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TERRIGENOUS SEDIMENTATION IN THE GREAT BARRIER REEF LAGOON: A MODEL FROM THE BURDEKIN REGION

GEOLOGICAL SURVEY

by

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TERRIGENOUS SEDIMENTATION IN THE GREAT BARRIER REEF LAGOON: A MODEL FROM THE BURDEKIN REGION

ABSTRACT

The Great Barrier Reef Province is characterised by a mainland prograding terrigenous clastic shoreline and an inner shelf dominated by fluvially-derived mud. The Burdekin River acts as a large point source of sediment which is dispersed to the northwest of the mouth. Fluvial sand is wholly contained within the coastal zone and the sand and gravel components of inner and middle shelf sediments are largely relict or palimpsest. Vertical accumulation of terrigenous mud is limited to a thin veneer on the inner shelf and is negligible on the middle shelf. Coastal progradation accounts for the bulk of Holocene terrigenous sedimentation which decreases in a northwesterly direction, from 2.5 m yr^{-1} at the present delta front to 0.1 m yr^{-1} on the coastal plain north of Townsville.

Progradation of the shoreline occurs as four distinct sedimentary assemblages (beach ridge plain, chenier plain, mangrove-mudflat plain and barrier bar-lagoon complex). The overall prograding coastal wedge, where preserved in the geological record, would have recognisable seismic stratigraphic elements (coastal onlap and toplap, distal downlap and marine offlap). The pattern of late Quaternary sea level oscillations suggests that terrigenous marine and/or alluvial sediments should predominate across most of the shelf of the Great Barrier Reef lagoon.

INTRODUCTION

North Queensland has a rimmed continental shelf along which an 1800 km long tract of discontinuous shelf-edge reefs restricts water circulation and wave action within the adjacent shelf lagoon. The inner shelf of the lagoon is dominated by terrigenous mud and sand along its entire length. Investigators working in the Great Barrier Reef Province have long recognised the influence of a mainland terrigenous source in the overall pattern of shelf sediment distribution (Fairbridge, 1950; Maxwell, 1968; Maxwell & Swinchatt, 1970; Marshall, 1977; Orme & Flood, 1980). However, most investigators have concentrated on the reef carbonate complexes of the outer shelf, and have paid little attention to the terrigenous zone. Indeed, Maxwell (1968, p. 230) expressed the view that negligible sedimentation is occurring on the shelf and attributed this to inadequate sediment sources and ineffectual processes of sedimentation. Recently, more detailed investigations of the terrigenous zone have documented ample evidence of significant Holocene terrigenous deposition along the inner shelf and coast (Frankel, 1971, 1974; Burgis, 1974; Belperio, 1978; Cook & Mayo, 1978). Geophysical data, albeit with little subsurface stratigraphic control, also indicate that terrigenous sedimentation has been of primary importance in the Quaternary evolution of the continental shelf (Searle, 1979; Searle & others, 1980, 1982; Johnson & others, 1982).

In this paper, the distribution, physical properties and accumulation rates of terrigenous sediment originating from the Burdekin River (Fig. 1) are examined. The relationship between recent sedimentary accumulations on the inner shelf and coast, together with the pattern of glacio-eustatic sea level fluctuations, are used to derive a wider model of late Quaternary sedimentation on the inner continental shelf.

REGIONAL GEOLOGICAL SETTING

The Queensland continental margin is a relatively young geological feature which evolved after a Cretaceous taphrogenic cycle centred on the present Coral Sea. Graben faulting and rifting were followed by sea floor spreading and the evolution of the Coral Sea Basin in the Paleocene to early Eocene (65-55 m.y. B.P.). Subsidence of rifted coastal blocks and of the Queensland continental shelf, and the establishment of a new equatorial circulation, led to the development of coral reefs on residual basement highs in the early Miocene (Taylor & Falvey, 1977; Mutter & Karner, 1980; Falvey & Mutter, 1981). Block faulting and elevation of the continental interior accompanied subsidence of the shelf (DeKeyser, 1964; DeKeyser & others, 1965; Paine, 1972; Ollier, 1978). Concomitant erosion and scarp retreat during the Tertiary and Quaternary led to the accumulation of a sequence of erosion products which make up the present day coastal plain.

The coastal plain and coastal escarpment are major physiographic features of present-day North Queensland. The deposits beneath the coastal plain are almost entirely of alluvial and colluvial origin and the plain is continuous with the shallow continental shelf (regional gradient 0.0008). The subsurface deposits of the shelf are largely unknown because of a paucity of boreholes. Active coastal plain aggradation, coupled with Quaternary sea level changes and continuing shelf subsidence, are thought to have caused complex interfingering of terrestrial and marine terrigenous, bioclastic and biohermal facies.

The Holocene marine transgression interrupted alluvial processes on the inner shelf between 8 000 and 6 000 radiocarbon years B.P. (Belperio, 1979a). Depositional progradation has resulted in extensive coastal marine deposits along the entire Queensland coastline. Greatest progradation has occurred in the vicinity of major rivers and in northward-facing embayments. In the Townsville-Burdekin region, the continental shelf is about 100 km wide, with maximum water depths on the outer shelf of 40 to 80 m. The terms "inner", "middle" and "outer" shelf are used to denote three distinct zones of sedimentation (terrigenous, palimpsest and reefal) which, in this area, correspond to water depths of about 0-20 m, 20-40 m and 40-80 m respectively (Fig. 1). The main focus of this paper is on the sedimentary regime of the inner shelf and coast, where the Burdekin River deltaic and marginal deltaic sediments are dominant features.

ENVIRONMENTAL PARAMETERS

The climate of the Townsville region is seasonally dry and ranges from tropical subhumid along the coastal plain to tropical semi-arid over most of the Burdekin drainage basin. Mean annual rainfall at Townsville is 1 130 mm, of which 85% falls between December and April, but rainfall is highly variable (Burdekin Project Committee, 1977). Streamflow patterns directly reflect the intensity and duration of rainfall in the hinterland and show an equally high seasonality and variability of flow. At the coast, 92% of the Burdekin River discharge occurs in the five months December to April. The Burdekin, which drains an area of 129 500 km^2, dominates coastal discharge in the study area, with a mean annual discharge on the coastal plain of 9.8×10^9 m^3 and recorded extremes of 0.2 and 28.8×10^9 m^3 (I.W.S.C., 1973). The average annual sediment discharge of the river has been calculated as 3.0 M tonnes of silt and clay size wash load, 0.45 M tonnes of sand size bed material load and 0.9 M tonnes of dissolved load (Belperio, 1979b). A turbid plume from the Burdekin River is visible on the inner shelf when river flow exceeds about 2 000 $m^3 s^{-1}$. This plume is advected northwestward, parallel to the coastline, and is largely contained within the inner shelf waters (Belperio 1978; Wolanski & Jones, 1981).

The maximum spring tide range at Townsville is 3.8 m (Easton, 1970), and results in significant intertidal exposure. The tide is dominantly semi-diurnal, and tidal currents in shallow embayments exceed 70 cm s^{-1} during springs (Belperio, 1978). Seas are usually slight to moderate because of protection from ocean swell by coral reefs on the outer shelf. From April to November, waves are generated predominantly by southeast Trade Winds blowing across the lagoon. The resulting waves are also predominantly from the east and southeast but wave heights rarely exceed 2.5 m (Walker, 1981a). Wind and waves maintain a well-mixed, isothermal and isohaline water column throughout the year, with the exception of the summer wet season (Brandon, 1970, 1973; Pickard, 1977; Walker, 1981b). The Trade Winds also create significant coastal turbidity and generate a strong northwestward drift of inner shelf water and suspended sediment (Belperio, 1978; Wolanski & Ruddick, 1981). Occasional cyclones generate strong winds from varying directions, rough seas, and storm surges capable of raising water levels by up to 3.0 m (Heron & others, 1979). In a 30 year period (1940-1969), 22 tropical cyclones passed within 167 km of Townsville (Oliver, 1978).

STUDY METHODS

Intertidal environments and deposits of the Burdekin delta and marginal deltaic plain were mapped from aerial photographs and ground reconnaissance studies. Hand augering along selected transects provided subsurface stratigraphic information. The level of cores and intertidal environments were related to tidal datum. Regional and local gradients were calculated from topographic and bathymetric charts and all available borehole data on the coastal plain were collated. Recent coastal changes were documented from historical aerial photographs and long-term changes were calculated from radiocarbon data. Marine surface sediment samples (240) were collected largely by scuba diving and 46 short cores were taken to a maximum depth of 2 m using a diver-operated hand corer. Bottom samples were collected on a systematic grid along the inner shelf between the Burdekin River mouth and Herald Island and out to the 25 m isobath.

Subsamples (200-300 gm) were wet sieved and individual sand and gravel fractions were retained. The mud fraction was dispersed in sodium hexametaphosphate solution and the silt and clay fractions separated by repeated settling and decantation (after Galehouse, 1971). Combustible organic and carbonate contents were determined for each grain fraction. For sand and silt fractions, organic carbon content was determined from weight loss on ignition at 550°C and carbonate content by weight loss after treatment with 10% HCL. For clay fractions, carbonate content was determined by CO_2 weight loss on ignition at 1000°C after prior ignition of 550°C to remove combustible organics. The remaining portion of each size fraction was considered to comprise the terrigenous (modern & relict) component of the sediment. Total carbonate, organic and terrigenous contents of each sample were calculated from the weighted mean of individual grain size fractions. Grain size statistical determinations (after Folk & Ward, 1957) were made on individual carbonate and terrigenous components of the sediment samples. All grain size and statistical data are listed by Belperio (1978, Vol. 3) and only selected data are presented here.

ENVIRONMENTS OF DEPOSITION

Terrigenous depositional environments are discussed in terms of three principal physiographic zones. First, the alluvial and colluvial sediments of the coastal plain extend from the coastal escarpment to the marine littoral. Second, modern intertidal environments and prograded coastal sediments are considered to comprise the marginal deltaic plain. Third, subtidal terrigenous sediments occupy the bulk of the inner shelf, from the coast to the 20 m isobath. The Burdekin delta proper is also discussed in terms of these three depositional zones, rather than as a single entity.

Coastal plain deposits (subaerial)

The coastal plain sediments in the study area (Fig. 2) are primarily of alluvial and colluvial origin. Holocene deposits are largely restricted to the flood plain and delta of the Burdekin River and to narrow terrace deposits of entrenched coastal streams. On the plain, the Burdekin River channel is about 1 km wide and 10 m deep, and has virtually no estuary at its mouth. The channel is constrained between wide levees which are built up about 3 to 4 m above the surrounding flood plain. Channel sediments comprise coarse arkosic sand and gravel, moulded into large lateral bars. Periods of active bedload transport during high river stages occur on only a few days of the year (Belperio, 1978, 1979b). Towards its mouth, the river becomes choked with sand and branches into a number of distributary channels (Fig. 2). These channels outline the present-day active delta, an area of about 450 km^2, which is inundated when river flow exceeds 27 000 cumec (recurrence period of 1 in 12 years). Flood plain deposits cover a further 2 000 km^2 of coastal plain between Home Hill and Cape Cleveland, and conceal older channel and levee deposits of the Burdekin. This area is occasionally inundated during extreme river flows, when the main channel overtops its banks (>38 000 cumec; recurrence period of 1 in 20 years). At these times, levee construction and sheet flooding result in aggradation of the coastal plain. However, the bulk of the fluvial sediment load, both bed load and suspended silt and clay, is transported directly into the sea where it is subject to marine and littoral dispersal processes (see below). Episodic shifting of the major channel has occurred primarily through levee bank rupture after excessive aggradation and results in a flood plain/levee/channel sediment association in the subsurface.

