek Section)

Om is the base of Unit C of the Eregunda Sandstone Member

BC-K1 (17m), BC-K2 (18m), BC-K3 (19m), BC-K6 (23m),

BC-K7 (23m), BC-K8 (31m), BC-K9 (33m), BC-K10 (34m),

BC-K11 (38m), BC-K13 (38m), BC-K14 (39m), BC-K15 (40m),

BC-K16 (41m), BC-K17 (42m).

Wirrealpa Basin: Section BC-Q (Balcoracana Creek Section)

BC-Q4 (Om), BC-Q9 (15m), BC-Q14 (37m), BC-Q15 (37m),

BC-Q18a (45m), BC-Q18b (45m).

Heysen Range: Section BR-A

BR-A21 (1m), BR-A23 (8m), BR-A25 (12m), BR-A26 (80m),

BR-A27 (92m).

Mount Scott Range: Section MS-B

MS-B28 (2m), MS-B37 (42m).

Mount Frome: Section MF-A

MF-A26 (26m), MF-A27 (27m), MF-A28 (29m),

MF-A30 (31m).

Erudina Siltstone Member

Reaphook Hill: Section RH-C

RH-C33 (Unit C, 30m).

Billy Creek Formation (sensu stricto) - Yalkalpo 2 borecore

YL2-512, YL2-333*, YL2-334.

Red Siltstones

Warragee Member

Wirrealpa Basin: Section BC-B (Type Section)

BC-C12 (254m).

Red Siltstones (cont'd)

Warragee Member (cont'd)

Wirrealpa Basin: Section BC-R

BC-R5 (68m), BC-R6 (87m).

Mount Scott Range: Section MS-B

MS-B9 (34m), MS-B10 (34m).

Heysen Range: Section BR-A

BR-A10 (54m).

Nildottie Siltstone Member

Wirrealpa Basin: Section BC-B (Type Section)

BC-D13 (73m), BC-D14 (74m), BC-D15 (76m), BC-D16 (96m),

BC-D17 (80m), BC-D18 (87m), BC-D19 (97m), BC-E3 (134m),

BC-E4 (196m), BC-E5 (221m), BC-E6 (222m), BC-E7 (265m),

BC-E9 (313m), BC-E10 (365m), BC-E11 (443m), BC-E12 (455m).

Wirrealpa Basin: Section BC-L

BC-L10 (98m).

Wirrealpa Basin: Section BC-N

BC-N1 (111m), BC-N5 (131m), BC-P3a (154m), BC-Z1 (144m), BC-Z2 (220m),

BC-Z3 (270m).

Wirrealpa Basin: Section BC-Q (Balcoracana Creek Section)

0m is the base of the Eregunda Sandstone Member.

BC-Q2 (-66m), BC-Q2a (-66m), BC-Q2b (-66m), BC-Q3 (-19m),

BC-Q5a (-0.2m), BC-Q5b (-0.2m), BC-Q5c (-0.2m).

Wirrealpa Basin: Section BC-R

BC-T14 (238m), BC-T15 (239m), BC-T21 (269m), BC-T22 (277m),

BC-T23a (279m).

Heysen Range: Section BR-A

BR-A15 (89m), BR-A16 (93m), BR-A17 (170m), BR-A18 (177m),

BR-A19 (228m), BR-A24 (341m).

Red Siltstones (cont'd)

Nildottie Siltstone Member (cont'd)

Mount Scott Range: Section MS-B

MS-B11 (2m), MS-B14 (82m), MS-B15 (99m), MS-B16 (100m), MS-B17 (101m), MS-B19 (118m), MS-B20 (118m), MS-B21 (122m), MS-B23 (136m), MS-B24 (141m), MS-B25 (148m), MS-B26 (176m).

Mount Frome: Section MF-A

MF-A10*(19m), MF-A12 (80m), MF-A13 (100m), MF-A15 (100m), MF-A16 (229m), MF-A18*(268m).

Chambers Gorge: Section CG-B

CG-B8*(55m), CG-B10*(78m), CG-B11*(136m), CG-B12 (150m), CG-B13 (185m).

Eregunda Sandstone Member

Wirrealpa Basin: Section BC-K (Ten Mile Creek Section)

BC-K4 (19m), BC-K5 (20m), BC-K22 (54m).

Wirrealpa Basin: Section BC-Q (Balcoracana Creek Section)

BC-Q11a (16m), BC-Q17 (41m).

Heysen Range: Section BR-A

BR-A24 (9m).

Mount Frome: Section MF-A

MF-A24 (3m).

Erudina Siltstone Member

Reaphook Hill: Section RH-A

RH-A28*(Unit B, 90m).

Reaphook Hill: Section RH-C

RH-C27*(Unit B, 41m), RH-C31*(Unit C, 122m), RH-C32*(Unit C, 131m), RH-C34 (Unit C, 152m), RH-C35 (Unit C, 162m), RH-C36*(Unit D, 203m), RH-C39*(Unit D, 214m), RH-C42 (Unit D, 264m).

Red Siltstones (cont'd)

Billy Creek Formation (sensu stricto) - Lake Frome No. 2 borecore

LF2-2407. LF2-2515+

Billy Creek Formation (sensu stricto) - Yalkalpo 2 borecore

YL2-519, YL2-440, YL2-428, YL2-414.

Red Shales

Warragee Member

Wirrealpa Basin: Section BC-R

BC-R4 (39m)+

Heysen Range: Section BR-A

BR-A11 (138m)

Mount Scott Range: Section MS-B

MS-B4 (11m).

Nildottie Siltstone Member

Wirrealpa Basin: Section BC-B (Type Section)

BC-D12 (71m).

Wirrealpa Basin: Section BC-N

BC-N6a (132m), BC-N6b (132m).

Eregunda Sandstone Member

Wirrealpa Basin: Section BC-K (Ten Mile Creek Section)

Om is the base of Unit C of the Eregunda Sandstone Member.

BC-K20 (53m), BC-K21 (53m), BC-K22 (54m).

Erudina Siltstone Member

Reaphook Hill: Section RH-A

RH-A27*(Unit A, 28m).

Interlaminated Red Shale and Siltstone

Nildottie Siltstone Member

Wirrealpa Basin: Section BC-N

BC-N2a (118m), BC-N2c (118m), BC-N4a (114m), BC-N4b (114m), BC-N10b (148m), BC-N10c (148m), BC-P2a (150m), BC-P2b (150m), BC-P2c (150m).

Erudina Siltstone Member

Reaphook Hill: Section RH-C

RH-C37 (Unit D, 213m), RH-C41 (Unit D, 262m), RH-C43 (Unit D, 266m).

Billy Creek Formation (sensu stricto) - Lake Frome Nos. 1 & 2 borecore

LF1-2560^{+}

LF2-2088, LF2-2523^{+}

Billy Creek Formation (sensu stricto) - Yalkalpo 2 borecore

YL2-327

Variegated Shales and Siltstones

Warragee Member

Wirrealpa Basin: Section BC-B (Type Section)

BC-D9 (301m).

Wirrealpa Basin: Section BC-R

BC-T4 (202m).

Billy Creek Formation (sensu stricto) - Lake Frome No. 1 borecore

LF1-1494^{+}, LF1-1663^{+}

Billy Creek Formation (sensu stricto) - Yalkalpo 2 borecore

YL2-391, YL2-289.

Green Sandstones

Eregunda Sandstone Member

Wirrealpa Basin: Section BC-K (Ten Mile Creek Section)

Om is the base of Unit C of the Eregunda Sandstone Member.

BC-K11 (38m), BC-K13 (38m).

Wirrealpa Basin: Section BC-Q (Balcoracana Creek Section)

BC-Q13 (36m)

Mount Scott Range: Section MS-B

MS-B27*(Om)

Mount Frome: Section MF-A

MF-A23 (1m).

Billy Creek Formation (sensu stricto) - Yalkalpo 2 borecore

YL2-499.

Green Siltstones

Warragee Member

Wirrealpa Basin: Section BC-B (Type Section)

BC-D11 (320m)

Chambers Gorge: Section CG-B

CG-B1*(18m).

Nildottie Siltstone Member

Chambers Gorge: Section CG-B

CG-B14*(189m)

Eregunda Sandstone Member

Wirrealpa Basin: Section BC-Q (Balcoracana Creek Section)

BC-Q4 (Om), BC-Q9 (15m), BC-Q11b (16m), BC-Q11c (16m).

Mount Frome : Section MF-A

MF-A19 (1m), MF-A20 (1m).

Green Siltstones (cont'd)

Billy Creek Formation (sensu stricto) - Lake Frome No. 1 borecore

LF1-1664+

Billy Creek Formation (sensu stricto) - Yalkalpo 2 borecore

YL2-459, YL2-442+, YL2-317+.

Green Shales

Warragee Member

Wirrealpa Basin: Section BC-B (Type Section)

BC-D4 (302m).

Wirrealpa Basin: Section BC-R

BC-R1 (23m), BC-R10 (197m), BC-T6 (222m).

Mount Scott Range: Section MS-B

MS-B6 (23m), MS-B7 (24m).

Billy Creek Formation (sensu stricto) - Lake Frome No. 2 borecore

LF2-2408.

Billy Creek Formation (sensu stricto) - Yalkalpo 2 borecore

YL2-472, YL2-447.

LITHOLOGICAL ASSOCIATION 2

Sandstones without Carbonate Grains or Appreciable Carbonate Cement

Coads Hill Member

Reaphook Hill: Section RH-A

RH-A6 (Unit B, 10m), RH-A7 (Unit B, 25m),

RH-A12 (Unit D, 70m).

Reaphook Hill: Section RH-F

RH-F6 (Unit B, 30m).

Sandstones without Carbonate Grains or Appreciable Carbonate Cement (cont'd)

Coads Hill Member (cont'd)

Reaphook Hill: Section RH-G

RH-G4 (Unit C, 31m), RH-G5 (Unit C, 34m), RH-G6 (Unit C, 58m), RH-G7 (Unit D, 65m), RH-G8 (Unit D, 72m), RH-G9 (Unit D, 72m).

Reaphook Hill: Section RH-J

RH-J6 (Unit F, 20m), RH-J7 (Unit F, 22m).

Reaphook Hill: Locality RH-K

RH-K1 (Unit B, 9m).

Calcarenitic Sandstones

Coads Hill Member

Reaphook Hill: Section RH-A

RH-A3 (Unit B, 0m), RH-A4a (Unit B, 0m), RH-A4b (Unit B, 0m), RH-A5 (Unit B, 2m), RH-A17 (Unit F, 90m).

Reaphook Hill: Section RH-B

RH-B3 (Unit B, 4m), RH-B5 (Unit C, 20m), RH-B15 (Unit F, 88m).

Reaphook Hill: Section RH-C (Type Section)

RH-C2 (Unit B, 6m), RH-C3 (Unit B, 9m), RH-C9 (Unit D, 59m), RH-C11 (Unit F, 77m), RH-C12a (Unit F, 78m), RH-C12b (Unit F, 78m).

