REPORT 172

Cainozoic History of the Torilla Peninsula, Broad Sound, Queensland

W. A. BURGIS

DEPARTMENT OF MINERALS AND ENERGY
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SUMMARY

Alluvium shed from highlands on the Torilla Peninsula was deposited in fans during the Tertiary. Bedrock and alluvium were lateritized during upper Tertiary time. During the Quaternary the lateritic soil profile was eroded in the highlands, and alluviation of the lowlands resumed. Some remnants of the Tertiary land surface were preserved in the lowlands, and further weathering of the relict lateritic profile under Quaternary climatic conditions has produced red earth soils and circular depressions. Alluvium has been partly indurated as soil hardpans during Cainozoic time.

During the last low stand of the sea in the late Pleistocene, marine and fluvial sediments were exposed to weathering. The sea transgressed across the surface to reach its maximum shoreline at the coastal grassland/upland boundary on the Torilla Plains about 6000 years ago. Cliffs were cut at this shore as the sea stabilized at its present level. The rate of sediment supply was greater than the rate of sediment removal, and the shoreline prograded. The intertidal, supratidal, and extratidal environments migrated seaward as the sea retreated, burying shallow marine and intertidal sand and mud, by mud deposited in mangrove swamps and on supratidal flats. Cheniers were built during periods of meagre sediment supply. Grass has colonized areas of the Torilla Plains now rarely inundated by sea water, and streams are depositing alluvial fans over the Holocene marine sediments.

Progradation of the Torilla Plains has changed the shape of the Broad Sound estuary. Today the rates of sediment supply and of tidal erosion are in equilibrium. Sediment eroded from one section of the shoreline is deposited in adjacent areas.