The subsurface deposits of the delta and coastal plain are known from numerous boreholes (I.W.S.C., 1964, 1967; Hopley, 1970). The deposits are a complex of interfingering channel sands, alluvial silt and clay, colluvial regolith and weathered soil horizons. Maximum thickness varies from about 150 m at the base of Cape Bowling Green (Wiebenga & others, 1975) to 40 m to the west of Townsville (Murtha, 1975), and decreases southward towards the coastal escarpment. Age control in the subsurface is very limited. I.W.S.C. (1967) recognised an older weathering surface about 4-6 m beneath more recent alluvials in the Haughton River area. Hopley (1970) distinguished a similar weathering horizon in the borehole records of the Burdekin Delta to which he attributed a late Pleistocene age. Carbonate nodules from this horizon, below 20 m of alluvial sediments, yielded a radiocarbon age of 15 100 ± 400 yr B.P. (Hopley & Murtha, 1975). A radiocarbon date on freshwater peat below 20 m of alluvium near the Haughton River (GAK6017, Fig. 2) yielded a minimal age of 27 350 yr B.P. Both these dates indicate a pre-Holocene age but are not accurate within the Pleistocene.

Interbedded Pleistocene marine deposits are rare and have been encountered in only two boreholes in the Burdekin Delta where they occur 20 km inland and beneath 12-18 m of fluvial sediments (Belperio, 1978). Numerous excavations and boreholes around Townsville have not revealed any subsurface Pleistocene marine strata. Intercalations of Holocene marine strata are common however, particularly where flood plain deposition has occurred over prograded coastal marine sediments.

Soil development on the coastal plain sediments is variable and has been used to infer relative ages of different deposits (Murtha, 1975; Hopley & Murtha, 1975). Soils on Holocene flood plain and levee deposits range from uniform coarse sands to brown gradational textured soils. Older alluvial sediments have primarily duplex texture-contrast soils as well as red earth and yellow earth gradational soils.

The marginal deltaic plain (intertidal)

Alluvial sedimentary processes on the shelf were interrupted by the rising Holocene sea which reached its present level about 6 000 radiocarbon years B.P. and, according to depositional evidence, has not deviated significantly (± 1 m) since then (Belperio, 1979a) (c.f. Hopley, 1980). Depositional progradation and shoreline retreat have left a very low gradient (0.0002) marine plain, up to 10 km wide, composed of sediments from clearly recognisable intertidal environments (Fig. 2). Late-Holocene alluvium now laps over the coastal marine sediments at their landward extremities. This is readily evident where stranded beach ridges are surrounded by alluvial plains and coastal grasslands.

Intertidal depositional environments are related to tidal levels and local wave energy (Fig. 3). Low wave energy environments on the western or lee side of headlands and spits include intertidal sand and mud flats, mangrove forests, high tide mud flats, supratidal flats and chenier plains. Higher wave energy environments include beaches, and barrier bars with associated lagoons. The main features of individual environments and their sediments are listed in Table 1.

The combination of intertidal processes and environments has resulted in four basic progradational sequences in the study area (Fig. 4). These are (i) a beach ridge progradational plain, (ii) a chenier progradational plain, (iii) a mangrove-tidal mud flat plain, and (iv) a barrier bar-lagoon association.

The beach ridge plain (Fig. 4a) is best represented south of Cape Cleveland where about 100 coalescing beach ridges have prograded about 6.5 km. Much of the sediment is thought to have originated from the Burdekin River when it discharged directly into Bowling Green Bay (Hopley, 1970). Accretion of beaches under a moderate wave regime results from progressive displacement of beach berms up the beach face on successively higher daily tides of a lunar cycle. Interdispersed amongst the beach ridges are small salt pan and mangrove sediment-filled depressions. Sand facies predominates into the intertidal zone but rapidly changes to mud facies below low water datum.

The chenier plain assemblage (Fig. 4b) develops in semi-protected embayments where slight wave action is sufficient to maintain a sandy intertidal flat. In central Bowling Green Bay, a chenier plain extends for up to 10 km inland and for 30 km along the coast (Fig. 5). A smaller plain occupies the protected head of Cleveland Bay. Coring demonstrates that the sand bodies rest on mangrove sediment and are surrounded by mangrove and high tide mud flat strata. In Bowling Green Bay, the most seaward chenier fronts the modern tidal sand flat but also rests on an eroded mangrove mud platform (Fig. 6). New mangrove stands are colonizing the tidal sand flat immediately in front of the chenier. Chenier formation occurs when a particularly severe storm (e.g., cyclone) erodes the prograding mangroves and constructs a sand ridge on the exposed mangrove mud platform from the tidal flat sands. A subsequent return to prolonged periods of low local wave energy allows recolonization of mangroves and a continuation of seaward progradation. Large tidal creeks transport suspended sediment landward behind the cheniers, resulting in rapid vertical accumulation of the high tide mud flats to supratidal level. The chenier plain, therefore, has a characteristically thin frontal mangrove fringe backed by wide, mature supratidal flats. The vertical sequence consists of an intertidal sand sheet separating subtidal muds from mangrove and supratidal muds, and with chenier ridges preserved as isolated, elongate sand lenses (Fig. 4b).

The mangrove forest facies (Fig. 4c) forms best in well protected embayments in association with a muddy tidal flat. Conditions in the southeast corner of Bowling Green Bay, where waves are non existent, are ideal for mangrove forest progradation (Fig. 7). Mangroves rapidly colonize the tidal mud flat and vertical accumulation of sediment within and behind mangroves is high. Vertical accumulation causes die-back of mangroves and areas of bare high tide mud flats form within and behind the forest (Aliano, 1978). Tidal channels amongst the forest are few and small, and muddy tidal waters advance and regress over wide fronts. The vertical succession is entirely dominated by mud.

The barrier bar-lagoon assemblage (Fig. 4d) forms where there is an ample input of coastal sand subject to significant longshore drift. Along the Burdekin delta coastline, sand moves northwards as a series of barrier bars and creates tidal back-bar lagoons (Fig. 8). The arkosic sand originates from the Burdekin River when floods dump large quantities of bedload as river mouth sand shoals (Belperio, 1979b). The northward migration of the barrier bars, calculated from historical air photographs, has averaged 185 m per year (Belperio, 1978). Growth of the northern ends of the Mud Creek Bar and Alva Bar (Fig. 8) has been matched by equivalent migration of their southern ends, so the size of the bars has remained relatively constant as they have migrated along the coast. Mud stirred into suspension on the inner shelf is carried into the lagoons by flood tides causing rapid infilling ofthe lagoons which are then colonized by mangroves. When infilled, the barrier bar becomes anchored to the coast, causing a unit increment in coastal accretion. Previous barrier bars, now accreted and with infilled lagoons, are evident on the coastal plain (Fig. 8). Longshore transport then shifts to a new generation of offshore bars. Rates of progradation depend on the rate of sand supply rather than the availability of mud. Some of the northward drifting sand nourishes Cape Bowling Green, a 22 km long recurved sand spit. Progradation of the spit commenced about 2 500 years ago and mean long term growth has been 8.8 m yr^{-1} (Belperio, 1978). Historical seaward growth of the northern end of the spit has been much more dramatic, averaging 35 m yr^{-1} (Fig. 8). The reservoir of sand comprising Cape Bowling Green and the accreted and active barrier bars (c.10^9 tonnes) is of the same order of magnitude as the bedload discharge calculations for the Burdekin River over the past 2 500 years (Belperio, 1979b).

All prograding sedimentary environments, particularly the well-defined mangrove strata, are related to modern tidal levels (Belperio, 1979a). Progradation rates calculated from site specific C-14 data, as well as for the overall accretionary coastal wedge, decrease with increasing distance northwestward away from the Burdekin River mouth (Table 2). The highest measured rate is 2.5 km/1000 years at the present delta mouth and the lowest rates are a few metres per 1000 years for isolated beaches. Coring to 6 m has failed to penetrate the entire Holocene coastal marine sequence. For a substrate gradient of 0.0008, the theoretical sediment thickness around the present Bowling Green Bay coastline should be at least 8 m.

Inner shelf sediments

Carbonate variations across the inner and middle shelf are shown in Fig. 9a. Total acid soluble carbonate is lowest along the mainland beach and intertidal zones and increases systematically across the inner shelf from about 5% to 30%. Low values for coastal sediments reflect rapid coastal progradation and limited residence time. Low values on the inner shelf reflect the dominance of infaunal communities adapted to a soft, shifting bottom (Arnold, 1980). Principal carbonate contributors are bivalves, gastropods and foraminifera. Between 20 m and 25 m, carbonate content increases rapidly from 30% to 50%. The gravelsized portion of total carbonate also increases rapidly at these depths (Fig. 9b). Epifaunal suspension feeders dominate at these depths, and the main contributors to bioclastic detritus are bryozoa, calcareous algae (principally Halimeda), large foraminifera, ascidians and sponges. Patches of "hard ground", algal encrustations and algal nodules are common. Further seaward, carbonate values increase to over 90% in the inter-reef areas of the outer shelf (Maxwell, 1968).

Terrigenous clay dominates over all other components on the inner shelf (Fig. 10a). Values increase to 80% of the sediment in large mud lobes off the delta front and in Bowling Green Bay. Underwater observations indicate the bottom is composed of low density fluid mud. The large mud lobe off the Burdekin River mouth represents the subaqueous part of the delta. Offshore from the centre of this lobe, clay content decreases from 80% to 1% over 4 km. A similar situation exists off Cape Bowling Green, where the sand spit has prograded in 15 m of water directly onto another mud lobe. Clay content decreases rapidly at 20-25 m water depth and also decreases in a northwesterly direction along the inner shelf. The width of the shelf mantled by terrigenous clay also increases in this direction (e.g., 5% clay contour).

Terrigenous silt distribution mimics the clay distribution pattern, with maximum values of 40%-50% coinciding with the liquid mud lobes (Fig. 10b). Values decrease to less than 2% in beach sediments and at the 20-25 m transition onto the middle shelf.

Terrigenous sand distribution is the reverse to that of silt and clay. Maximum values of 90-100% are found in beach and intertidal sand flats and barrier bars (Table 1). Minimum values of 1%-5% occur in the liquid mud lobes and in tidal mud flat, mangrove and supratidal environments. Sand content increases again seaward of the 20 m isobath. The sand grains here are pitted and ferruginized, and represent a different population to the fluvially-derived nearshore sands.

Terrigenous gravel distribution provides the best evidence for the relict or palimpsest origin of middle shelf terrigenous sediments (Fig. 10c). Gravel on the inner shelf is related to local sources such as headlands and islands, and granite shoals in Halifax Bay, and no gravel is associated with the mud lobes. The increase in the terrigenous gravel component to over 10% on the middle shelf reflects a relict source as it is not possible for modern terrigenous gravel to be transported across the mud lobes.

Mean grain size also reflects the predominance of clay size material on the inner shelf (Fig. 10d). Mean size is 8 phi in the mud lobes and intertidal mud flats and increases in a northwesterly direction. Increasing mean size in the nearshore zone (depth <2 m) reflects the intertidal sand bodies and increasing mean size on the middle shelf reflects the predominance of a relict sand and gravel population.

Other grain size statistical information is of limited use in interpreting sedimentological trends. The majority of inner shelf muds are very poorly sorted, the major mud lobes are poorly sorted and beach, chenier and intertidal sands are moderately sorted (Fig. 10e). Skewness values are unreliable indicators of depositional environment. River, beach, dune and intertidal sands for example have a similar range of skewness values (Table 1). On the inner shelf, the mud lobes are negatively skewed compared to the remaining inner shelf sandy muds (Fig. 10f).