Reaphook Hill: Section RH-F

RH-F3 (Unit B, 8m), RH-F4 (Unit B, 18m), RH-F5 (Unit B, 19m), RH-F7 (Unit F, 57m), RH-F8 (Unit F, 62m), RH-F9 (Unit F, 72m), RH-F10 (Unit F, 78m).

Reaphook Hill: Section RH-G

RH-G1 (Unit B, 18m), RH-G2 (Unit C, 25m), RH-G3 (Unit C, 25m).

Reaphook Hill: Section RH-J

RH-J1 (Unit B, 0m), RH-J2 (Unit B, 2m), RH-J3 (Unit B, 3m), RH-J5 (Unit F, 15m), RH-J9 (Unit F, 27m), RH-J10 (Unit F, 32m).

Calcarenitic Sandstones (cont'd)

Coads Hill Member (cont'd)

Reaphook Hill: Locality RH-K

RH-K3 (Unit B, 10m), RH-K4 (Unit B, 15m).

Calcarenitic Siltstones

Coads Hill Member

Reaphook Hill: Section RH-A

RH-A18 (Unit F, 103m)

Immature (slightly clayey) Sandstone

Coads Hill Member

Reaphook Hill: Section RH-A

RH-A13 (Unit D, 70m), RH-A16 (Unit E, 81m).

Reaphook Hill: Section RH-G

RH-G10 (Unit F, 79m), RH-G11 (Unit F, 81m), RH-G13 (Unit F, 100m), RH-G14 (Unit F, 101m).

Very Immature (clayey) Sandstone

Coads Hill Member

Reaphook Hill: Section RH-B

RH-B6 (Unit C, 25m)

Reaphook Hill: Section RH-C (Type Section)

RH-C4 (Unit C, 43m), RH-C5 (Unit C, 43m), RH-C6 (Unit C, 45m), RH-C7 (Unit C, 47m), RH-C8 (Unit C, 48m).

Reaphook Hill: Section RH-G (Type Section)

RH-G12 (Unit F, 98m).

LITHOLOGICAL ASSOCIATION 3

Carbonate Mudstones

Warragee Member

Wirrealpa Basin: Section BC-B (Type Section)

BC-C14^{s} (275m), BC-C15^{s} (298m), BC-C16^{d} (298m), BC-C17^{d} (299m), BC-D1^{d} (300m).

Wirrealpa Basin: Section BC-R

BC-T8a^{s} (236m), BC-T8b^{s} (236m).

Mount Frome: Section MF-A

MF-A7^{s} (95m)

Coads Hill Member

Reaphook Hill: Section RH-A

RH-A24 (Unit H, 190m)

Reaphook Hill: Section RH-C

RH-C18^{ss} (Unit H, 186m), RH-C20^{ss} (Unit H, 189m), RH-C21^{ss} (Unit H, 191m).

Calcisiltites

Warragee Member

Mount Frome: Section MF-A

MF-A5 (6m), MF-A6 (8m).

Coads Hill Member

Reaphook Hill: Section RH-A

RH-A14 (Unit D, 66m)

Reaphook Hill: Section RH-B

RH-B16 (Unit F, 85m)

Reaphook Hill: Section RH-F

RH-F12 (Unit G, 110m).

Calcisiltites (cont'd)

Erudina Siltstone Member

Reaphook Hill: Section RH-A

RH-A26 (Unit A, 21m)

Wackestones

Warragee Member

Wirrealpa Basin: Section BC-B (Type Section)

BC-C2 (13m), BC-C11 (251m).

Coads Hill Member

Reaphook Hill: Section RH-A

RH-A15^{vs} (Unit E, 80m), RH-A22^{vs} (Unit G, 158m), RH-A23^{vs} (Unit G, 187m).

Reaphook Hill: Section RH-B

RH-B8^{vs} (Unit C, 49m), RH-B9^{vs} (Unit E, 52m), RH-B10^{vs} (Unit D, 56m).

Reaphook Hill: Section RH-C

RH-C10^{vs} (Unit E, 67m), RH-C14^{d} (Unit G, 150m), RH-C15^{d} (Unit H, 175m).

Reaphook Hill: Section RH-F

RH-F14^{vs} (Unit G, 133m), RH-F16^{vs} (Unit H, 144m).

Erudina Siltstone Member

Reaphook Hill: Section RH-C

RH-C23^{d} (Unit A, 8m), RH-C26a^{d} (Unit A, 38m), RH-C26b^{d} (Unit A, 38m).

Packestones

Warragee Member

Chambers Gorge : Section CG-B

CG-B2A (23m).

Coads Hill Member

Reaphook Hill: Section RH-A

RH-A25 (Unit H, 196m).

Grainstones

Coads Hill Member

Reaphook Hill: Section RH-C (Type Section)

RH-C22 (Unit J, 191m).

Reaphook Hill: Section RH-F

RH-F19 (Unit J, 150m).

Boundstones

Warragee Member

Wirrealpa Basin: Section BC-B (Type Section)

BC-C3^{ds} (27m), BC-C4^{ds} (28m), BC-C5^{ds} (32m), BC-C6^{ds} (52m),

BC-C9 (247m), BC-C10 (251m).

Coads Hill Member

Reaphook Hill: Section RH-C (Type Section)

RH-C19a^{ds} (Unit H, 188m), RH-C19b^{ds} (Unit H, 188m).

Reaphook Hill: Section RH-F

Om is the base of the Coads Hill Member.

RH-F15^{ds} (Unit H, 142m), RH-F17 (Unit H, 148m).

Billy Creek Formation (sensu stricto) - Lake Frome No. 1 borecore

LF1-1672^{ds}

LITHOLOGICAL ASSOCIATION 4

Crystal Tuffs

Warragee Member

Wirrealpa Basin: Section BC-B (Type Section)

BC-C8 (147m), BC-D7 (306m), BC-D8 (306m).

Wirrealpa Basin: Section BC-R

BC-R2 (22m), BC-R8 (152m), BC-T1 (199m), BC-T2 (200m),

BC-T3 (200m).

Crystal Tuffs (cont'd)

Nildottie Siltstone Member

Mount Frome: Section MF-A

MF-A11 (21 m).

Coads Hill Member

Reaphook Hill: Section RH-A

RH-A20 (Unit G, 143m), RH-A21 (Unit G, 157m).

Reaphook Hill: Section RH-C

RH-C13 (Unit G, 149m), RH-C16 (Unit H, 177m).

Erudina Siltstone Member

Reaphook Hill: Section RH-C (Type Section)

RH-C30 (Unit B, 67m), RH-C40 (Unit D, 252m).

Billy Creek Formation (sensu stricto) - Lake Frome No. 1 borecore

LF1-2561+

Billy Creek Formation (sensu stricto) - Yalkalpo 2 borecore

YL2-524, YL2-443, YL2-436.

Table C1. Modal Analyses, Lithological Association 1 Red Sandstones

Modal Component	BC-K1[+] (E.Sst.Mbr.) Pt. Count %	BC-K2[+] (E.Sst.Mbr.) Pt. Count %	BC-K3[+] (E.Sst.Mbr.) Pt. Count %	BC-K6[+] (E.Sst.Mbr.) Pt. Count %	BC-K7[+] (E.Sst.Mbr.) Pt. Count %
Quartz	39.8	39.8	42.8	53.4	46.0
Feldspars: Orthoclase	18.2	19.2	20.6	26.0	19.8
Feldspars: Microcline	0.2	0.6	0.4	0.2	0.2
Feldspars: Perthite	-	0.8	0.4	-	0.6
Feldspars: Plagioclase	1.0	4.0	3.0	2.6	4.6
Muscovite	1.8	2.8	1.8	2.0	1.0
Biotite	1.0	1.2	0.8	1.0	1.2
Heavy Minerals	0.8	0.8	3.2	2.0	2.2
Rock fragments: Sedimentary	0.8	1.0	0.2	0.8	0.8
Rock fragments: Igneous	-	-	-	-	-
Rock fragments: Metamorphic	0.6	0.6	0.4	-	0.4
Rock fragments: Indeterminate	1.0	0.8	0.4	0.2	0.2
Overgrowths	9.2	8.2	10.6	5.8	8.6
Iron cement	12.4	15.4	10.0	5.2	11.6
Carbonate cement & matrix	-	-	-	-	-
Indeterminate matrix	13.2	4.8	5.4	0.8	2.8
Q: F: R	65 : 31 : 4	60 : 37 : 4	63 : 36 : 1	64 : 35 : 1	63 : 35 : 2
Clan name	arkose	arkose	arkose	arkose	arkose

[+]500 point counts.

Table C1. (cont'd) Modal Analyses, Lithological Association 1, Red Sandstones

Modal Component		BC-K8+ (E.Sst.Mbr.) Pt. Count %	BC-K9+ (E.Sst.Mbr.) Pt. Count %	BC-K10+ (E.Sst.Mbr.) Pt. Count %	BC-K14+ (E.Sst.Mbr.) Pt. Count %	BC-K15+ (E.Sst.Mbr.) Pt. Count %
Quartz		47.0	35.8	37.0	42.4	38.6
Feldspars	Orthoclase	22.2	30.8	27.8	21.4	26.6
	Microcline	-	0.2	0.6	0.2	0.2
	Perthite	-	1.0	0.8	-	0.4
	Plagioclase	4.2	3.0	3.4	2.0	3.2
Muscovite		2.2	1.0	1.8	0.2	1.8
Biotite		2.8	0.4	0.4	-	1.0
Heavy Minerals		2.2	-	1.6	2.6	1.4
Rock fragments	Sedimentary	1.0	0.2	0.6	2.2	1.8
	Igneous	-	-	-	-	-
	Metamorphic	0.4	0.4	1.0	0.4	0.8
	Indeterminate	0.4	0.4	0.6	0.6	0.4
Overgrowths		5.2	11.4	5.8	11.4	10.6
Iron cement		8.4	13.6	14.8	10.6	11.0
Carbonate cement & matrix		-	-	-	-	-
Indeterminate matrix		4.0	1.8	3.8	6.0	2.2
Q : F : R		63 : 29 : 2	50 : 49 : 1	52 : 45 : 3	61 : 34 : 5	54 : 42 : 4
Clan name		arkose	arkose	arkose	arkose	arkose

+500 point counts.

Table C1. (cont'd) Modal Analyses, Lithological Association 1, Red Sandstones

Modal Component		BC-K16+ (E.Sst.Mbr.) Pt. Count %	BC-K17+ (E.Sst.Mbr.) Pt. Count %	BR-A23* (E.Sst.Mbr.) Pt. Count %	BR-A27* (E.Sst.Mbr.) Pt. Count %	MS-B27* (E.Sst.Mbr.) Pt. Count %
Quartz		47.2	42.0	35.2	40.0	44.0
Feldspars	Orthoclase	24.0	32.2	23.2	16.0	8.0
	Microcline	0.2	0.4	-	-	-
	Perthite	-	-	0.4	0.8	-
	Plagioclase	4.6	1.4	5.6	1.6	0.8
Muscovite		2.0	1.6	1.2	1.6	3.6
Biotite		4.0	1.2	0.8	1.6	1.2
Heavy Minerals		0.8	0.2	-	-	0.8
Rock fragments	Sedimentary	0.2	0.2	-	-	-
	Igneous	-	-	-	-	-
	Metamorphic	-	0.8	0.4	1.2	0.4
	Indeterminate	0.4	0.6	-	0.4	-
Overgrowths		5.8	8.6	17.2	10.0	12.0
Iron cement		10.0	7.6	13.6	21.6	8.0
Carbonate cement & matrix		-	-	-	-	5.2
Indeterminate matrix		0.8	3.2	2.4	5.2	16.0
Q : F : R		62 : 38 : 1	54 : 44 : 2	54 : 45 : 1	67 : 31 : 3	83 : 17 : 1
Clan name		arkose	arkose	arkose	arkose	subarkose

+500 point counts.
*250 point counts.