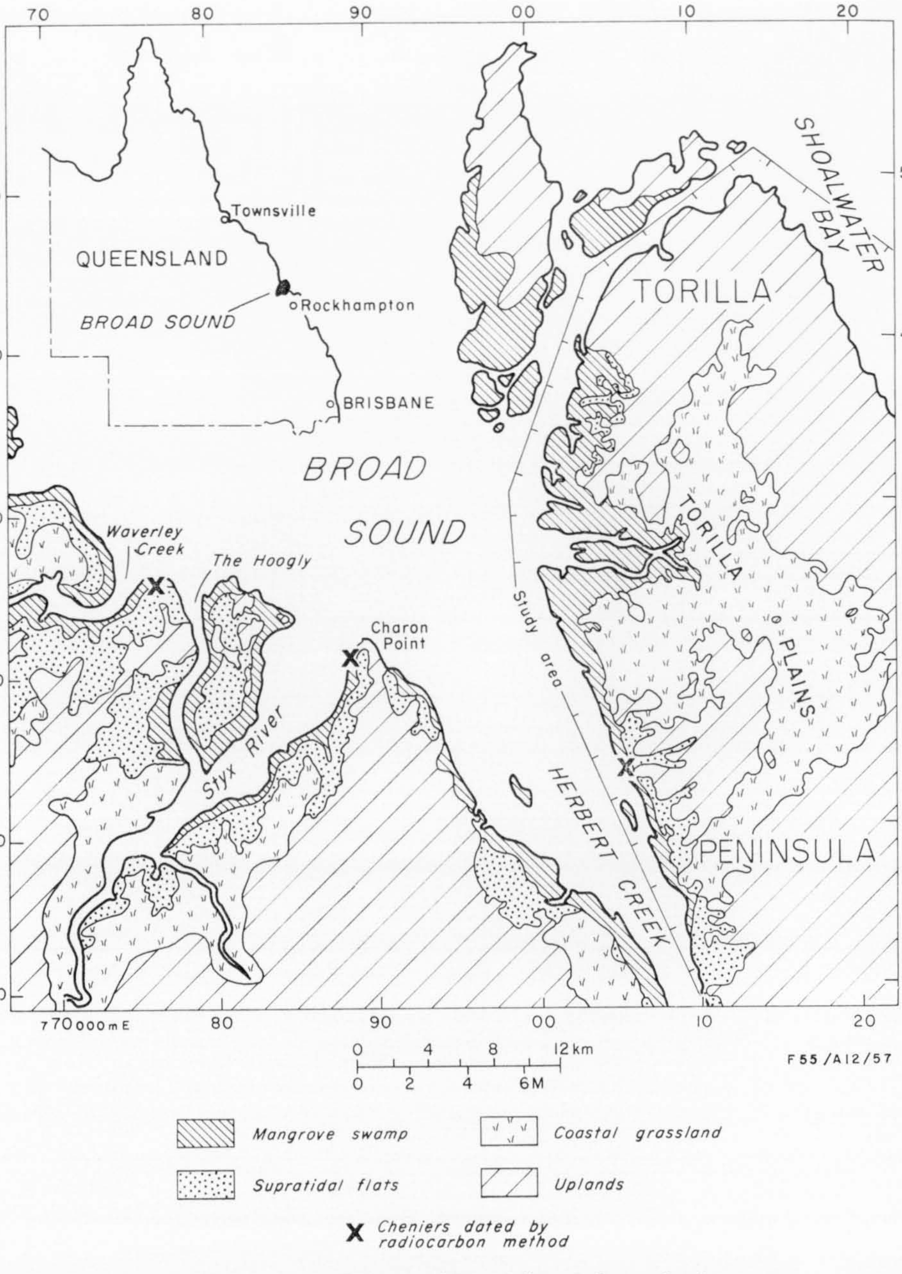


Fig. 1 — Locality map of Broad Sound, Queensland.

INTRODUCTION

In 1970 the Bureau of Mineral Resources began a comparative study of modern sedimentation in a tropical estuary (Broad Sound, Queensland) and in a temperate estuary (Mallacoota Inlet, Victoria). The Cainozoic history of an estuary has a marked influence on the distribution of modern sediments and sedimentary environments, and therefore Cainozoic events were studied as part of the Estuary Study Project. Previous investigations (Malone, Olgers, & Kirkegaard, 1969; Kirkegaard, Shaw, & Murray, 1970; Malone, 1970) established the general outlines of the Cainozoic history of the Broad Sound area. Cook & Polach (1973) discussed the Holocene history of the chenier plain on the western shore of Broad Sound. Cook & Mayo (in press) present a comprehensive account of the sedimentology and Quaternary history of the Broad Sound estuary. This report focuses on evidence which elaborates the Cainozoic history of the peninsula east of Broad Sound, which Jardine (1928) called the Torilla Peninsula (Fig. 1). It also documents subsurface data which present a detailed history of the Holocene progradation of the grassed Torilla Plains.

Shallow stratigraphic holes were drilled, and surficial sediments and landforms mapped on the Torilla Peninsula. Drilling sites were selected before the 1971 field

TABLE 1. DRILL-HOLE STATISTICS

Drill Hole	*Total Depth (m)*	*Total Core (m)*	*Thickness of Holocene Marine Sediment (m)*
Port Clinton 1	5.79	2.59	3.56
Port Clinton 2	13.72	2.41	0.56
Port Clinton 3	9.17	3.61	2.08
Port Clinton 4	4.64	3.07	3.09
Port Clinton 5	35.97	6.45	3.89
St Lawrence 1	1.83	—	—
St Lawrence 2	8.84	5.87	5.10

TABLE 2. AUGER-HOLE STATISTICS

Auger Hole	*Total Depth (m)*	*Thickness of Holocene Marine Sediment (m)*
1	3.38	3.04
2	2.38	2.38
3	2.74	2.74
4	2.90	0.20
5	2.04	2.04
6	1.79	1.78
7	2.87	2.86
8	3.67	3.67
9	3.06	3.06
10	3.06	3.06
11	2.96	2.88
12	2 00	1.82
13	2.51	1.08
14	4.20	4.20
15	2.46	—
16	3.20	—