Grain size spectra maps are useful for interpreting spatial variations in grain size data (Dowling, 1977). The technique involves contour mapping in the space-size-frequency domain along a profile of interest. Two profiles of terrigenous grain data from the coast to the 25 m isobath are presented in Fig. 10, g & h. Three facies are evident for the transect off the mouth of the Burdekin River (Fig. 10h). River mouth sand shoals extend for 2 km offshore and are predominantly fine sands (3 phi) with a subordinate population of silt and clay and positive skewness. The delta mud lobe consists almost entirely of clay (8-10 phi) with a subordinate proportion (10%) of silt. The contours also indicate poor sorting, negative skewness and consistent mean grain size across the mud lobe. Between 9 and 11 km offshore, the grain size characteristics change rapidly from 95% silt and clay to 75% sand and gravel, and from unimodal to bimodal sediment. The sand and gravel mode is unrelated to the nearshore sands, is very poorly sorted, and its mean size decreases seaward. The subordinate clay mode of this relict sand facies is related to the delta mud lobe and results from diffusive transport of clay onto the middle shelf (Belperio, 1978). A second grain size spectra map for a shore-normal transect in Halifax Bay is shown in Fig. 10g. Three major facies are once again evident. The nearshore sand and beach facies is coarser and better sorted than the sand component of the inner shelf. A sandy mud facies dominates most of the inner shelf and passes laterally into a relict sand facies. Significant mud intermixing extends to over 18 km offshore here.

Submarine sediment cores indicate that the Holocene marine sediment blanket on the inner shelf floor is merely a veneer which decreases in thickness to the northwest away from the Burdekin River mouth. Marine sediment thickness exceeds 2.0 m in the mud lobes of Bowling Green Bay, is approximately 1.0 m in Cleveland Bay and is less than 0.5 m in Halifax Bay. Thickness increases landward of the 5 m contour where it exceeds 2 m (the limit of corer penetration). In most cases the cores bottomed in a stiff clay of variable nature. This clay is brown, nodular and gravelly, and is part of a soil horizon formed on alluvial sediment. Underwater observations along several kilometres of the vertical wall of the Townsville shipping channel have confirmed this. A one metre blanket of Holocene marine sediment rests variously on thin, basal transgressive mangrove deposits, and on pre-Holocene terrestrial soils, alluvium, colluvium and weathered granite. Geophysical and borehole data from Cleveland Bay also support these observations (Anonymous, 1964). Holocene marine sediment thickness in cores between Townsville and Magnetic Island varies from 0.9 to 2.0 m, and the underlying alluvial clays are between 1 and 10 m thick resting directly on weathered granite bedrock.

DISCUSSION

The inner shelf in the Townsville region of the Great Barrier Reef Province is dominated by terrigenous mud. However, mud blanketing is subordinate to coastal deposition and coastal progradation. Coastal progradation, particularly of bayhead chenier plains (terminology of Otvos & Price, 1979) is ubiquitous to much of northern tropical Australia (e.g., Cook & Polach, 1973b; Jennings & Coventry, 1973; Burgis, 1974; Smart, 1976; Belperio, 1978; Clarke & others, 1979; Rhodes, 1982). The Burdekin River acts as a large point source of this sediment which is advected northwestward, primarily by wave-induced resuspension and transport by wind drift currents (Belperio, 1978). With northwesterly transport along the inner shelf, much of the suspended sediment is accreted back onto the coast but some diffuses onto the middle shelf where it intermixes with relict sand and gravel and modern bioclastic detritus. Belperio (1978) estimated that coastal sedimentation accounts for 80% of the terrigenous sediment budget. Arnold (1979) has shown that a sharp discontinuity in benthic faunal composition occurs at depths of 22-23 m and this corresponds to the maximum depth of bottom resuspension by waves.

The textural and mineralogical immaturity of intertidal sands result from their very limited transport paths and residence time in the marine realm prior to aggradation. Intertidal sands are largely indistinguishable from river sands other than by the presence of marine fossils. However, carbonate is readily leached in the intertidal environment and is lacking in early Holocene beach ridges. Some of the innermost beach ridges on the Townsville and Burdekin coastal plains have been assigned Pleistocene ages (Hopley, 1970; Hopley & Murtha, 1975). The evidence cited is the generally advanced weathering, and various radiocarbon ages on carbonate nodules in the range 14 000 to 29 000 yr B.P. Although Pleistocene marine interbeds at and below present sea level are to be expected (Fig. 11), the almost complete lack of Pleistocene marine interbeds in the subsurface of the coastal plain is enigmatic. It suggests that either large scale erosion or reworking of previously deposited strata has occurred, or continuing subsidence of the shelf has resulted in the bulk of Pleistocene marine strata being seaward of the present coastal plain (Fig. 12).

Implications for Quaternary shelf development

After 6 000 years of relatively stable sea level, the coastal sediments have prograded seaward about 10 km. Belperio (1978) calculated that at present progradation rates the three principal embayments of the study area would completely infill with sediment in the next 10 000 years, resulting in a more linear shoreline. Progradation of the clastic shoreline is occurring as a two-layer wedge. The shallow subtidal portion consists of seaward sloping muds and sandy muds (gradient >0.001) whilst the upper part is nearly horizontally bedded (gradient 0.0002) and planated to an upper base level corresponding to maximum spring tide elevation (Fig. 4). For a uniformly sloping substrate, the thickest accumulation occurs beneath the coastline (c. mid-tide level). The thickness of the coastal wedge increases with time as the coast progrades seawards into deeper water. The continued seaward development of this progradational (regressive) sequence depends largely on the duration of the present stable sea level phase.

Glacio-eustatic sea level fluctuations are known to have caused periodic transgressions and regressions of the sea across the Queensland continental shelf (Davies, 1974; Marshall, 1977; Thom & others, 1978). The best documented of these are the late Quaternary sea level highs that occurred at about 125 000, 105 000 and 82 000 yrs B.P. (Fig. 11). The best current estimates of the tectonically corrected inundation levels of these marine transgressions are about +3, -14 and -20 m relative to present sea level respectively (Bloom & others, 1974; Chappell, 1974, 1976). In South Australia, corresponding sea level inundations have been documented at about +3, -8 and -14 m (Hails & others, 1983) and, as expected, other world-wide measurements of these sea levels are equally variable (e.g., Matthews, 1973; Fairbanks & Matthews, 1978; Cronin & others, 1981). Although the local inundation levels of previous high sea level phases are not known with any certainty, they would have resulted in a seaward shift of the coastline and of the coastal progradational wedge. In addition, major sea level regressions occurring between each high sea level period were accompanied by a decrease in mean annual rainfall on the North Queensland hinterland (Fig. 11). The time available for pedogenesis, alluvial reworking, and possible alluvial aggradation on the shelf was much greater than the time available for marine sedimentation. At these times, the Burdekin and other coastal rivers would have discharged seaward of the present barrier reefs. A combination of alluviation during low sea level phases, and coastal marine progradation along changing loci of deposition during high sea level phases, strongly suggest that terrigenous strata (coastal plain & coastal marine) will dominate in the subsurface of the continental shelf.

The only data presently available on pre-Holocene sedimentation processes on the shelf come from continuous seismic profiles (Orme & others, 1978; Searle & others, 1980, 1982; Searle & Hegarty, 1982; Johnson & others, 1982; Harvey & Searle, 1983;). The pre-Holocene surface of the shelf away from reefs is incised by numerous channels of apparent fluvial origin, but the degree of alluvial aggradation as opposed to fluvial reworking and/or pedogenesis of marine intervals is unknown. Four depositional models are possible: (1) Massive alluvial aggradation occurred on the shelf during low sea level phases and preceeding marine deposits were largely reworked and eliminated. If this situation prevailed, the shelf sediments would be composed entirely of coastal plain alluvial strata. (2) Alluvial sedimentation may have covered and preserved marine strata to produce interdigitating marine and terrestrial sediments in the subsurface. (3) Alluvial aggradation may have been limited during low sea level phases but fluvial processes may still have largely eroded previously deposited marine strata. (4) Fluvial processes may have been limited during low sea level phases (entrenched streams) and earlier marine strata were subject only to subaerial pedogenesis prior to inundation by other marine trangressions.

Lower mean annual rainfall during periods of subaerial exposure, and probable entrenchment of streams accompanying base level lowering (e.g., Begin & others, 1981) are arguments against models 1 & 2. Low rates of alluvial aggradation are more likely to have characterised the interglacial intervals. The last sedimentation model (4) has been confirmed in Spencer Gulf, South Australia (Hails & others, 1983) and a schematic reconstruction for a north-south section through Bowling Green Bay is shown in Fig. 12. The prograding coastal wedge should have distinctive seismic stratigraphic elements (proximal coastal onlap and toplap, distal downlap, and marine offlap) which should be useful for the recognition of older sequences. Superposition of late Quaternary prograding units results in a terrigenous marine sequence with numerous internal pedogenic horizons. Pedogenic alteration may have reached an advanced stage, as in Spencer Gulf, where the original marine features of the sediment are largely obliterated. Irrespective of which depositional model is ultimately confirmed by shelf coring, terrigenous sedimentation, either alluvial or marine or both, will predominate in the shelf sequences.

Purdy (1974) drew an analogy between sediments of the Belize Barrier Reef lagoon and the Great Barrier Reef shelf floor, suggesting they were both drowned karst marginal plains. Choi & Ginsburg (1982) have since shown sections of the Belize Shelf are of siliclastic coastal plain origin rather than karst. Similarly this study, and seismic studies (Searle & others, 1982), provide no evidence to support Purdy's contention for the Barrier Reef lagoon.

CONCLUSIONS

Major rivers along the Great Barrier Reef coastline act as point sources of sediment which is dispersed in a northwesterly direction. The inner shelf and coast are dominated by terrigenous mud sedimentation to about 20-25 m water depth. Intertidal sedimentation and coastal progradation are quantitatively more important than inner shelf mud blanketing. Across-shelf transport of mud is insignificant and fluvial sands are largely contained at the coast. Terrigenous sediments on the middle shelf are relict or palimpsest.

Coastal progradation results in a regressive, mud dominated sequence which is planated to an upper base level of sedimentation corresponding to upper tidal limits. Variations in progradational processes result in four recognisable intertidal regressive sequences (beach ridge plain, chenier plain, mangrove-mudflat plain, barrier bar-lagoon). Consideration of late Quaternary sea levels and possible alluvial, marine and pedogenic processes, leads to several possible depositional models, all of which indicate a predominance of terrigenous sediments on the greater part of the shelf floor.

ACKNOWLEDGEMENTS

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REFERENCES

Aliano, W.L., 1978. A study of the clay mineralogy of an area on Cape Bowling Green. B.Sc. (Hons.) Thesis, James Cook University of North Queensland (unpublished).

Anonymous, 1964. Geophysical survey of the Port of Townsville. Queensland Department of Harbours and Marine (unpublished).

Arnold, P.W., 1980. Soft-bottom polychaete communities in Halifax Bay, Queensland. Ph.D. Thesis, James Cook University of North Queensland (unpublished).

Begin, Z.B., Meyer, D.F. & Schumm, S.A., 1981. Development of longitudinal profiles of alluvial channels in response to base level lowering. Earth Surface Processes, 6, 49-68.

Belperio, A.P., 1978. An inner shelf sedimentation model for the Townsville region, Great Barrier Reef Province. Ph. D. Thesis, James Cook University of North Queensland (unpublished).

Belperio, A.P., 1979a. Negative evidence for a mid-Holocene high sea level along the coastal plain of the Great Barrier Reef Province. Marine Geology, 32, M1-M9.

Belperio, A.P., 1979b. The combined use of wash load and bed material load rating curves for the calculation of total load: An example from the Burdekin River, Australia. Catena, 6, 317-29.

Bloom, A.L., Broecker, W.S., Chappell, J.M.A., Matthews, R.K. & Mesolella, K.J., 1974. Quaternary sea level fluctuations on a tectonic coast: New $^{230}Th/^{234}U$ dates from the Huon Peninsula, New Guinea. Quaternary Research, 4, 185-205.

Brandon, D.E., 1970. Oceanography of the Great Barrier Reef and the Queensland continental shelf, Australia. Ph.D. Thesis, University of Michigan (unpublished).

Brandon, D.E., 1973. Waters of the Great Barrier Reef Province. In Jones, A.O., & Endean, R. (editors), Biology and Geology of Coral Reefs, Volume 1, Geology 1. Academic Press, New York, 187-232.