Table C1 (cont'd) Modal Analyses, Lithological Association 1, Red Sandstones

Modal Component		MS-B28* (E.Sst.Mbr.) Pt. Count %	MF-A27* (E.Sst.Mbr.) Pt. Count %	MF-A30* (E.Sst.Mbr.) Pt. Count %	RH-C33* (E.Sst.Mbr.) Pt. Count %	YL2-512* (B.Ck.Fm.) Pt. Count %
Quartz		49.6	40.8	40.4	42.8	43.2
Feldspars	Orthoclase	13.2	9.2	15.6	6.0	20.0
	Microcline	-	-	-	-	-
	Perthite	-	-	0.4	0.8	1.6
	Plagioclase	1.2	3.6	3.6	3.2	4.0
Muscovite		1.6	2.4	3.0	4.0	0.8
Biotite		-	1.2	2.0	3.2	0.8
Heavy Minerals		2.8	0.4	-	-	-
Rock fragments	Sedimentary	-	1.6	-	-	4.8
	Igneous	-	-	-	-	-
	Metamorphic	-	-	-	-	2.4
	Indeterminate	-	-	-	0.8	2.4
Overgrowths		14.4	18.4	20.0	16.0	10.0
Iron cement		9.6	14.4	6.8	20.4	6.0
Carbonate cement & matrix		4.4	0.8	4.0	-	-
Indeterminate matrix		3.2	7.2	4.4	2.8	4.0
Q : F : R		78 : 22 : 0	74 : 23 : 3	67 : 33 : 0	80 : 19 : 1	55 : 33 : 12
Clan name		subarkose	arkose	arkose	subarkose	arkose

*250 point counts.

Table C2. Modal Analyses, Lithological Association 1, Green Sandstones

Modal Component		BC-K11[+] (E.Sst.Mbr.) Pt. Count %	BC-K13[+] (E.Sst.Mbr.) Pt. Count %	MF-A20* (E.Sst.Mbr.) Pt. Count %	MF-A23* (E.Sst.Mbr.) Pt. Count %	YL2-499* (B.Ck.Fm) Pt. Count %
Quartz		41.6	41.4	46.8	56.8	43.2
Feldspars	Orthoclase	20.6	27.8	8.4	7.2	16.0
	Microcline	-	-	-	-	-
	Perthite	-	-	0.8	-	0.4
	Plagioclase	1.8	3.0	0.4	3.2	4.4
Muscovite		3.0	2.4	8.4	2.8	0.8
Biotite		4.0	3.6	6.2	1.2	-
Heavy Minerals		1.8	1.6	-	1.6	-
Rock fragments	Sedimentary	1.0	0.8	0.8	-	12.8
	Igneous	-	-	-	-	-
	Metamorphic	0.2	-	-	-	-
	Indeterminate	0.6	0.2	-	-	3.2
Overgrowths		16.6	16.4	19.6	10.8	5.6
Iron cement		0.8	0.4	1.6	3.6	0.8
Carbonate cement & matrix		-	-	1.2	0.8	11.2
Indeterminate matrix		8.0	2.4	5.6	11.2	1.6
Q : F : R		63 : 34 : 3	57 : 42 : 1	82 : 17 : 1	85 : 15 : 0	54 : 26 : 20
Clan name		arkose	arkose	subarkose	subarkose	lithic arkose

[+]500 point counts.
*250 point counts.

Table C3. Modal Analyses, Lithological Association 2. Sandstones without appreciable carbonate

Model Component		RH-A7* (Coads Hill Mbr.) Pt. Count %	RH-A12* (Coads Hill Mbr.) Pt. Count %	RH-G5* (Coads Hill Mbr.) Pt. Count %	RH-G8* (Coads Hill Mbr.) Pt. Count %	RH-J7* (Coads Hill Mbr.) Pt. Count %
Quartz		73.2	69.6	76.0	73.6	56.8
Feldspars	Orthoclase	3.6	2.4	0.4	7.2	4.8
Feldspars	Microcline	2.8	2.0	0.4	1.6	1.6
Feldspars	Perthite	2.4	-	-	0.8	1.6
Feldspars	Plagioclase	2.8	2.8	0.8	0.8	2.4
Muscovite		-	-	-	-	-
Biotite		-	-	-	-	-
Heavy Minerals		-	0.8	0.8	-	0.8
Rock fragments	Sedimentary	-	0.8	-	2.4	-
Rock fragments	Igneous	-	-	-	-	-
Rock fragments	Metamorphic	-	-	-	-	-
Rock fragments	Indeterminate	-	-	-	-	-
Overgrowths		12.0	13.6	20.4	12.8	15.2
Iron cement		-	-	-	-	-
Carbonate cement & matrix		-	-	-	-	12.8
Indeterminate matrix		3.2	8.0	1.2	0.8	4.0
Q : F : R		86 : 14 : 0	90 : 9 : 1	98 : 2 : 0	85 : 12 : 3	84 : 15 : 1
Clan name		subarkose	subarkose	quartzarenite	subarkose	subarkose

*250 point counts.

Table C.4. Modal Analyses, Lithological Association 2. Calcarenitic Sandstones

Modal Component		BC-W21* (Warragee Mbr.) Pt. Count %	BC-W22* (Warragee Mbr.) Pt. Count %	BC-W24* (Warragee Mbr.) Pt. Count %	BC-X8* (Warragee Mbr.) Pt. Count %	BC-X9* (Warragee Mbr.) Pt. Count %
Quartz		66.8	67.6	69.6	58.4	66.4
Feldspars	Orthoclase	-	0.4	0.4	0.8	0.8
	Microcline	0.8	1.6	1.6	1.6	1.2
	Perthite	0.4	-	-	-	-
	Plagioclase	0.4	0.4	-	0.8	2.0
Muscovite		-	-	0.4	-	-
Biotite		-	-	-	-	-
Heavy Minerals		-	0.8	0.8	0.4	-
Rock fragments	Sedimentary	3.2	2.8	1.2	0.4	2.8
	Igneous	-	-	-	-	-
	Metamorphic	-	-	-	-	0.4
	Indeterminate	-	-	-	-	-
Overgrowths		13.6	7.2	11.6	0.8	13.2
Iron cement		-	-	-	-	-
Carbonate matrix & cement		14.4	18.4	14.4	37.4	12.8
Indeterminate matrix		0.4	0.8	-	0.8	0.4
Q : F : R		93 : 2 : 4	93 : 3 : 4	96 : 3 : 2	94 : 5 : 1	90 : 5 : 4
Clan name		sublitharenite	sublitharenite	quartzarenite	subarkose	subarkose

*250 point counts.

Table C.4. (cont'd) Modal Analyses, Lithological Association 2. Calcarenitic Sandstones

	Modal Component	RH-C3* (Coads Hill Mbr.) Pt. Count %	RH-C9* (Coads Hill Mbr.) Pt. Count %	RH-C11* (Coads Hill Mbr.) Pt. Count %	RH-F4* (Coads Hill Mbr.) Pt. Count %	RH-F9* (Coads Hill Mbr.) Pt. Count %
	Quartz	63.2	67.2	54.4	63.6	54.8
Feldspars	Orthoclase	1.2	1.2	0.8	5.2	2.8
Feldspars	Microcline	2.0	-	-	0.8	0.8
Feldspars	Perthite	-	0.8	-	-	-
Feldspars	Plagioclase	-	0.4	0.8	2.4	0.8
	Muscovite	-	-	-	-	-
	Biotite	-	-	-	-	-
	Heavy Minerals	-	0.8	0.4	0.8	0.4
Rock fragments	Sedimentary	2.4	4.8	11.6	2.0	6.8
Rock fragments	Igneous	-	-	-	-	-
Rock fragments	Metamorphic	-	-	-	-	-
Rock fragments	Indeterminate	-	-	-	-	-
	Overgrowths	14.0	7.2	3.6	9.2	9.6
	Iron cement	-	-	-	-	-
	Carbonate cement & matrix	16.4	16.4	26.0	11.6	16.4
	Indeterminate matrix	0.8	1.2	2.4	4.4	7.6
	Q : F : R	92 : 5 : 3	90 : 3 : 6	80 : 2 : 17	86 : 11 : 3	83 : 7 : 10
	Clan name	subarkose	sublitharenite	sublitharenite	subarkose	sublitharenite

*250 point counts.

Table C.5. Modal Analyses, Lithological Association 2. Slightly immagure (clayey) sandstones

Modal Component		RH-A8* (Coads Hill Mbr.) Pt. Count %	RH-A16* (Coads Hill Mbr.) Pt. Count %	RH-G11* (Coads Hill Mbr.) Pt. Count %
Quartz		62.8	56.0	64.0
Feldspars	Orthoclase	1.6	0.8	1.6
	Microcline	1.2	2.0	0.8
	Perthite	0.8	0.4	-
	Plagioclase	2.4	0.8	-
Muscovite		-	-	-
Biotite		-	-	-
Heavy Minerals		0.8	0.8	0.8
Rock fragments	Sedimentary	-	1.6	-
	Igneous	-	-	-
	Metamorphic	-	-	-
	Indeterminate	-	-	-
Overgrowths		8.8	7.2	2.0
Iron cement		8.0	-	-
Carbonate cement & matrix		-	-	-
Clay & silt matrix		13.6	30.4	30.8
Q : F : R		91 : 9 : 0	91 : 6 : 3	96 : 4 : 0
Clan name		subarkose	subarkose	quartzarenite

*250 point counts.

Table C.6. Modal Analyses, Lithological Association 2. Immature (very clayey) sandstones

Modal Component		RH-C4* (Coads Hill Mbr.) Pt. Count %	RH-C6* (Coads Hill Mbr.) Pt. Count %	RH-C8* (Coads Hill Mbr.) Pt. Count %
Quartz		40.8	40.4	52.8
Feldspars	Orthoclase	0.8	0.8	1.6
	Microcline	2.4	-	0.8
	Perthite	0.8	0.8	-
	Plagioclase	-	1.2	-
Muscovite		-	-	0.4
Biotite		-	-	-
Heavy Minerals		0.4	-	-
Rock fragments	Sedimentary	9.2	4.4	0.4
	Igneous	-	-	-
	Metamorphic	-	-	-
	Indeterminate	-	-	-
Overgrowths		2.0	-	7.2
Iron cement		-	-	-
Carbonate cement & matrix		4.4	1.6	5.6
Indeterminate matrix		39.2	50.8	31.2
Q : F : R		76 : 7 : 17	84 : 6 : 9	95 : 4 : 1
Clan name		sublitharenite	sublitharenite	quartzarenite

*250 point counts.