Burdekin Project Committee, 1977. Resources and potential of the Burdekin River Basin, Queensland. Australian Government Publishing Service, Canberra.

Burgis, W.A., 1974. Cainozoic history of the Torrilla Peninsula, Broad Sound, Queensland. Bureau of Mineral Resources, Australia, Report 172.

Chappell, J., 1974. Geology of coral terraces, Huon Peninsula, New Guinea: A study of Quaternary tectonic movements and sea level changes. Geological Society of America, Bulletin. 85, 553-70.

Chappell, J., 1976. Aspects of late Quaternary palaeogeography of the Australian-east Indonesia region. In Kirk, R.L., & Thorne, A.G. (editors), The Origin of the Australians. Australian Institute of Aboriginal Studies, Canberra, 11-22.

Choi, D.R., & Ginsburg, R.N., 1982. Siliclastic foundations of Quaternary reefs in the southernmost Belize Lagoon, British Honduras. Geological Society of America, Bulletin 93, 116-126.

Clarke, M.F., Wasson, R.J., & Williams, M.A.J., 1979. Point Stuart chenier and Holocene sea levels in northern Australia. Search, 10, 90-92.

Cook, P.J., 1973. Supratidal environment and geochemistry of some recent dolomite concretions, Broad Sound, Queensland, Australia. _Journal of Sedimentary Petrology_, 43, 998-1011.

Cook, P.J., & Polach, H.A., 1973a. Discovery of recent supratidal dolomite at Broad Sound, Queensland. _Search_, 4, 78-79.

Cook, P.J., & Polach, H.A., 1973b. A chenier sequence at Broad Sound, Queensland, and evidence against a Holocene high sea level. _Marine Geology_, 14, 253-68.

Cook, P.J., & Mayo, W., 1978. Sedimentology and Holocene history of a tropical estuary (Broad Sound, Queensland). _Bureau of Mineral Resources, Australia, Bulletin_ 170.

Coventry, R.J., Hopley, D., Campbell, J.B., Douglas, I., Harvey, N., Kershaw, A.P., Oliver, J., Phipps, C.V.G., & Pye, K., 1980. The Quaternary of northeastern Australia. _In_ Henderson, R.A. & Stephenson, P.J. (editors), The Geology and Geophysics of Northeastern Australia. _Geological Society of Australia (Queensland Division), Brisbane_, 375-418.

Cronin, T.M., Szabo, B.J., Ager, T.A., Hazel, J.E., & Owens, J.P., 1981. Quaternary climates and sea levels of the U.S. Atlantic coastal plain. _Science_, 211, 233-40.

Davies, P.J., 1974. Subsurface solution unconformities of Heron Island, Great Barrier Reef. _Proceedings, 2 nd International Symposium on Coral Reefs, Brisbane_, 2, 573-78.

De Keyser, F., 1964. Innisfail, Qld., 1:250 000 Geological Series. _Bureau of Mineral Resources, Australia, Explanatory Notes_ SE/55-6.

De Keyser, F., Fardon, R.S.H., & Cuttler, L.G., 1965. Ingham, Qld., 1:250 000 Geological Series. Bureau of Mineral Resources, Australia, Explanatory Notes SE/55-10.

Dowling, J.J., 1977. A grain size spectra map. Journal of Sedimentary Petrology, 47, 281-84.

Easton, A.K., 1970. The tides of the continent of Australia. Horace Lamb Centre for Oceanographic Research, Research Paper 37.

Fairbanks, R.G. & Mathews, R.K., 1978. The marine oxygen isotope record in Pleistocene coral, Barbados, West Indies. Quaternary Research, 10, 181-96.

Fairbridge, R.W., 1950. Recent and Pleistocene coral reefs of Australia. Journal of Geology, 58, 330-401.

Falvey, D.A. & Mutter, J.C., 1981. Regional plate tectonics and the evolution of Australia's passive continental margins. BMR Journal of Australian Geology & Geophysics, 6, 1-29.

Folk, R.L., & Ward, W.C., 1957. Brazos River bar, a study in the significance of grain size parameters. Journal of Sedimentary Petrology, 27, 3-27.

Frankel, E., 1971. Recent sedimentation in the Princess Charlotte Bay and Edgecumbe Bay areas, Great Barrier Reef Province. Ph.D. Thesis, University of Sydney (unpublished).

Frankel, E., 1974. Recent sedimentation in the Princess Charlotte Bay area, Great Barrier Reef Province. Proceedings, 2nd International Symposium on Coral Reefs, Brisbane, 2, 355-69.

Galehouse, J.S., 1971. Sedimentation analysis. In Carver, R.E. (editor), Procedures in Sedimentary Petrology. John Wiley, New York, 69-95.

Hails, J.R., Belperio, A.P., & Gostin, V.A, 1983. Quaternary changes of sea level in northern Spencer Gulf, South Australia. Marine Geology (in press).

Harvey, N., & Searle, D.E., 1983. Seismic investigations of late Quaternary reefal and inter-reefal sediments of the Great Barrier Reef Province. In Barnes, D.J. (editor), Perspectives on Coral Reefs. Australian Institute of Marine Science.

Heron, M.L., Harvey, N., & Hopley, D., 1979. Fourier analysis of aperiodic storm surges. Australian Geographical Studies, 17, 53-63.

Hopley, D., 1970. The geomorphology of the Burdekin Delta, North Queensland. Department of Geography, James Cook University, Monograph Series, 1.

Hopley, D., 1980. Mid-Holocene high sea levels along the coastal plain of the Great Barrier Reef Province: A discussion. Marine Geology, 35, M1-M9.

Hopley, D., & Murtha, G.G., 1975. The Quaternary deposits of the Townsville coastal plain. Department of Geography, James Cook University of North Queensland, Monograph Series, 8.

I.W.S.C., 1964. Progress report on the water resources of the Burdekin Delta. Queensland Irrigation and Water Supply Commission (unpublished).

I.W.S.C., 1967. Report on groundwater investigations, Haughton River. Queensland Irrigation and Water Supply Commission (unpublished).

I.W.S.C., 1973. Stream flow records to 1969. Queensland Irrigation and Water Supply Commission.

Jennings, J.N., & Coventry, R.J., 1973. Structure and texture of a gravelly barrier island in the Fitzroy estuary, Western Australia, and the role of mangroves in the shore dynamics. Marine Geology, 15, 145-67.

Johnson, D.P., Searle, D.E., & Hopley, D., 1982. Positive relief over buried post-glacial channels, Great Barrier Reef Province, Australia. Marine Geology, 46, 149-59.

Jones, M.R., & Stephens, A.W., 1983. Transport of beach sand around headlands, Trinity Bay, North Queensland: Implications for coastal change. Queensland Government Mining Journal, 84, 5-11.

MacNae, W., 1966. Mangroves in eastern and southern Australia. Australian Journal of Botany, 14, 67-104.

Marshall, J.F., 1977. Marine geology of the Capricorn Channel area. Bureau of Mineral Resources, Australia, Bulletin 163.

Matthews, R.K., 1973. Relative elevation of late Pleistocene high sea level stands: Barbados uplift rates and their implications. Quaternary Research, 3, 147-53.

Maxwell, W.G.H., 1968. Atlas of the Great Barrier Reef. Elsevier, Amsterdam.

Maxwell, W.G.H., & Swinchatt, J.P., 1970. Great Barrier Reef: Regional variation in a terrigenous-carbonate province. Geological Society of America, Bulletin, 81, 691-724.

Mitchum, R.M., Vail, P.R., & Thompson, S., 1977. Seismic stratigraphy and global changes of sea level, Part 2: The depositional sequence as a basic unit for stratigraphic analysis. _In_ Payton, C.E. (editor), Seismic Stratigraphy-Applications to Hydrocarbon Exploration. _American Association of Petroleum Geologists, Memoir_ 26, 53-62.

Murtha, G.G., 1975. Soils and land use on the northern section of the Townsville coastal plain, North Queensland. _CSIRO, Australia, Soils and Land Use Series_, 55.

Mutter, J.C., & Karner, G., 1980. The continental margin off northeast Australia. _In_ Henderson, R.A. & Stephenson, P.J. (editors), The Geology and Geophysics of Northeastern Australia. _Geological Society of Australia (Queensland Division), Brisbane_, 47-69.

Oliver, J., 1978. The climatic environment of the Townsville area. _In_ Hopley, D. (editor), Geographical Studies in the Townsville Area. _Department of Geography, James Cook University of North Queensland, Monograph Series, Occasional Paper_, 2, 3-17.

Ollier, C.D., 1978. Tectonics and geomorphology of the eastern highlands. _In_ Davies, J.L., & Williams, M.A.J. (editors), Landform Evolution in Australasia. _Australian National University Press, Canberra_, 5-47.

Orme, G.R., & Flood, P.G., 1980. Sedimentation in the Great Barrier Reef Province, adjacent bays and estuaries. _In_ Henderson, R.A. & Stephenson, P.J. (editors), The Geology and Geophysics of Northeastern Australia. _Geological Society of Australia (Queensland Division), Brisbane_, 419-34.

Orme, G.R., Webb, J.P., Kelland, N.J., & Sargent, G.E.G., 1978. Aspects of the geological history and structure of the northern Great Barrier Reef. Philosophical Transactions of the Royal Society of London A, 291, 23-35.

Otvos, E.G. & Price, W.A., 1979. Problems of chenier genesis and terminology - an overview. Marine Geology, 31, 251-63.

Paine, A.G.L., 1972. Proserpine, Qld., 1:250 000 Geological Series. Bureau of Mineral Resources, Australia, Explanatory Notes. SF/55-4.

Pickard, G.L., 1977. A review of the physical oceanography of the Great Barrier Reef and Western Coral Sea. Australian Institute of Marine Science, Monograph Series 2.

Purdy, E.G., 1974. Reef configurations: cause and effect. In Laporte, L.F. (editor), Reefs in Time and Space. Society of Economic Paleontologists and Mineralogists, Special Publication, 18, 9-76.

Reid, G.J., 1977. Seasonal and shorter term beach changes, Turtle Bay, North Queensland. B.A. (Hons.) Thesis, James Cook University of North Queensland (unpublished).

Rhodes, E.G., 1982. Depositional model for a chenier plain, Gulf of Carpentaria, Australia. Sedimentology 29, 201-22.

Searle, D.E., 1979. Trinity Bay continuous seismic profiling survey. Geological Survey of Queensland, Record 1979/1.

Searle, D.E., & Hegarty, R.A., 1982. Results of a continuous seismic profiling survey in the Princess Charlotte Bay area. Geological Survey of Queensland, Record 1982/17.

Searle, D.E., Harvey, N., & Hopley, D., 1980. Preliminary results of continuous seismic profiling in the Great Barrier Reef Province between 16°10'S and 19°20'S. Geological Survey of Queensland, Record, 1980/23.

Searle, D.E., Harvey, N., Hopley, D., & Johnson, D.P., 1982. Significance of results of shallow seismic research in the Great Barrier Reef Province between 16°10'S and 20°05'S. Proceedings, 4th International Symposium on Coral Reefs, Manila.

Smart, J., 1976. The nature and origin of beach ridges, Western Cape York Peninsula, Queensland. BMR Journal of Australian Geology & Geophysics, 1, 211-18.

Taylor, L.W.H., & Falvey, D.A., 1977. Queensland Plateau and Coral Sea Basin: stratigraphy, structure and tectonics. The APEA Journal, 17, 13-29.

Thom, B.G., Orme, G.R., & Polach, H.A., 1978. Drilling investigation of Bewick and Stapleton Islands. Philosophical Transactions of the Royal Society of London A, 291, 37-54.

Walker, T.A., 1981a. Dependence of phytoplankton chlorophyll on bottom resuspension in Cleveland Bay, Northern Queensland. Australian Journal of Marine and Freshwater Research, 32, 981-86.

Walker, T.A., 1981b. Annual temperature cycle in Cleveland Bay, Great Barrier Reef Province. Australian Journal of Marine and Freshwater Research, 32, 987-91.