APPENDIX D

Petrographic Data,

Kangaroo Island

Table Dl. Modal Analyses, Conglomerate Facies Association Sandstones

Modal Component		KI-BR-5* White Pt. Cgl. Pt. Count %	KI-WP-1* White Pt. Cgl. Pt. Count %	KI-Fl-1* White Pt. Cgl. Pt. Count %	KI-Fl-2* White Pt. Cgl. Pt. Count %	KI-FL-3* White Pt. Cgl. Pt. Count %
Quartz		29.2	37.6	52.0	46.8	42.8
Feldspars	Orthoclase	1.6	3.2	3.2	1.6	3.2
	Microcline	0.8	0.8	3.2	0.8	1.6
	Perthite	-	-	-	2.0	1.2
	Plagioclase	-	2.8	-	1.6	0.8
Muscovite		1.6	-	-	-	0.8
Biotite		0.4	-	-	-	-
Heavy Minerals		7.2	1.2	1.2	-	-
Rock fragments	Sedimentary	20.0	16.8	10.0	14.4	15.2
	Igneous	-	-	-	-	-
	Metamorphic	-	-	-	-	-
	Indeterminate	-	-	-	-	-
Overgrowths		-	4.4	1.6	2.0	2.8
Iron cement		1.2	1.2	-	-	-
Carbonate cement & matrix		36.4	29.6	28.8	30.8	31.6
Indeterminate matrix		1.6	2.4	-	-	-
Q: F: R		57 : 5 : 39	61 : 11 : 27	76 : 9 : 15	70 : 9 : 21	66 : 10 : 23
Clan name		sedlitharenite	feldspathic sedlitharenite	sublitharenite	feldspathic sedlitharenite	feldspathic sedlitharenite

*250 point counts.

Table D1. (cont'd) Modal Analyses, Conglomerate Facies Association Sandstones

Modal Component		KI-FL-5* Boxing Bay Fm. Pt. Count %	KI-PM-1* Boxing Bay Fm. Pt. Count %	KI-PM-2* Boxing Bay Fm. Pt. Count %	KI-CE-1* Boxing Bay Fm. Pt. Count %	KI-CE-2* Boxing Bay Fm. Pt. Count %
Quartz		47.6	34.2	46.4	32.8	41.8
Feldspars	Orthoclase	0.8	1.2	7.2	4.0	10.8
	Microcline	2.4	1.2	4.4	1.6	-
	Perthite	0.8	-	0.4	2.0	0.8
	Plagioclase	0.4	1.6	1.6	0.4	2.4
Muscovite		-	0.4	0.8	1.6	1.2
Biotite		-	0.8	-	0.4	-
Heavy Minerals		-	0.8	1.6	5.6	2.4
Rock fragments	Sedimentary	4.0	32.0	6.8	16.8	2.8
	Igneous	-	-	0.4	-	-
	Metamorphic	-	1.6	0.8	-	-
	Indeterminate	-	-	-	-	-
Overgrowths		6.8	2.4	10.4	6.8	4.8
Iron cement		-	0.8	-	-	2.8
Carbonate cement & matrix		29.2	17.6	14.0	26.4	22.8
Indeterminate matrix		-	4.4	5.2	1.6	8.0
Q : F : R		85 : 8 : 7	48 : 6 : 47	68 : 20 : 12	57 : 14 : 29	71 : 24 : 5
Clan name		subarkose	sedlitharenite	lithic arkose	feldspathic litharenite	arkose

*250 point counts.

Table D2. Modal Analyses, Sandstone Facies Association Sandstones

Modal Component		KI-BR-1* White Pt. Cgl. Pt. Count %	KI-WP-4* White Pt. Cgl. Pt. Count %	KI-FL-4* White Pt. Cgl. Pt. Count %	KI-FL-7* White Pt. Cgl. Pt. Count %	KI-FL-8* White Pt. Cgl. Pt. Count %
Quartz		41.6	38.4	55.2	35.6	38.8
Feldspars	Orthoclase	8.0	14.4	11.2	11.6	14.0
	Microcline	2.0	-	1.6	0.4	-
	Perthite	1.2	1.2	1.6	0.8	0.8
	Plagioclase	4.8	3.6	7.6	4.0	3.2
Muscovite		3.2	1.2	0.8	3.6	4.0
Biotite		-	0.8	-	0.8	-
Heavy Minerals		1.2	1.2	0.4	4.0	2.0
Rock fragments	Sedimentary	-	-	0.8	-	-
	Igneous	-	-	-	-	-
	Metamorphic	-	-	-	-	-
	Indeterminate	0.4	-	-	-	-
Overgrowths		8.0	4.0	8.4	6.0	6.0
Iron cement		0.8	29.2	4.6	7.6	14.4
Carbonate cement & matrix		19.6	1.6	-	-	-
Indeterminate matrix		9.2	4.4	7.6	25.6	16.8
Q : F : R		72 : 28 : 0	67 : 33 : 0	71 : 28 : 1	68 : 32 : 0	68 : 32 : 0
Clan name		arkose	arkose	arkose	arkose	arkose

*250 point counts.

Table D2. (cont'd) Modal Analyses, Sandstone Facies Association Sandstones

Modal Component		KI-FL-6* Boxing Bay Fm. Pt. Count %	KI-PM-5* Boxing Bay Fm. Pt. Count %	KI-WP-14* Boxing Bay Fm. Pt. Count %	KI-WP-16* Boxing Bay Fm. Pt. Count %	KI-WP-17* Boxing Bay Fm. Pt. Count %
Quartz		41.2	43.2	42.4	34.8	41.6
Feldspars	Orthoclase	21.2	21.6	21.6	22.4	23.2
	Microcline	0.4	0.8	2.4	1.6	0.8
	Perthite	1.2	0.8	-	-	-
	Plagioclase	7.2	4.6	7.2	10.0	6.8
Muscovite		4.8	0.4	2.4	1.6	2.0
Biotite		2.0	0.8	1.2	1.6	-
Heavy Minerals		3.6	1.2	-	-	0.8
Rock fragments	Sedimentary	-	-	-	-	-
	Igneous	-	-	-	-	-
	Metamorphic	-	0.8	-	-	-
	Indeterminate	-	-	-	-	-
Overgrowths		13.2	14.0	18.0	21.6	11.6
Iron cement		2.0	7.6	3.6	2.8	7.4
Carbonate cement & matrix		-	-	-	-	-
Indeterminate matrix		3.2	4.0	1.2	3.6	5.6
Q : F : R		58 : 42 : 0	60 : 39 : 1	58 : 42 : 0	51 : 49 : 0	57 : 43 : 0
Clan name		feldsarenite	feldsarenite	feldsarenite	feldsarenite	feldsarenite

*250 point counts.

Plate 130: Lower, silty portion of the Carrickalinga Head Formation as exposed on the northeast coast of Kangaroo Island, approximately 2km east of Hummocky Point. This interval corresponds with the Blowhole Creek Siltstone Member of the formation, as defined by Daily and Milnes (1971) on Fleurieu Peninsula.

Plate 131: General view of the northeast coast Kangaroo Island outcrops, looking west, with Hummocky Beach in the foreground. The first headland comprises the upper portion of the Carrickalinga Head Formation (Campana Creek Member equivalent), and the succeeding headland comprises the conformably overlying Stokes Bay Sandstone.

Plate 132: Major sandy interval in the upper portion of the Carrickalinga Head Formation, with channels and multiple intersecting sets of trough cross-stratification. The sandstone content of the sequence increases markedly from this point onwards, and indicates a well-defined transition into the conformably overlying Stokes Bay Sandstone. Channel is approximately 1.2m deep. Location: approximately 1km west of Hummocky Beach.

Plate 133: Lenticular bedding (middle of photo) and sand-streaked green shales. Pen: 14cm long. Location: middle portion of the Carrickalinga Head Formation at Hummocky Beach.

Plate 134: Plan view of large burrows. Lenscap: 54mm diameter. Location: Blowhole Creek Siltstone Member equivalent in the Carrickalinga Head Formation, 2km east of Hummocky Point.

Plate 135: Sand infilled retrusive burrows indicative of rapid sedimentation. Lenscap: 54mm diameter. Location: Blowhole Creek Siltstone Member equivalent in the Carrickalinga Head Formation, 2km east of Hummocky Point.

Plate 136: Cross section of curved, sand-infilled burrow in poorly developed lenticular-bedded facies. Scale: 29mm diameter. Location: middle portion of the Carrickalinga Head Formation on the western leadland of Hummocky Beach.

Plate 137: Sub-horizontal worm burrows in lenticular bedded facies. Lenscap: 54mm diameter. Location: middle portion of the Carrickalinga Head Formation west of Hummocky Beach.

Plate 138: Plan view of sinuous crawling tracks attributed to trilobites. Location: middle portion of the Carrickalinga Head Formation west of Hummocky Point.

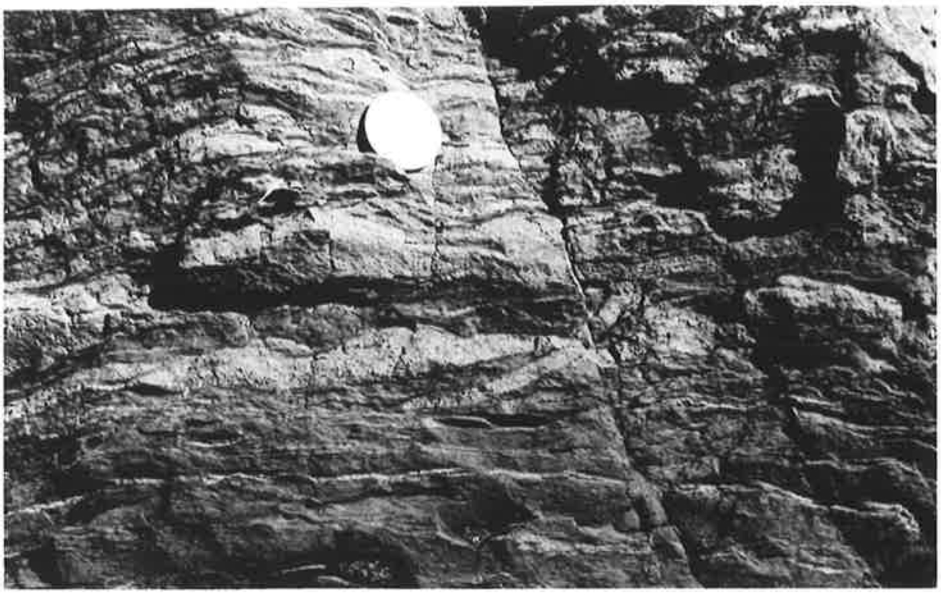
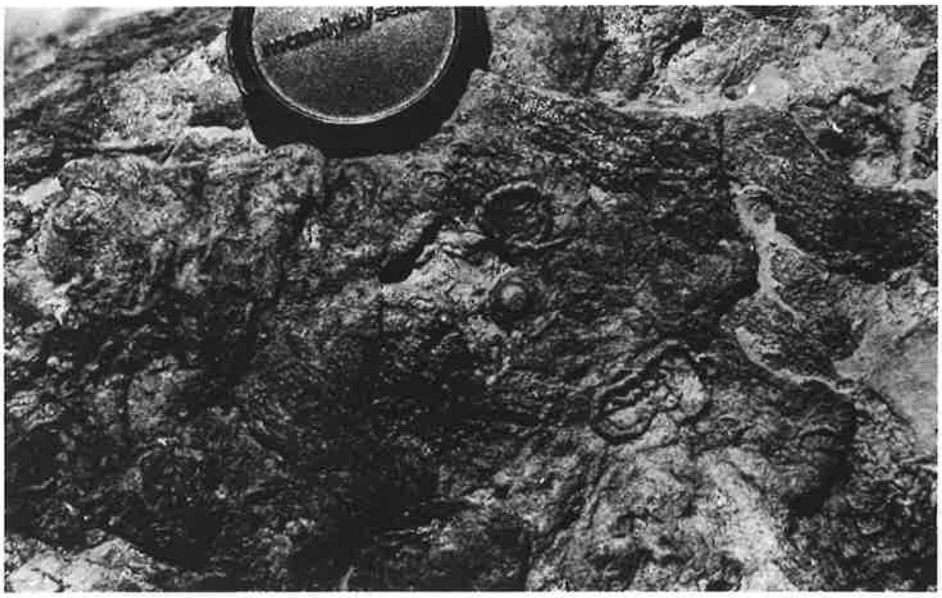




Plate 139: Cross-section of linsen-bedded facies, comprising reddish brown rippled sandstone lenses intercalated with greyish green mudstone. Outcrop height is approximately 0.8m. Location: middle portion of the Carrickalinga Head Formation west of Hummocky Beach.

Plate 140: General view of predominantly linsen-bedded facies showing abundance of lingnoid current ripples preserved on bedding plane surfaces. Outcrop width is approximately 5.5m. Location: middle portion of the Carrickalinga Head Formation west of Hummocky Beach.

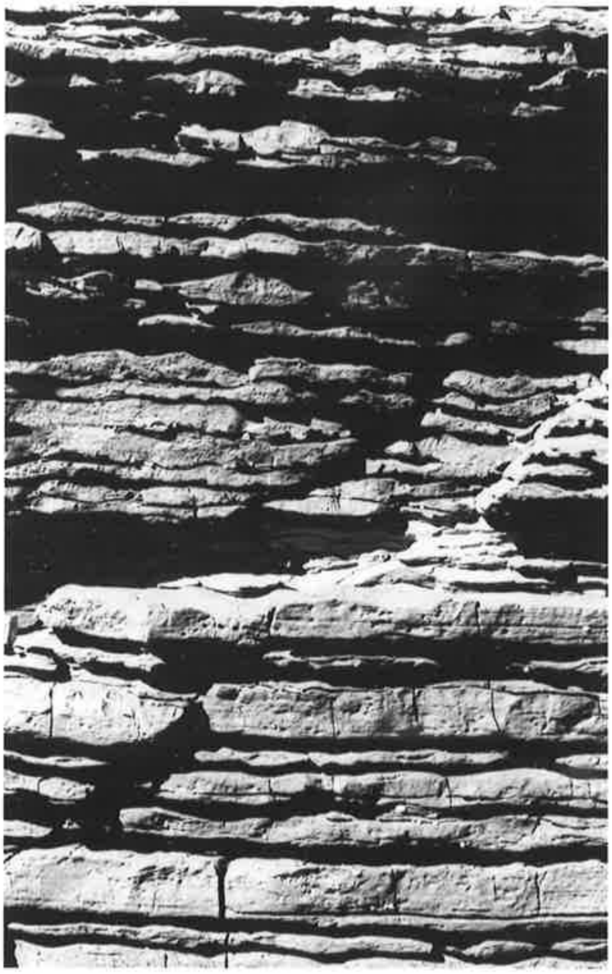
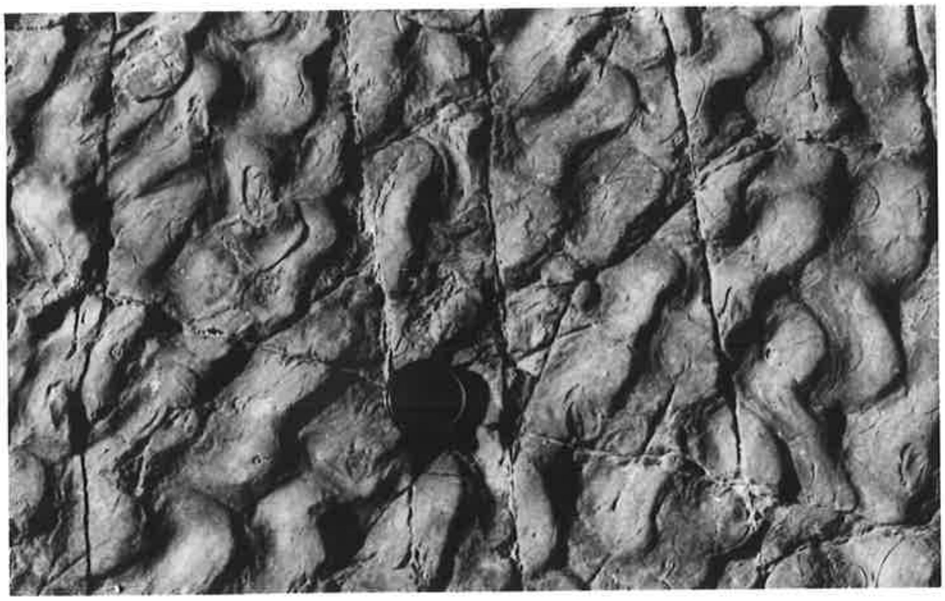
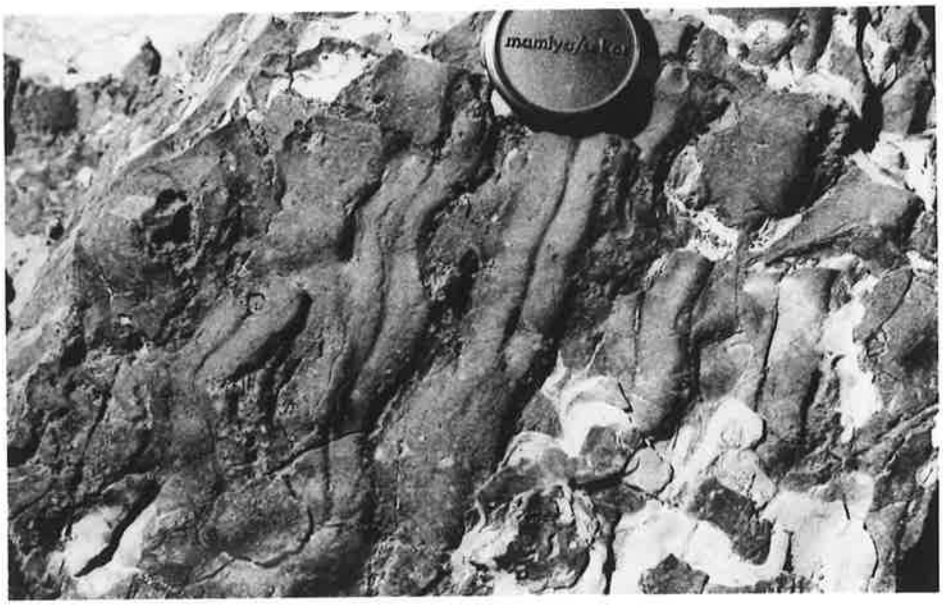


Plate 141: Lingnoid current ripples in the linsen bedded facies. Current from left to right. Lenscap: 54mm diameter. Location: middle portion of the Carrickalinga Head Formation west of Hummocky Beach.

Plate 142: Double crested ripples indicative of falling water level during sedimentation. Lenscap: 54mm diameter. Location: middle portion of the Carrickalinga Head Formation west of Hummocky Beach.

Plate 143: Cross-section of continuously rippled sandstone facies. Cross-laminae have curved basal surfaces and foresets dip in a variety of orientations. Commonly, the internal orientation of laminae bears no resemblance to the external ripple form. These criteria are considered to provide good evidence of wave-generation. Lenscap: 54mm diameter. Location: upper portion of the Carrickalinga Head Formation west of Hummocky Point.

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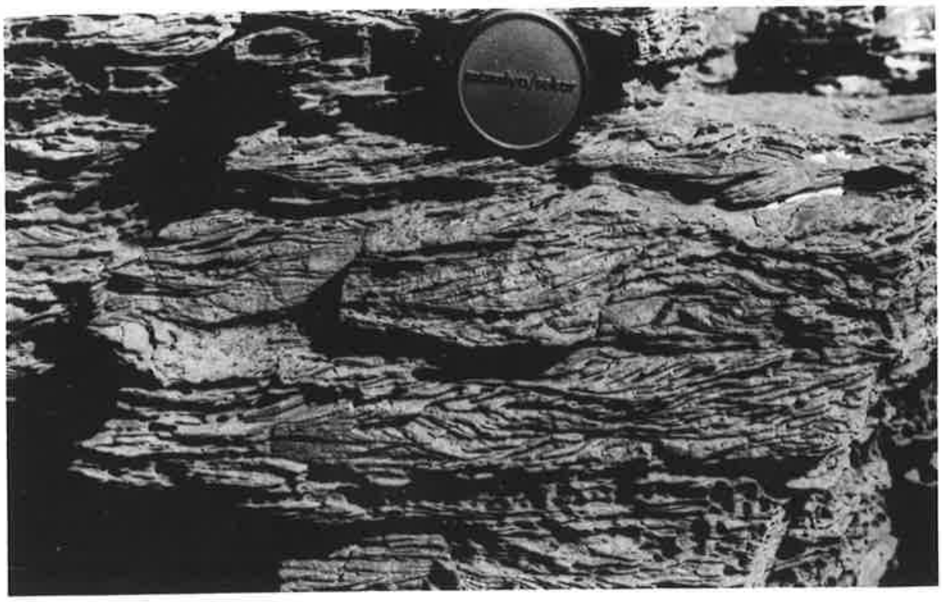


Plate 144: Trough cross-stratified reddish brown sandstone, formed by the migration of megaripples on the seafloor. Hammer: 31cm long. Location: upper portion of the Carrickalinga Head Formation west of Hummocky Point.

Plate 145: Trough cross-stratified reddish brown sandstone. Hammer: 31cm long. Location: upper portion of the Carrickalinga Head Formation west of Hummocky Point.

Plate 146: Trough cross-stratified and minor planar-tabular cross-stratified calcareous sandstone, containing abundant carbonate ooliths. Hammer: 29cm long. Location: middle portion of the Carrickalinga Head Formation west of Hummocky Point.

Plate 147: General view of the lower portion of Stokes Bay Sandstone near Stokes Bay. Reddish-brown medium-grained arkoses in the foreground are trough cross-stratified.