Wiebenga, W.A., Polak, E.J., Andrew, J.T.G., Wainwright, M. & Kevi, L., 1975. Burdekin Delta underground water investigation, North Queensland, 1962-1963. Bureau of Mineral Resources, Australia, Report, 177.

Wolanski, E., & Jones, M., 1981. Physical properties of Great Barrier Reef lagoon waters near Townsville, I. Effects of Burdekin River floods. Australian Journal of Marine and Freshwater Research, 32, 305-19.

Wolanski, E., & Ruddick, B., 1981. Water circulation and shelf waves in the northern Great Barrier Reef lagoon. Australian Journal of Marine and Freshwater Research, 32, 721-40.

TABLE 1 : Lithology, morphology and grain size statistics for sediments of the intertidal zone.

ENVIRONMENT	MORPHOLOGY	LITHOLOGY	n[1]	% $CaCO_3$	% Org.	% Terrig.	Terrigenous Fraction % Sand	% Silt	% Clay	Ø Mean	Ø St.Dev.	Skew.	Kurt.
River mouth shoals	Broad peritidal flats to 3 km wide; ridge & runnel topography	Immature, coarse arkosic sand & gravel; mafic & heavy minerals	4	0.5	0.0	99.5	98.9	0.8	0.3	0.9	0.8	0.0	0.8
Beach	Low angle, dissipative with low tide terrace; confined to bay-headland cells with little off-shore movement[3]	Mod. well sorted arkosic sand; higher carbonate away from coastal rivers	5	2.7	0.4	96.9	99.9	0.1	0.0	1.5	0.8	0.0	1.1
Barrier-bar	Beach-dune complex rising to 12 m, 0.5 km wide, 4 km long, with associated lagoon	Immature, mod. to poorly sorted arkosic sand	5	2.5	0.4	97.1	98.9	0.2	0.9	1.5	1.0	0.2	1.4
Chenier	Elongate ridges to 3 m high, 50 m wide, 4 km long; rest on mangrove mud	Mod. to poorly sorted arkosic sand; up to 30% mollusc debris	2	16.0	0.6	83.4	99.5	0.2	0.2	2.0	1.0	0.3	1.2
Tidal sandflat	Broad, low tide flats, 2 km wide	Mod. to poorly sorted, arkosic silty sand; clay drapes & flaser bedding	6	4.2	1.0	94.8	97.3	1.2	1.5	2.4	0.8	0.1	1.2
Tidal mudflat	Broad, low tide flats, 2 km wide	Soft, organic, poorly sorted grey-brown mud; bioturbated & structureless	9	9.2	6.2	84.6	8.2	39.3	52.5	7.4	2.1	-0.4	0.5
Mangrove woodland	Broad mid-tide flats, 3 km wide, zonation of mangrove species[4]	Organic, allocthonous, anoxic mud; bioturbated & structureless	36[2]	4.1	7.0	88.9	9.1	30.2	60.7	7.3	2.3	-0.5	0.8
High tide mudflat	Bare flats within & behind mangrove forest to 3 km wide; Algal & halophyte association	Brown, silty algal-laminate clay; predominance of kaolinite[5]	31[2]				6.0	24.0	70.0				
Supratidal flat	Bare, unvegetated flats to 5 km wide; salt pan depressions, salting scarps & clay dunes	Mottled gypseous plastic mud; dolomitic in subsurface[6]											

1. n = number of samples averaged
2. additional data of Aliano (1978)
3. Reid (1977), Belperio (1978), Jones & Stephens (1983)
4. Macnae (1966), Aliano (1978)
5. Aliano (1978)
6. Cook (1973), Cook & Polach (1973a)

TABLE 2 : Progradation rates for the coastal plain sections shown in Fig. 2 (after Belperio, 1978).

Environment	Progradation rate (km/1000 yr.)
Beach ridge plain	1.1(A), 0.8(E), 0.3(I), 0.1(F)
Chenier plain	1.9(D), 2.0(K)
Mangrove-mudflat	1.4(H)
Barrier bar-lagoon	2.5(C), 1.5(J), 1.1(G)

FIGURE CAPTIONS

Fig. 1:Locality map and physiography of the coastal plain and continental shelf in the Townsville region of north Queensland.

Fig. 2:Geomorphology of the Townsville and Burdekin coastal plain. Also shown are location of auger holes, C-14 dated samples, coastal progradation sections, and subsurface occurrences of Holocene marine sediments beneath the flood plain.

Fig. 3:Schematic representation of the relationships between tide level, wave energy and depositional environments.

Fig. 4:Four prograding coastal assemblages; (a) beach ridge plain; (b) chenier plain; (c) mangrove forest-mud flat plain; and (d) barrier bar-lagoon complex.

Fig. 5:The chenier plain coastline of central Bowling Green Bay. The narrow seaward mangrove fringe (a) is backed by high tide mud flats (b), supratidal flats (c) and isolated chenier ridges (d).,

Fig. 6:The most seaward chenier of the Bowling Green Bay coastal plain. Mangroves (a) are colonizing the tidal sand flat (b), and older outcropping mangrove strata (c) underlies the chenier sand ridge (d).

Fig. 7:The prograding mangrove forest in southeastern Bowling Green Bay. Bare high tide mud flats (a) are present within and behind the mangrove forest (b). Supratidal flats (c) are in the background.

Fig. 8:Migration of barrier bars (1942-1947) and the end of Cape Bowling Green (1942-1977) interpreted from historical aerial photographs (after Belperio, 1978).

Fig. 9:Carbonate component of shelf sediments; (a) total acid soluble carbonate, (b) % gravel of total carbonate.

Fig. 10:Terrigenous grain size component variations, (a) % clay, (b) % silt, (c) % gravel, (d) mean grain size, (e) standard deviation, (f) skewness, (g) grain size spectra map for shore-normal transect in Halifax Bay, (h) grain size spectra map for shore-normal transect at the Burdekin River mouth.

Fig. 11:Periods of pedogenesis and marine sedimentation on the inner shelf (<20 m) during the late Quaternary. Note periods of low mean annual rainfall associated with subaerial exposure of the shelf and high mean annual rainfall associated with periods of marine sedimentation. Sea level curve after Bloom & others (1974) and Chappell (1974, 1976) and rainfall curve after Kershaw in Coventry & others (1980).

Fig. 12:Seismic stratigraphic elements of the prograding Holocene coastal wedge in Bowling Green Bay (terminology after Mitchum & others, 1977) and model of late Pleistocene deposition on the inner shelf (125k, 105k and 82k yr B.P. sea level highs were below present sea level). This model assumes fluvial aggradation or degradation have been ineffective during low sea level periods and palaeosols delimit the former individual marine units. Coastal plain data are from I.W.S.C. (1967).

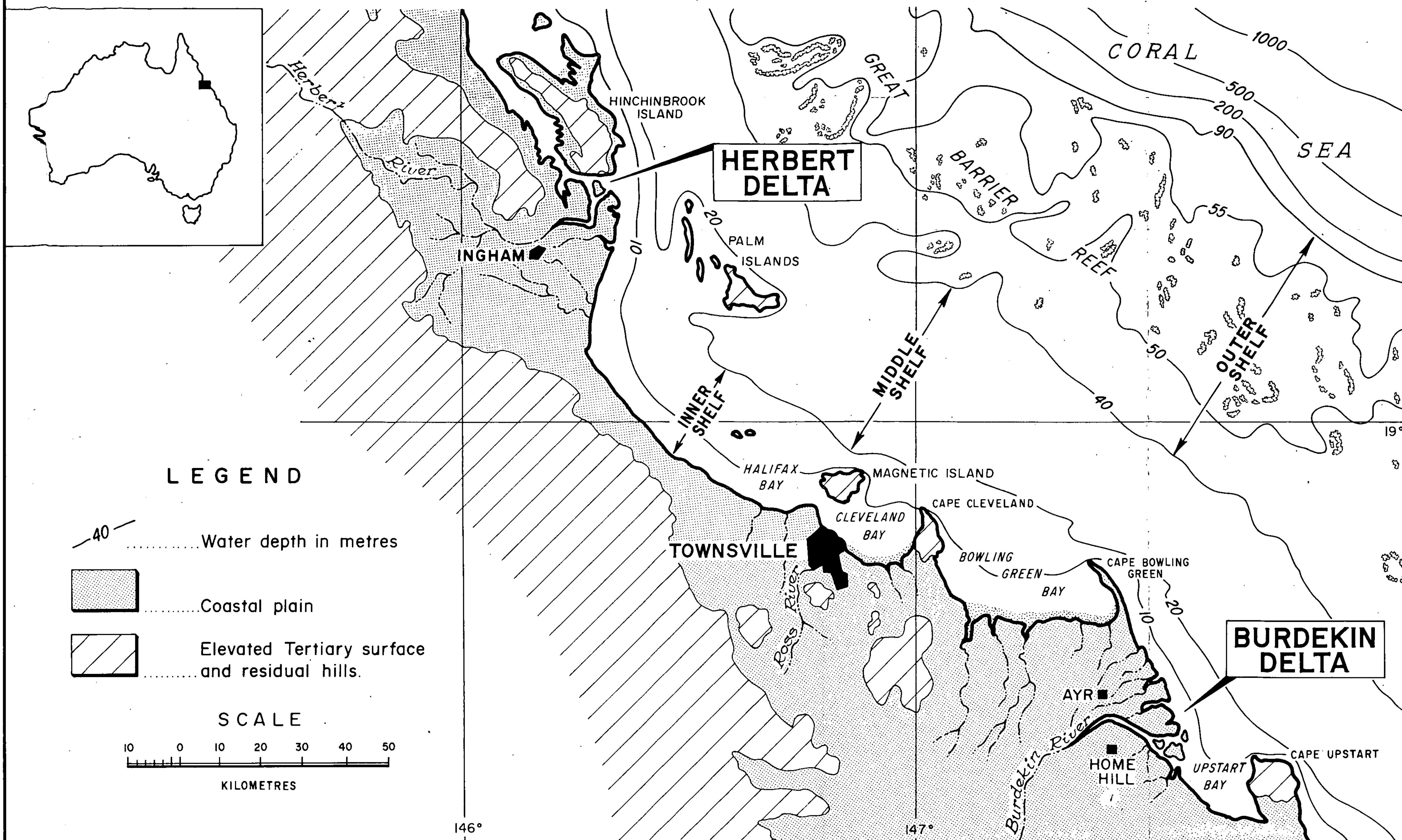

Figure 1

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

THE BURDEKIN REGION – QUEENSLAND

PHYSIOGRAPHY OF THE HERBERT TO BURDEKIN REGION

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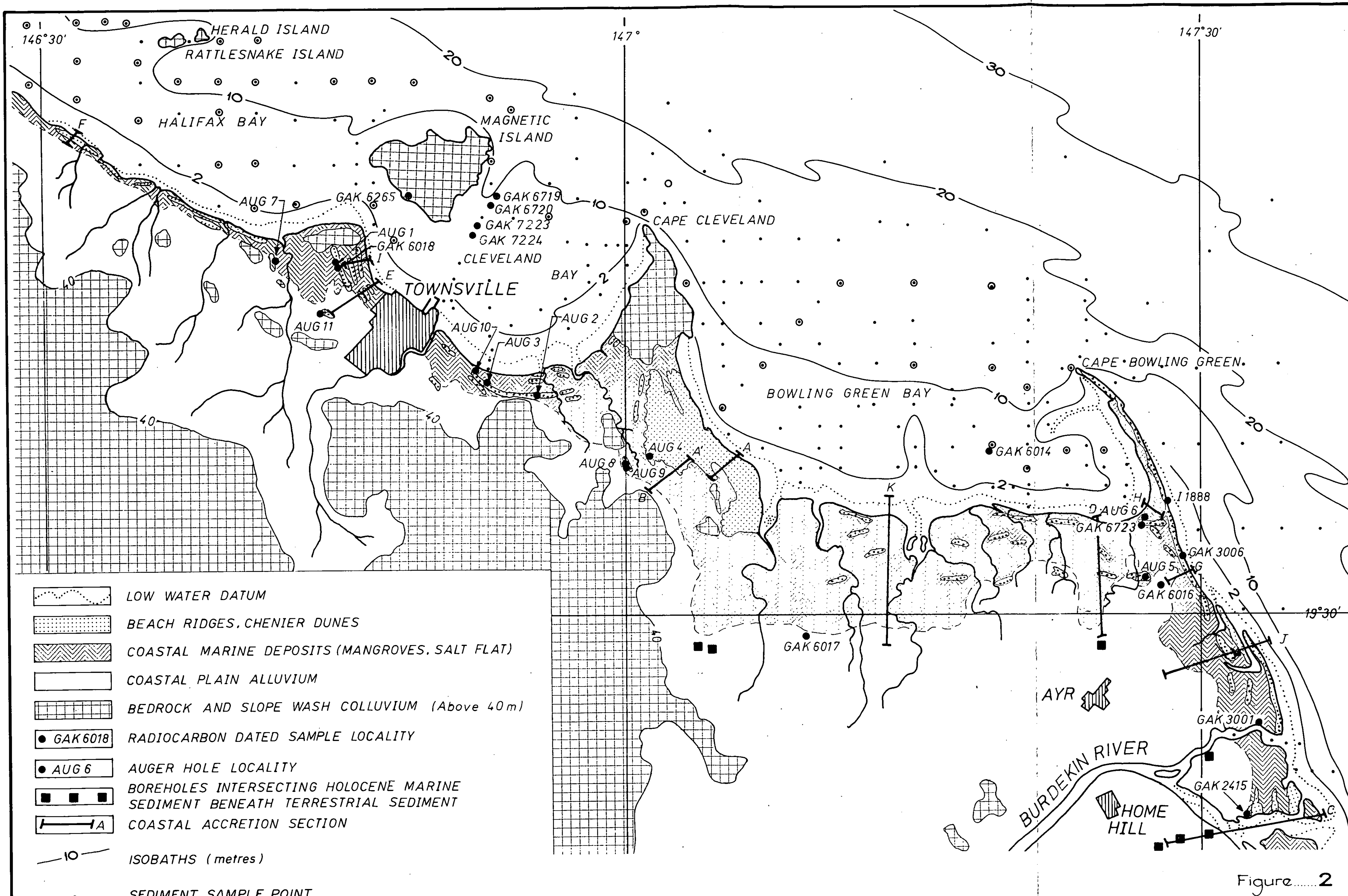

Figure 2

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

THE BURDEKIN REGION – QUEENSLAND

GEOMORPHOLOGY OF THE BURDEKIN AND TOWNSVILLE COASTAL PLAIN

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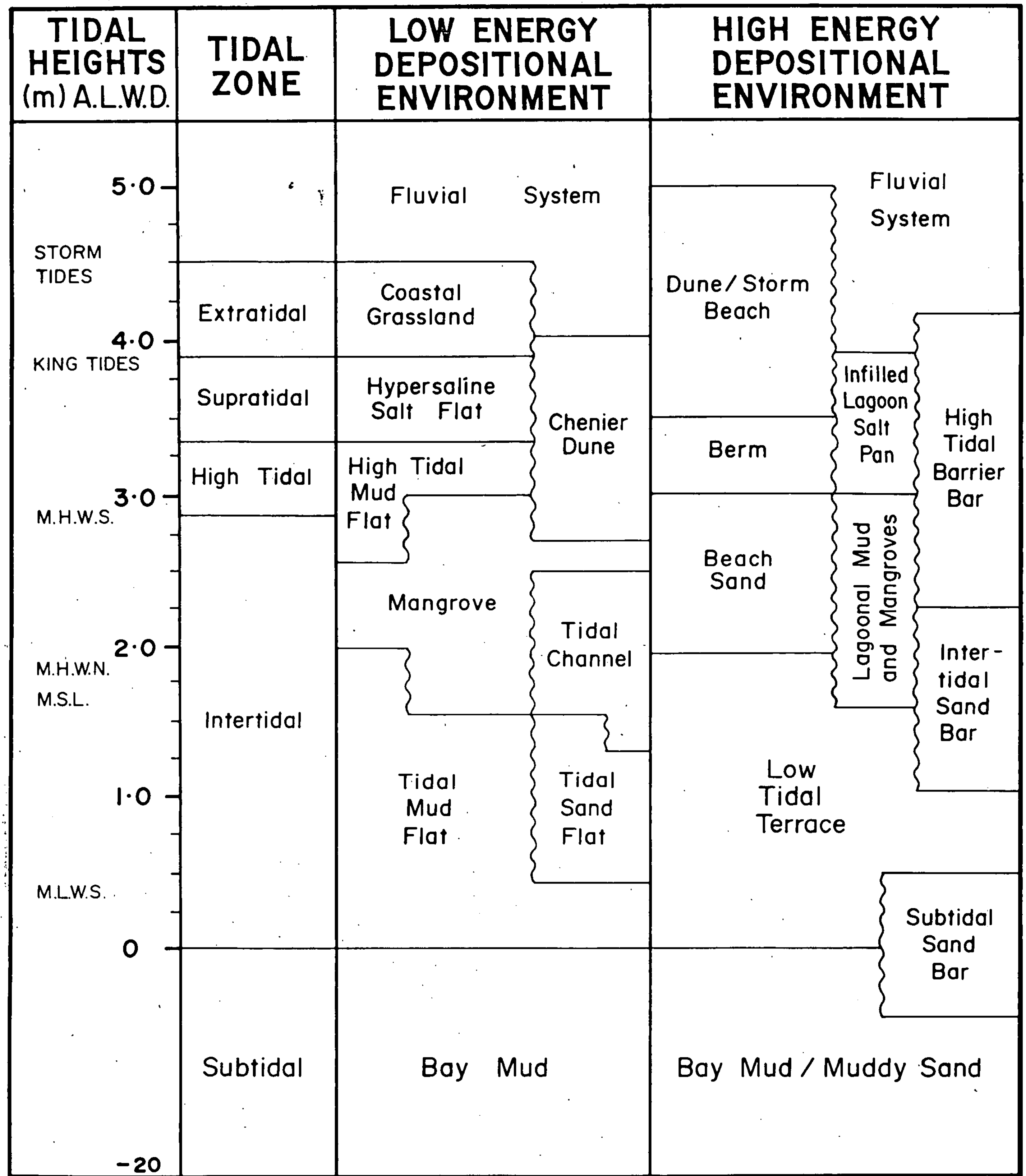

A.L.W.D. .... Above Low Water Datum
M.H.W.S. .... Mean High Water Springs (2·9 m)
M.H.W.N. .... Mean High Water Neaps (1·95 m)
M.S.L. .... Mean Sea Level (1·59 m)
M.L.W.S. .... Mean Low Water Springs (0·4 m)

Figure 3

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

THE BURDEKIN REGION - QUEENSLAND

RELATION BETWEEN TIDE LEVEL, WAVE ENERGY AND DEPOSITIONAL ENVIRONMENT

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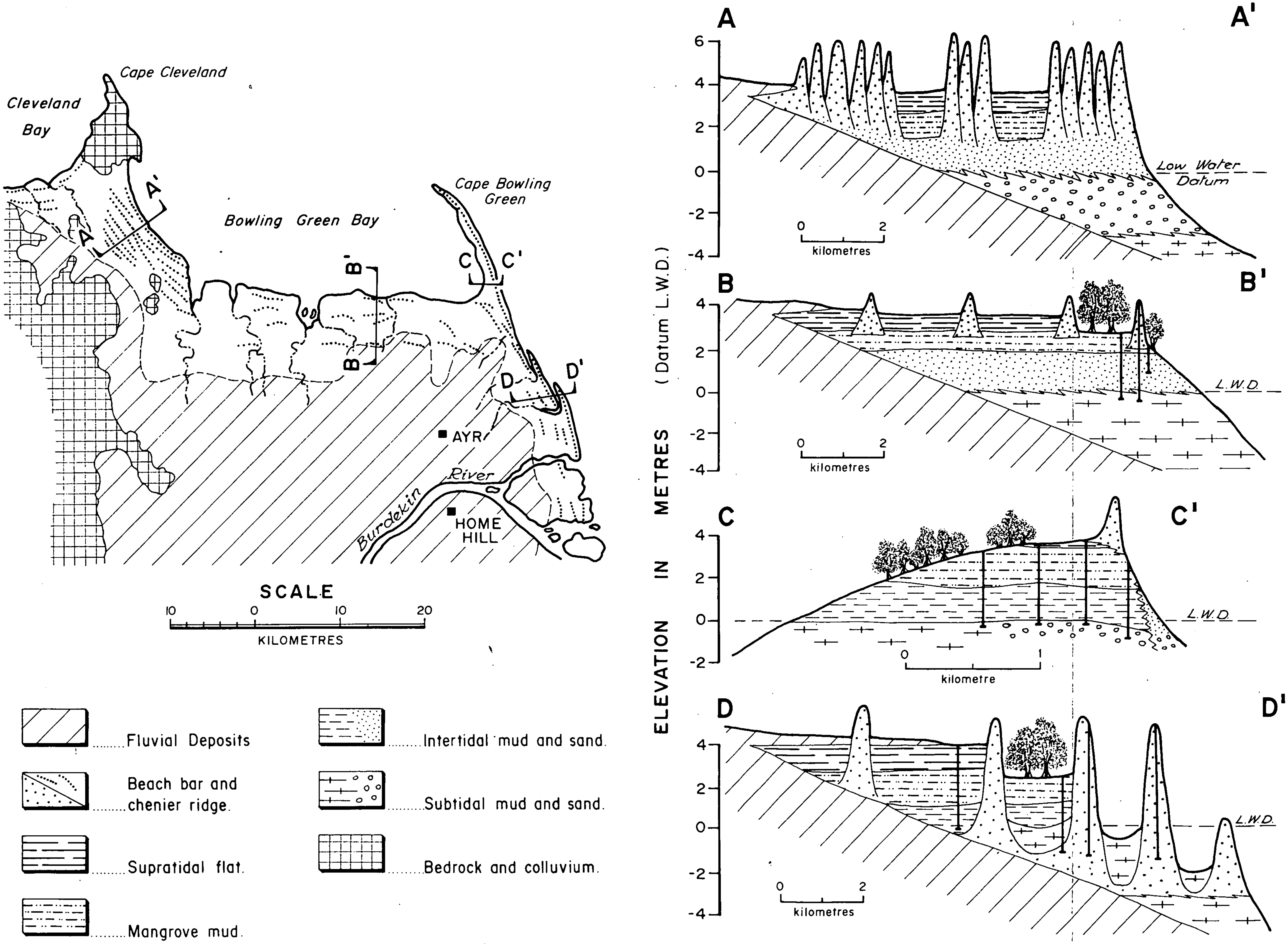

Figure 4

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

THE BURDEKIN REGION - QUEENSLAND

FOUR PROGRADING COASTAL ASSEMBLAGES

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DATE June '83	PLAN NUMBER	
CHECKED	83-240	

3137

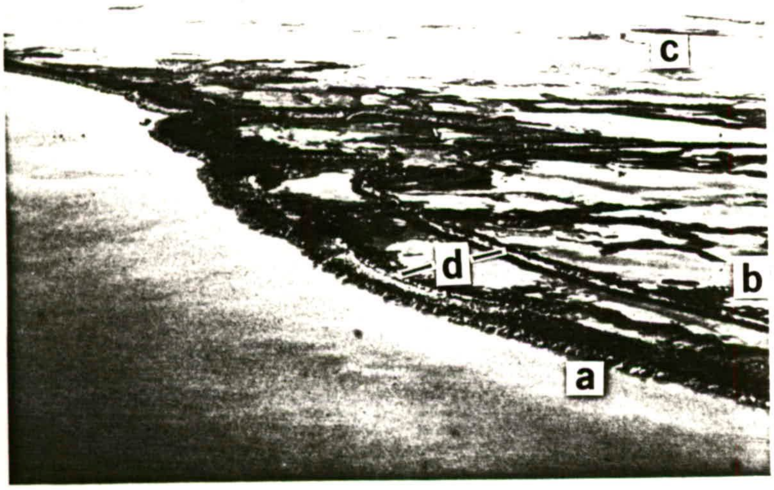

Figure 5. Chenier plain coastline showing mangrove fringe (a), high tide mudflats (b), supratidal flats (c) and chenier ridge (d).