Plate 148: Contorted bedding in medium-grained, red-brown arkose. Hammer: 31cm long. Location: upper portion of the Stokes Bay Sandstone east of Dashwood Bay (Fig. 13-2).

Plate 149: Contorted bedding in medium-grained reddish brown arkose. Hammer: 31cm long. Location: upper portion of the Stokes Bay Sandstone east of Dashwood Bay.

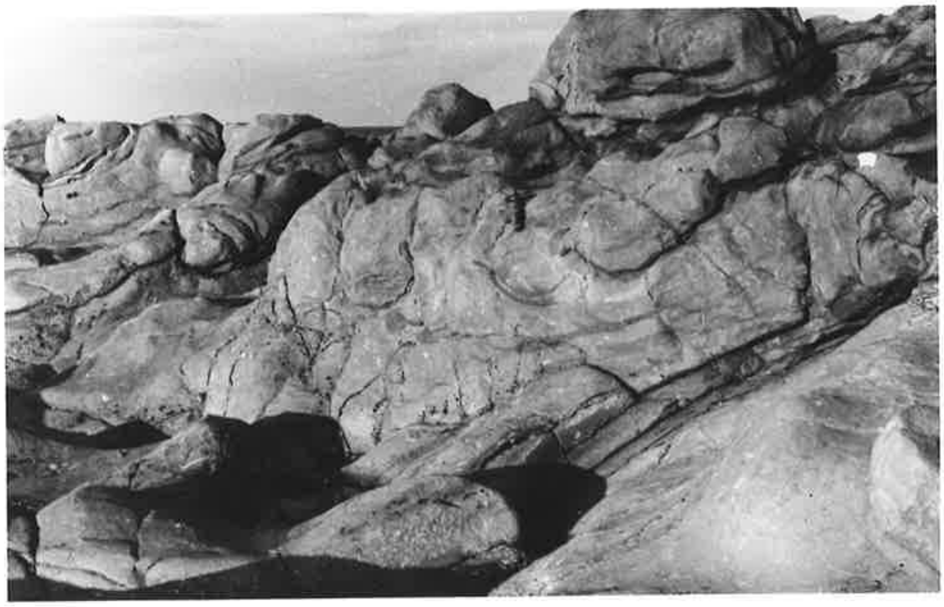




Plate 150: Large polygonal sand-infilled desiccation cracks in red shale. Hammer length: 31cm. Location: lower portion of the Smith Bay Shale immediately to the east of Smith Bay (Fig. 13-2).

Plate 151: Large exhumed polygonal desiccation crack and in-fillings in red shale. Hammer length: 31cm. Location: lower portion of the Smith Bay Shale immediately to the east of Smith Bay.

Plate 152: Sand-infilled worm burrows on the sole of a thin sandstone bed. Lenscap: 54mm diameter. Location: upper portion of the Smith Bay Shale east of Bald Rock.

Plate 153: Contorted, reddish brown, medium-grained arkose. Hammer: 31cm long. Location: basal portion of the Smith Bay Shale east of Smith Bay.

Plate 154: Small load structures at the base of evenly bedded reddish brown arkose overlying greyish red shale. Location: lower portion of the Smith Bay Shale on the eastern side of Smith Bay.

Plate 155: Cross-stratified, medium-grained, pale brown oolitic grainstone (light coloured unit in cliff), approximately 1.5m in thickness. Location: uppermost portion of the Smith Bay Shale east of Bald Rock.

Plate 156: Bedding surface of polymictic boulder conglomerate. Note the abundance of carbonate clasts (light coloured). Location: "The Ledge", middle portion of the White Point Conglomerate west of Cape D'Estaing.

Plate 157: Red shales with thin pebbly interbeds. Location: uppermost portion of the White Point Conglomerate west of Cape D'Estaing.

Plate 158: Evenly laminated and contorted reddish brown arkosic sandstones, overlying 2m thick unit of cobble to boulder conglomerate. Location: middle portion of the White Point Conglomerate west of Cape D'Estaing.

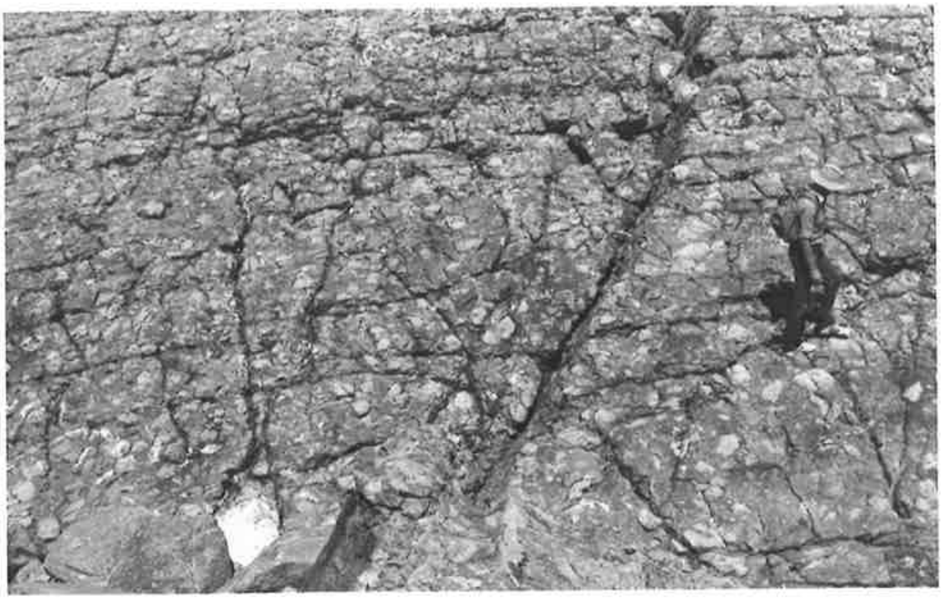
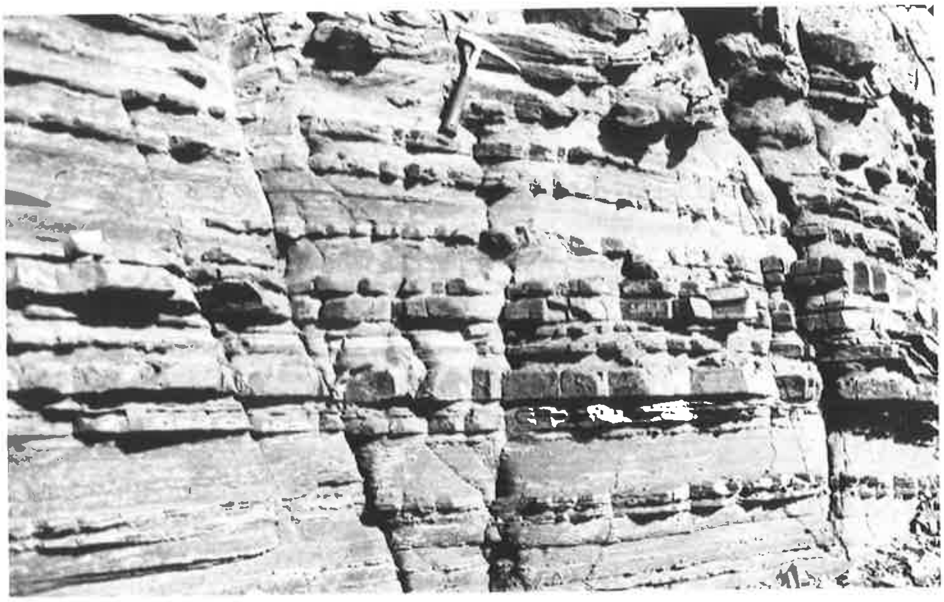


Plate 159: Interbedded greyish green shale and evenly bedded, ripple laminated and slumped reddish brown arkose. Hammer: 31cm long. Location: middle portion of the Emu Bay Shale east of The Big Gully.

Plate 160: Lenticular, cobble conglomerate, with loaded and channeled base. Hammer: 31cm long. Location: middle portion of the Emu Bay Shale east of The Big Gully.

Plate 161: Tracks attributed to trilobite in greyish red siltstone (plan view). Pen: 15cm long. Location: upper portion of the Emu Bay Shale east of The Big Gully.



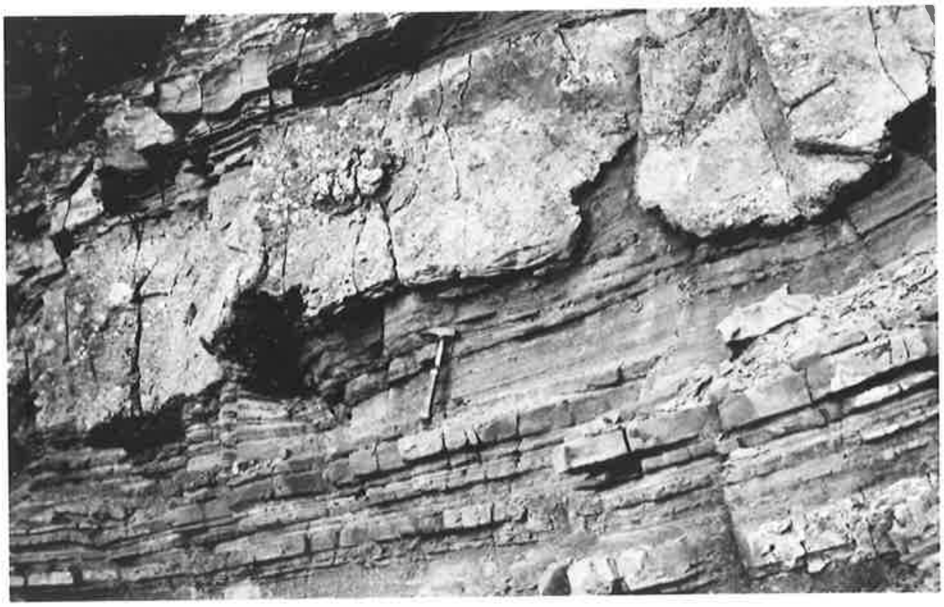


Plate 162: Contorted bedding in reddish brown, medium-grained arkose. Arkosic sandstones are the dominant lithology in the Boxing Bay Formation. Hammer: 31 cm long. Location: Boxing Bay Formation immediately west of White Point.

Plate 163: Lenticular granule to cobble conglomerate beds with channeled bases eroding red shale and siltstone. Hammer: 29cm long. Location: Boxing Bay Formation at White Point.

Plate 164: Trough cross-stratified and channeled pebble to cobble conglomerates and associated greyish green coarse calcareous sandstones. Hammer: 31cm long. Location: Boxing Bay Formation at Pt. Marsden.

Plate 165: Horizontally bedded coarse (cobble to boulder) conglomerate. Hammer: 31cm long. Location: middle portion of the White Point Conglomerate east of Hawk Nest.

Plate 166: Trough cross-stratified fine (pebble to cobble) conglomerate with associated coarse grey calcareous sandstone. Hammer: 31cm long. Location: Boxing Bay Formation at Pt. Marsden.