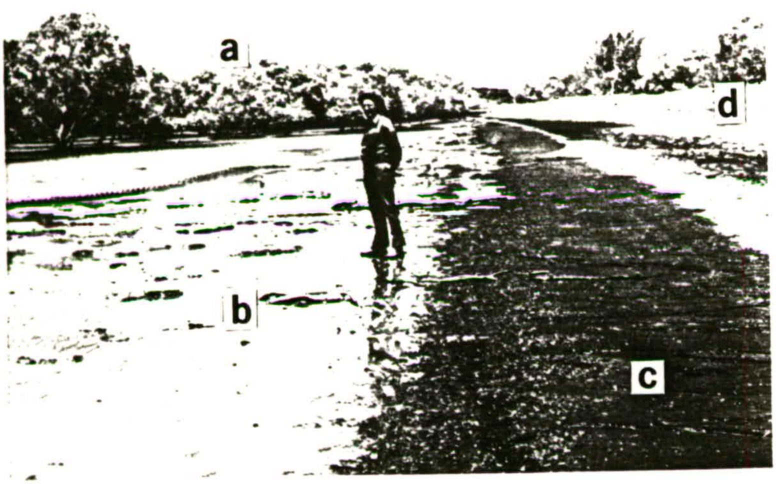

Figure 6. Mangroves (a) colonizing the modern tidal sand flat (b). An outcropping older mangrove stratum (c) underlies the chenier ridge (d).

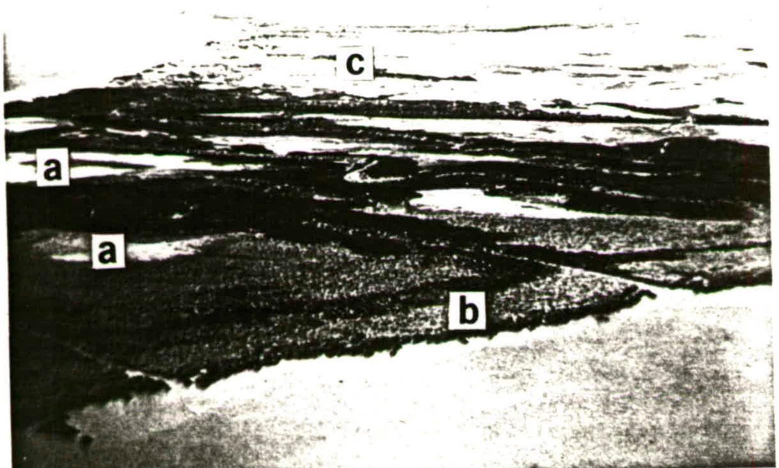

Figure 7. Prograding mangrove forest coastline. Bare high tide mudflats (a) occur within and behind the mangrove forest (b). Supratidal flats (c) are in the background.

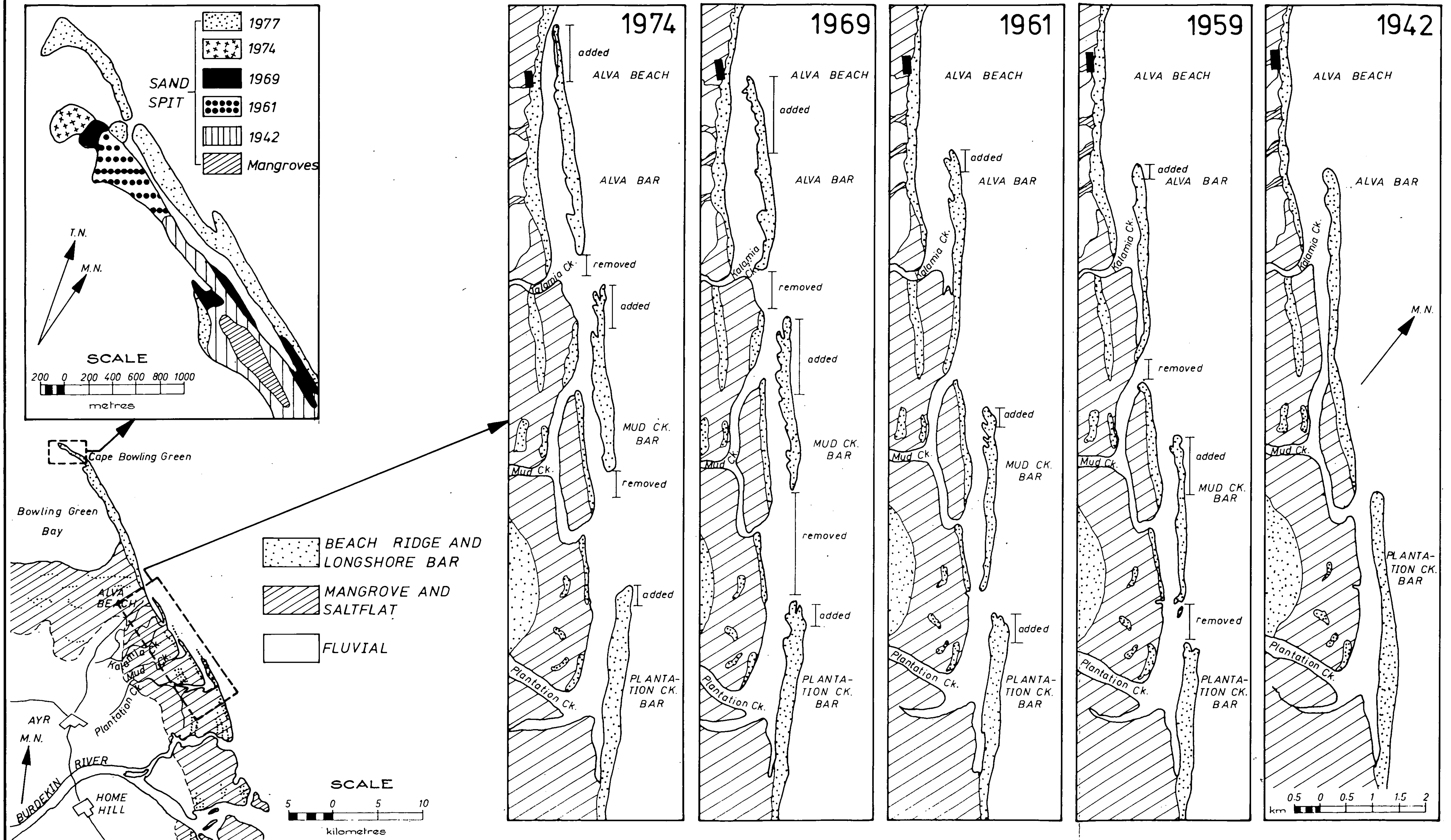

Figure 8

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

THE BURDEKIN REGION - QUEENSLAND

MIGRATION OF BARRIER BARS AND THE END OF CAPE BOWLING GREEN

COMPILED T.B.	C.D.O. 25 7 83 DATE
DRAWN T.B.	SCALE As shown
DATE June '83	PLAN NUMBER
CHECKED	83-242

3137

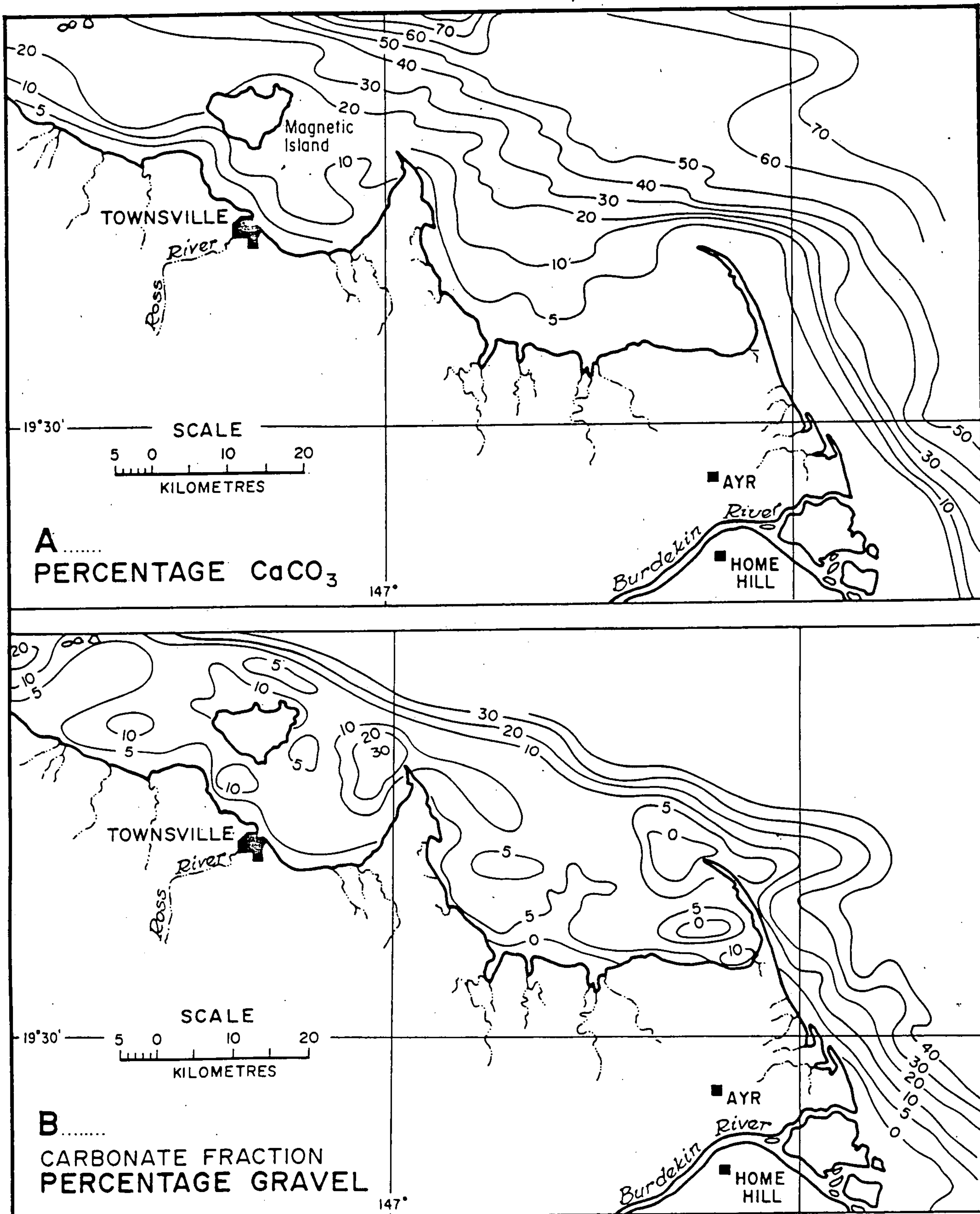

Figure........9

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

THE BURDEKIN REGION – QUEENSLAND

CARBONATE COMPONENTS OF SHELF SEDIMENTS

COMPILED T.B.	C.D.O.	DATE 25·7·83
DRAWN M.R.	SCALE As shown	
DATE June '83	PLAN NUMBER	
CHECKED	S 16694	

3137

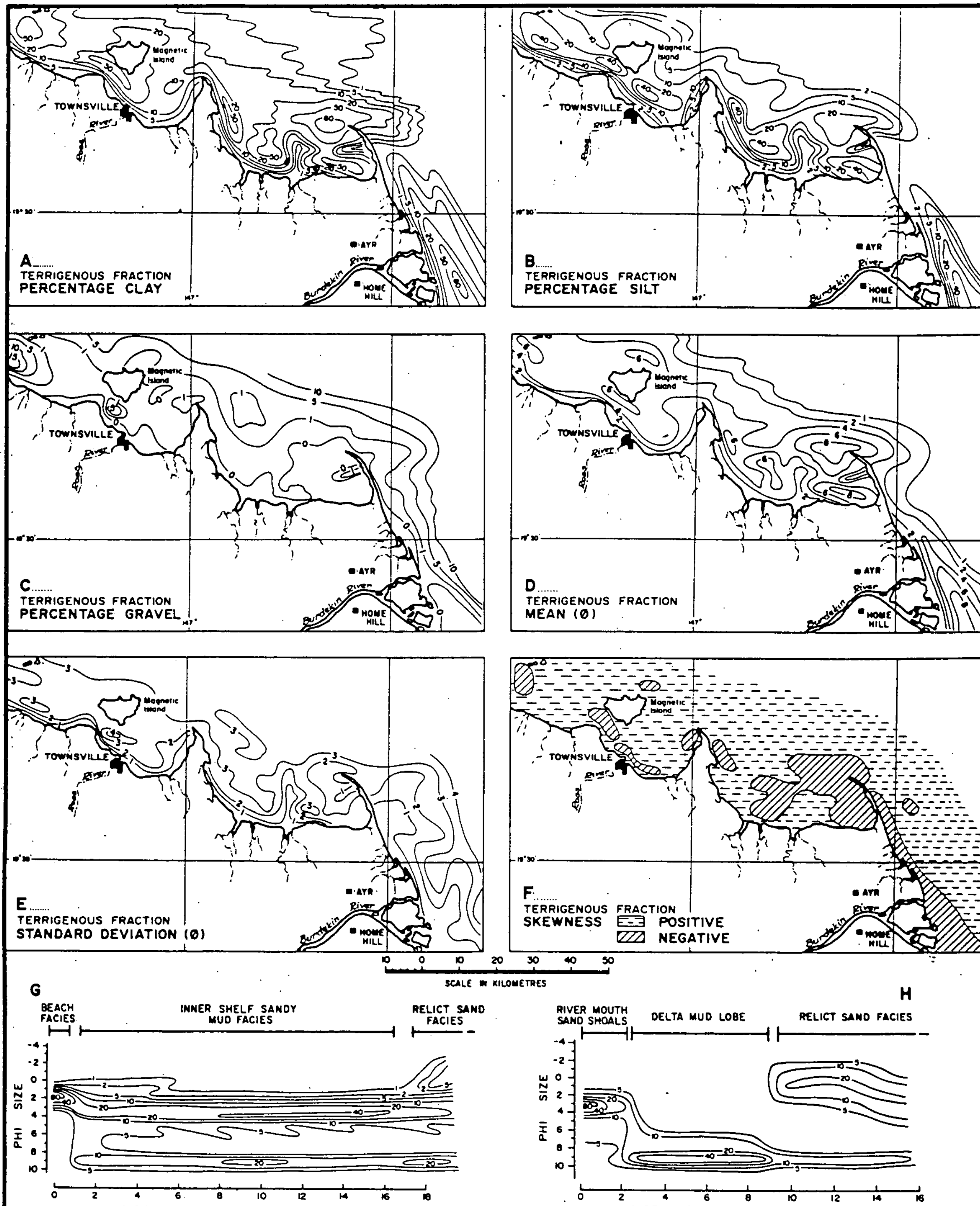

Figure 10

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED T. B.	C.D.O. 25·7·83 DATE
THE BURDEKIN REGION - QUEENSLAND	DRAWN M.R.	SCALE As shown
TERRIGENOUS GRAIN SIZE DATA	DATE June '83 / CHECKED	PLAN NUMBER S 16696

3137

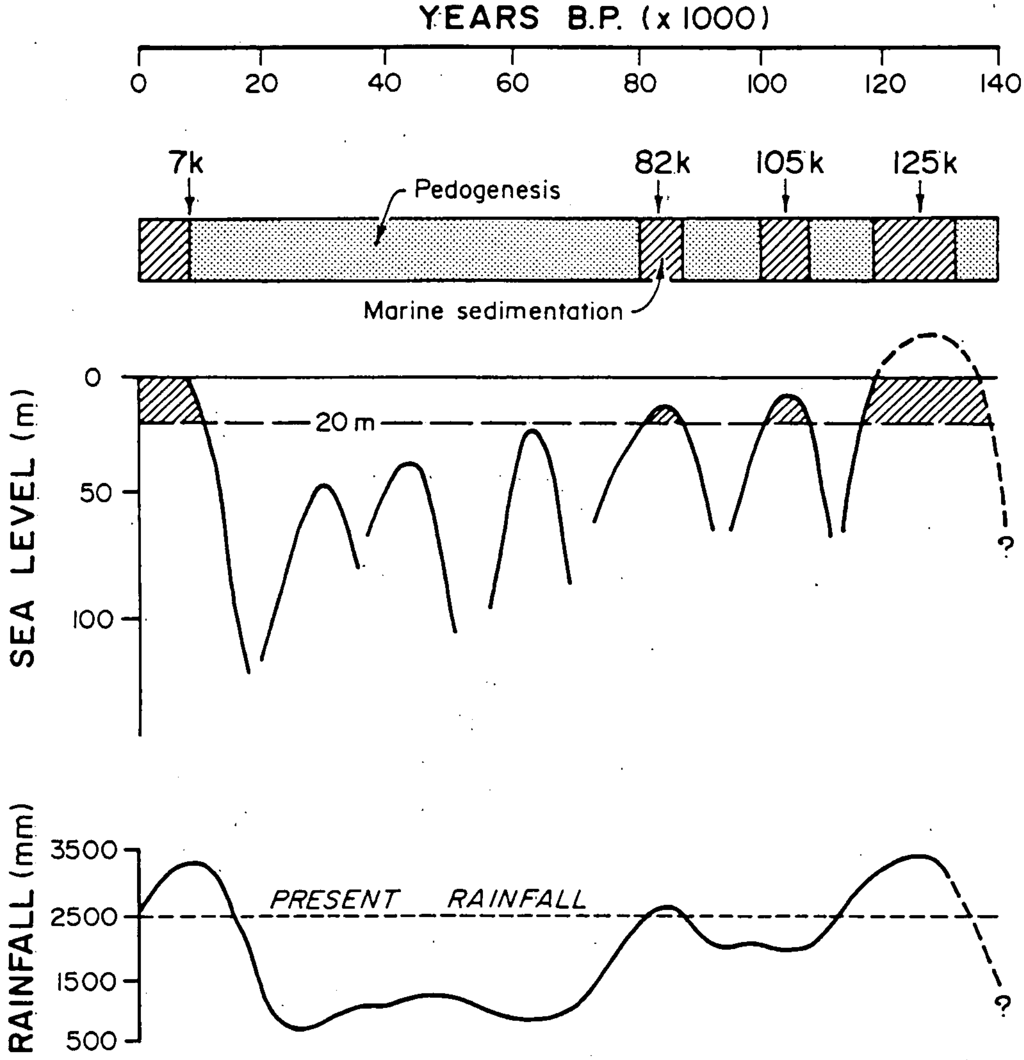

Figure 11

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

THE BURDEKIN REGION – QUEENSLAND

LATE QUATERNARY SEA LEVELS AND RAINFALL

COMPILED	T.B.	C.D.O.	DATE 25·7·83
DRAWN	M.R.	SCALE	
DATE	June '83	PLAN NUMBER	S 16695
CHECKED			

3137

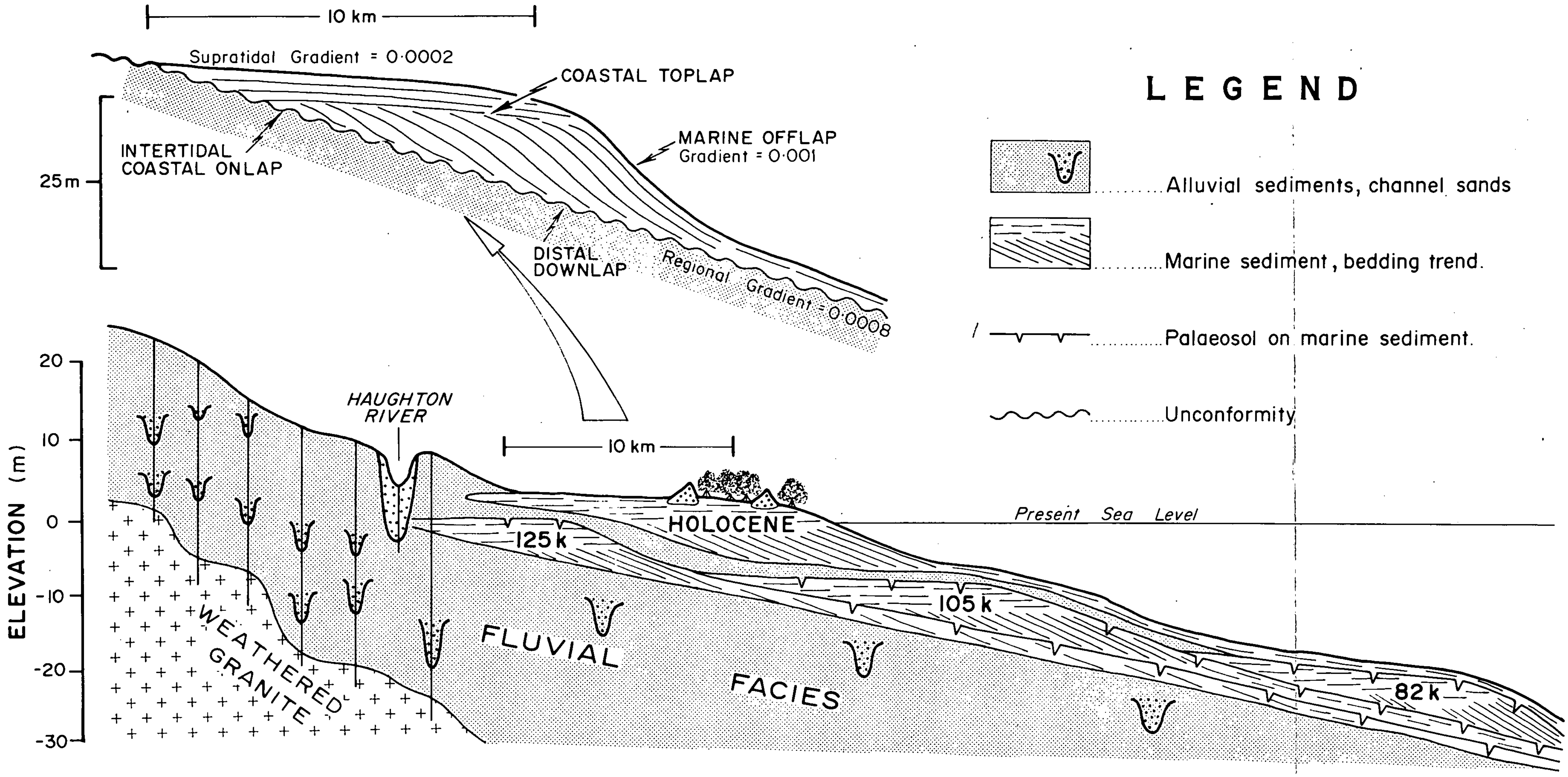

Figure 12

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED T.B.	C.D.O. 25·7·83 DATE
THE BURDEKIN REGION – QUEENSLAND	DRAWN M.R.	SCALE N.T.S.
LATE QUATERNARY STRATIGRAPHY OF THE INNER SHELF	DATE June '83 CHECKED	PLAN NUMBER 83-241

3137