Plate 167: Subangular to subrounded clasts of limestone and dolomite, showing pressure solution effects at the clast contacts. Lenscap: 54mm diameter. Location: middle portion of the White Point Conglomerate just east of Hawk Nest.

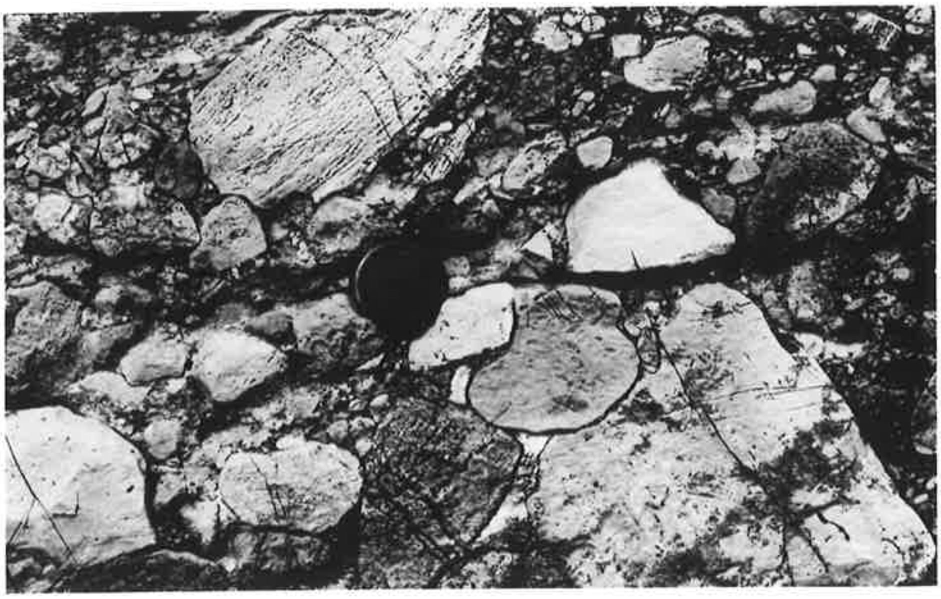


Plate 168: Imbricate clasts in horizontally bedded coarse conglomerate, indicating frow from left to right. Hammer: 31cm long. Location: middle portion of the White Point Conglomerate just east of Hawk Nest.

Plate 169: Edge of large, conglomerate-infilled channel cut into reddish brown arkosic sandstone. Hammer: 31cm long. Location: Boxing Bay Formation at Pt. Marsden.

Plate 170: Trough cross-stratified fine (granule) conglomerate. Location: middle portion of the White Point Conglomerate west of Cape D'Estaing.



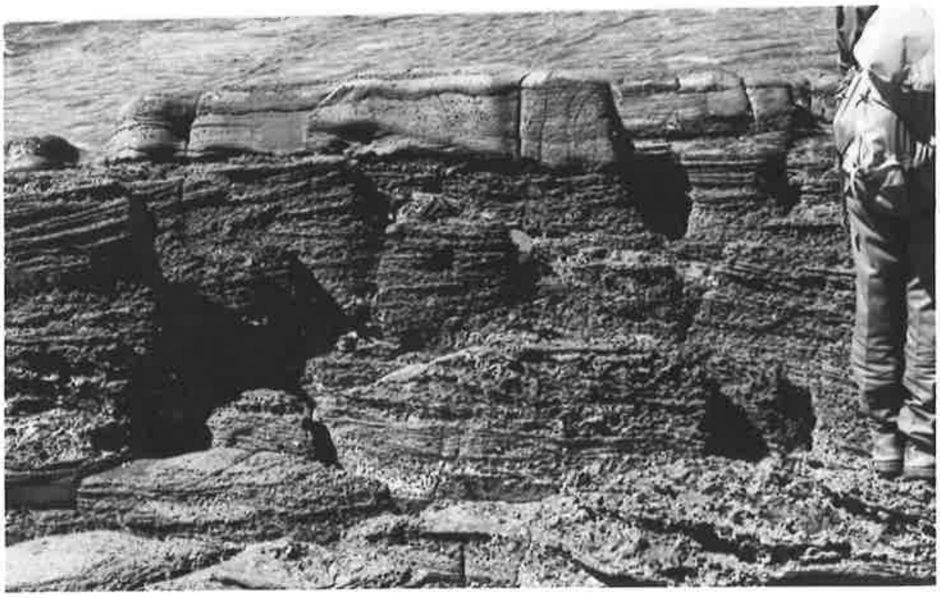


Plate 171: Trough cross-stratified reddish brown arkosic sandstone, capped with a thin unit of horizontally laminated sandstone. Hammer: 31cm long. Location: middle portion of the White Point Conglomerate west of Cape D'Estaing.

Plate 172: Interbedded units of trough cross-stratified and horizontally laminated reddish brown arkose. Hammer: 31cm long. Location: Boxing Bay Formation west of Pt. Marsden.

Plate 173: Trough cross-stratified and contorted reddish brown to greyish brown arkose. Hammer: 31cm long. Location: lower portion of the Boxing Bay Formation east of The Big Gully.

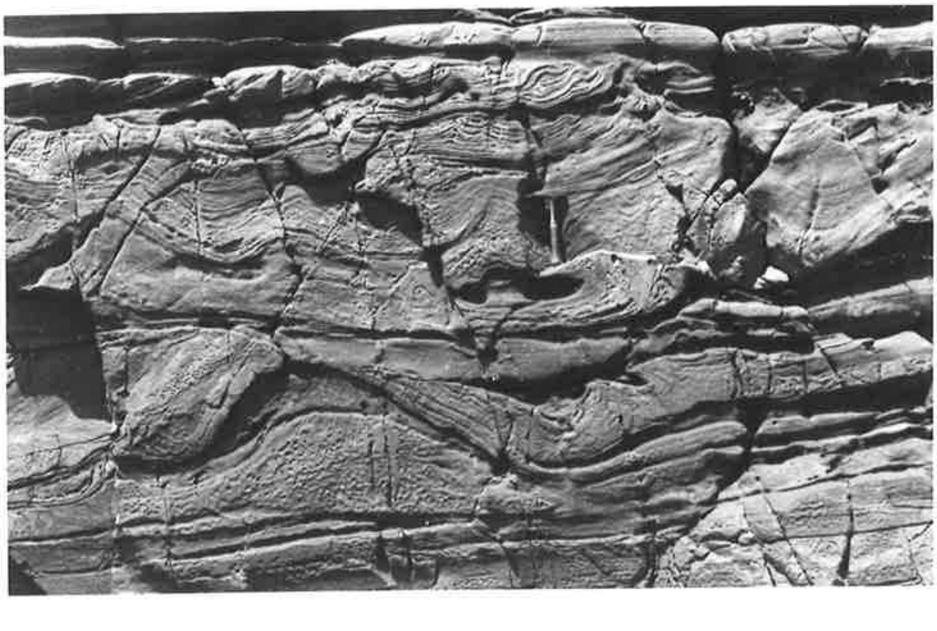
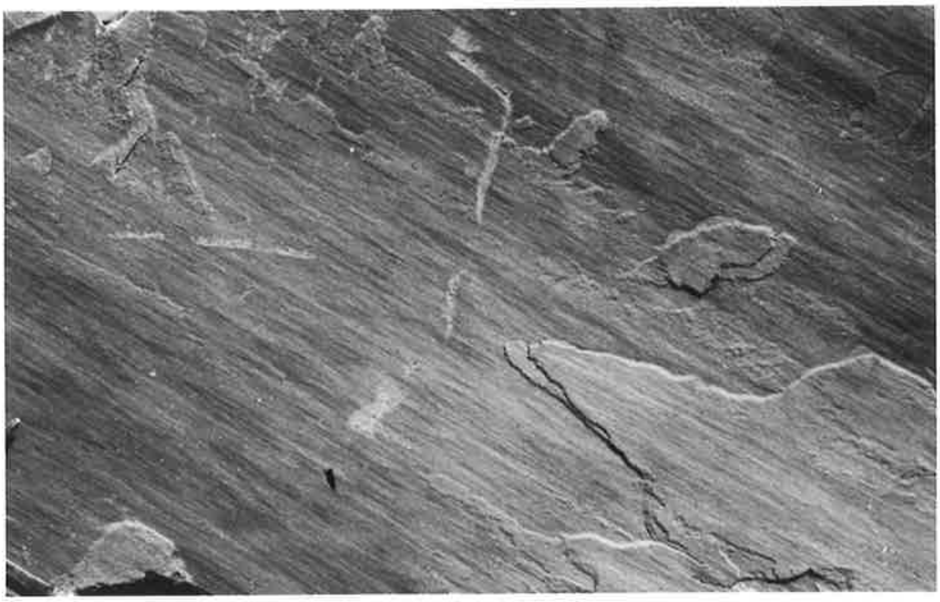


Plate 174: Contorted reddish brown medium-grained arkose. Hammer: 31cm long. Location: Boxing Bay Formation west of Pt. Marsden.

Plate 175: Current lineations in reddish brown medium-grained arkose. Location: basal portion of the Boxing Bay Formation east of The Big Gully.

Plate 176: Cross-section of ripple laminated reddish brown micaceous arkose. Location: middle portion of the White Point Conglomerate west of Cape D'Estaing.



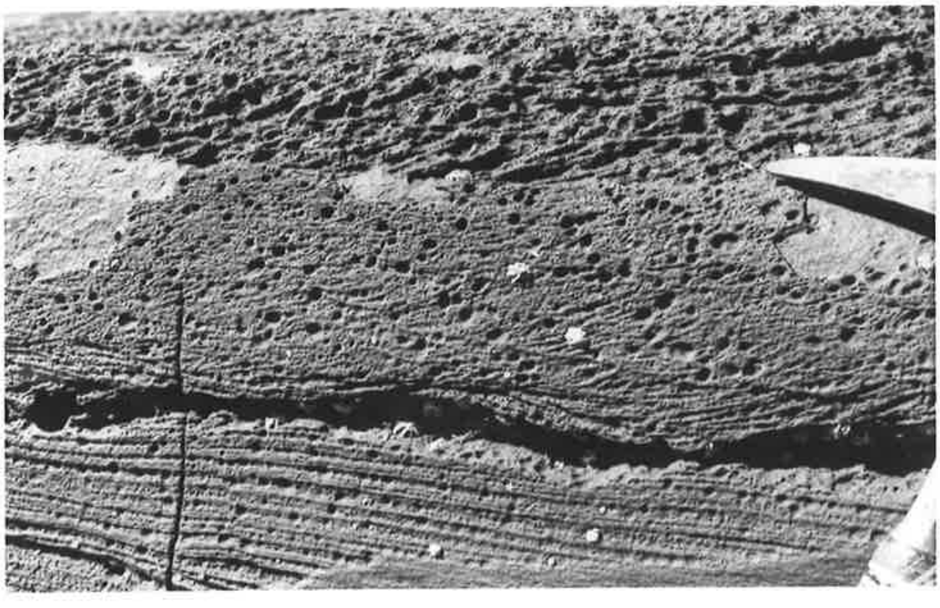
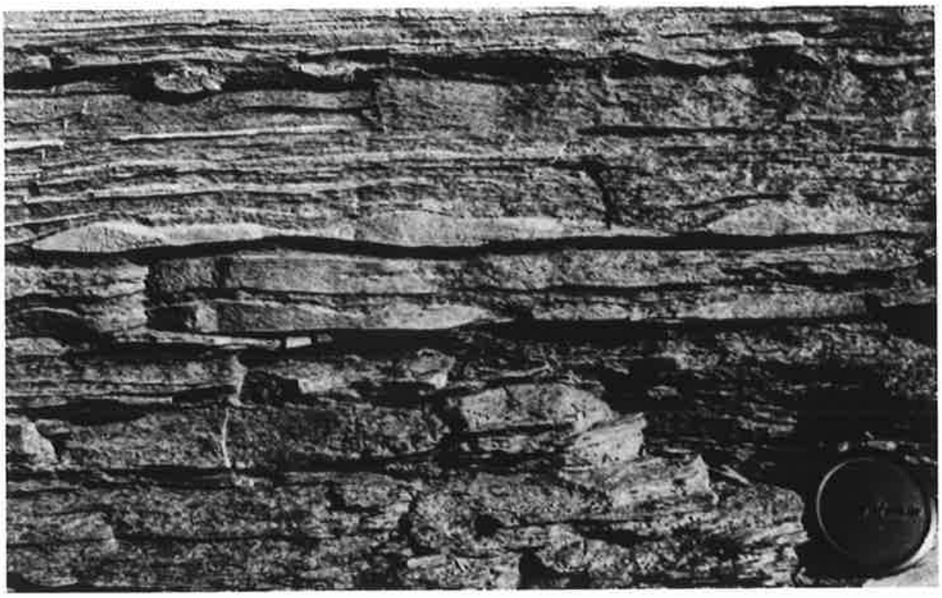
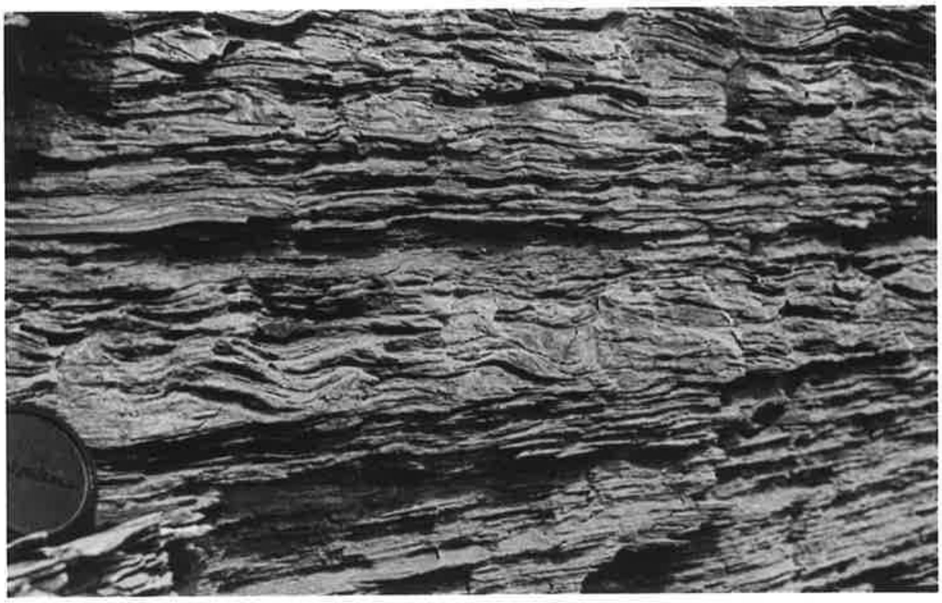


Plate 177: Lenticular bedding in greyish green sandy siltstone. Lenscap: 54mm diameter. Location: middle portion of the Emu Bay Shale east of The Big Gully.

Plate 178: Continuously rippled greyish brown very fine sandstone. Lenscap: 54mm diameter. Location: upper portion of the Emu Bay Shale east of The Big Gully.

Plate 179: Symmetrical ripples in coarse red siltstone. Note superimposed molluscan trail (top left), faint trilobite tracks (bottom left) and worm burrows (right). Scale: 12cm long. Location: middle portion of the White Point Conglomerate east of Hawk Nest.





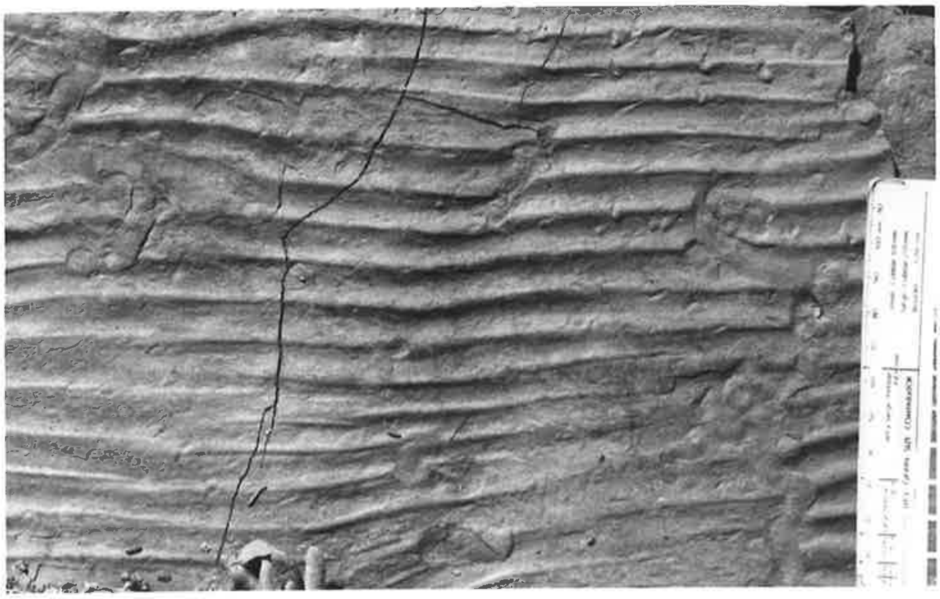
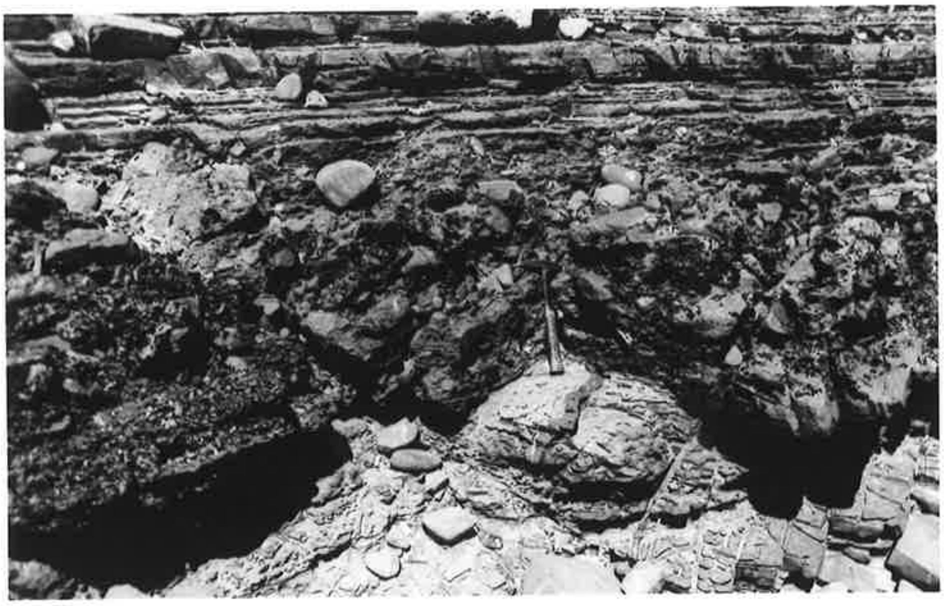


Plate 180: Abundant small tracks and scratch marks attributed to trilobites, on the sole of a greyish brown very fine sandstone bed. Lenscap: 54mm diameter. Location: upper portion of the Emu Bay Shale east of The Big Gully.

Plate 181: Cobble conglomerate with coarse sandstone matrix infilling desiccation crack (just to the right of the hammer handle) in underlying red silty shale. Hammer: 31cm long. Location: Boxing Bay Formation just west of White Point.

Plate 182: Burrow-mottled grey argillaceous limestone. Hammer: 31cm long. Location: upper portion of the White Point Conglomerate, west of Cape D'Estaing.



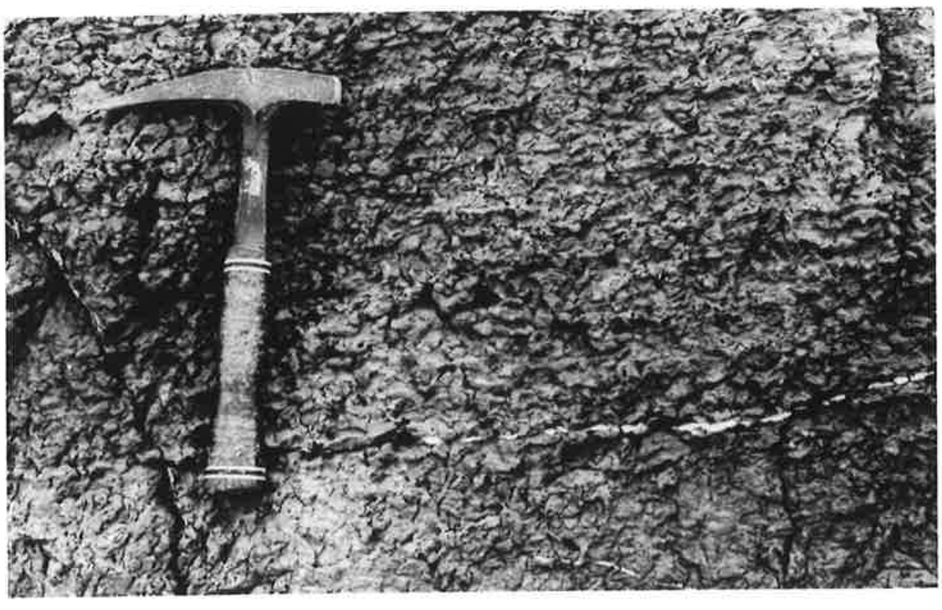


Plate 183: Massive, reverse-graded conglomerate with dispersed megaclast fabric (Fig. 16-8B). Location: Boxing Bay Formation on the foreshore of White Point.

Plate 184: Shoreward-facing megaripple interbedded in a sequence of red shales and siltstones. The megaripple comprises trough cross-stratified medium-grained arkose. Hammer: 31cm long. Location: Boxing Bay Formation west of White Point.

Plate 185: Plane laminated, current-lineated reddish brown arkose overlying limestone-rich cobble conglomerate. Hammer: 31cm long. Location: Boxing Bay Formation at Cape D'Estaing.