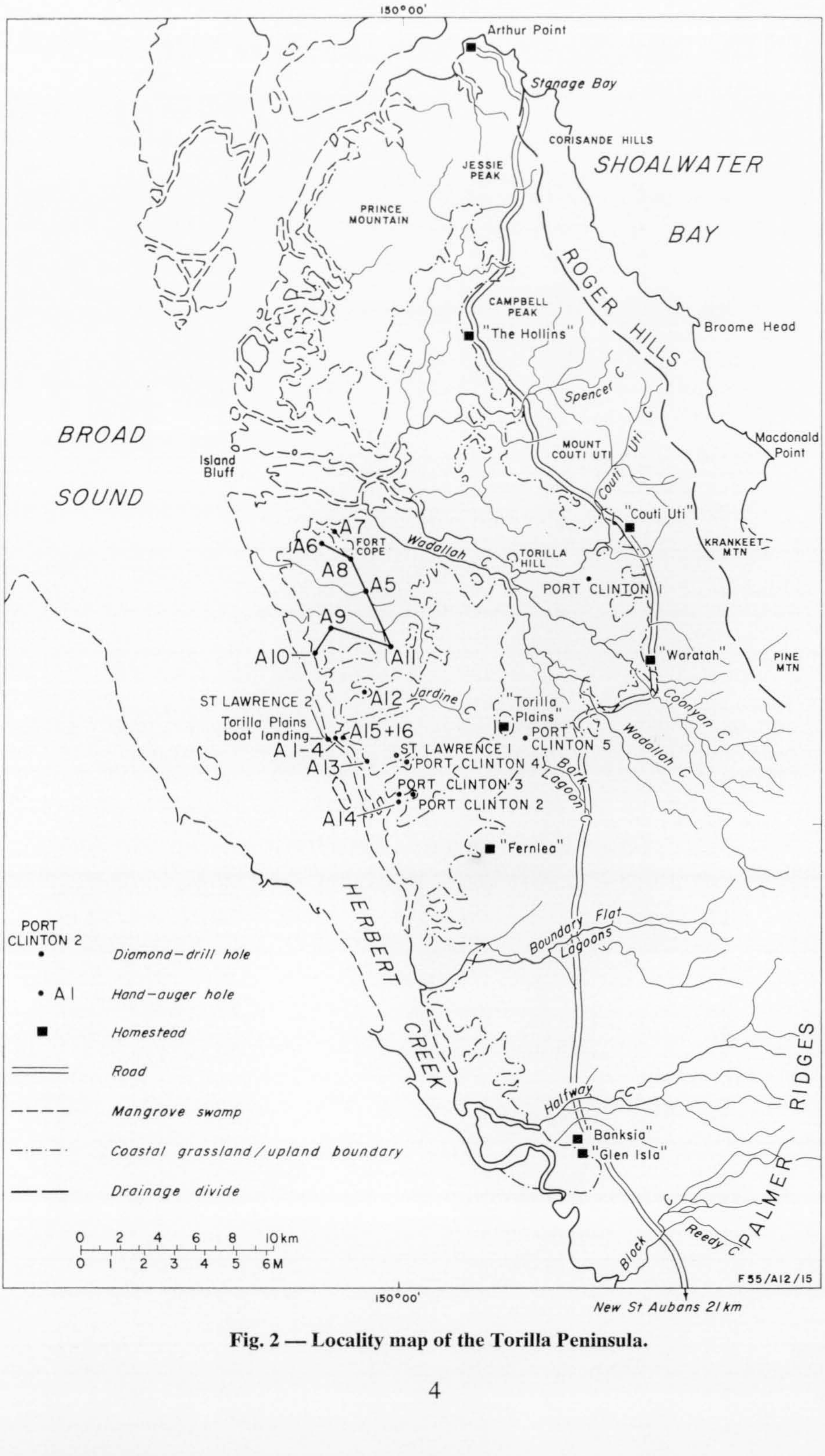


Fig. 2 — Locality map of the Torilla Peninsula.

season along traverses at several latitudes across the grassed coastal plains, but many were inaccessible because of very heavy rain. Hand-auger holes sunk by P. J. Cook and W. Mayo in areas inaccessible to the drilling rig extend the area from which subsurface information is available (Fig. 2). In seven diamond-drill holes a total of 80.0 m was drilled, 24.0 m of which was cored. Individual holes range from 1.8 to 36.0 m deep (Table 1) and usually terminate in pre-Tertiary basement or deeply weathered alluvium. The depth of hand-auger holes was restricted by the poor recovery of deeper sediments owing to their high water content. A total of 45.2 m of sediment was augered in 16 holes which range from 1.8 to 4.2 m deep and have an average depth of 2.8 m (Table 2). Surficial mapping was limited to the eastern edge of the coastal grassland between Torilla Plains homestead and The Hollins (Figs. 2, 4) and to wooded uplands west of Torilla Plains homestead. A map of Cainozoic geology (Fig. 4) was compiled from these data, from geological, topographic and land system maps (Malone, Olgers, & Kirkegaard, 1969; Kirkegaard, Shaw, & Murray, 1970; Malone, 1970; Gunn et al., 1972), and from airphoto interpretation.

The Geological Society of America Rock-color Chart has been used for soil and rock colour determinations.

General Geography

The Torilla Peninsula lies within the St Lawrence and Port Clinton 1:250 000 Sheet areas.

The area has a subtropical, subhumid climate. Rainfall averages 1000 mm per annum and is concentrated in the summer months. Flooding is restricted to summer, and streams are lowest in late winter and early spring (Commonwealth Bureau of Meteorology, 1965).

The tidal range at the head of Broad Sound is about 10 m (Maxwell, 1968).

Geomorphology

The Torilla Peninsula lies in the coastal highlands and coastal plains landform zones of the Fitzroy region (Galloway, 1967). The boundary between them runs roughly southeastwards down the peninsula from Prince Mountain to Waratah homestead (Fig. 2) and separates hilly land with peaks rising to 375 m in the east from a broader area of plains and rolling country in the west.

Lower Palaeozoic metamorphic rocks form Prince Mountain in the highland zone (Fig. 3). The Roger Hills are composed of the same resistant metamorphic rocks and constitute the highest section of the drainage divide which runs along the eastern edge of the peninsula (Fig. 2). South of Couti Uti homestead alluvium and colluvium cover highland slopes west of the drainage divide (Fig. 4). Relatively high land is close to the shore on the western coast of Shoalwater Bay, where the development of mangrove swamps, supratidal flats, and coastal grassland is restricted to small areas in sheltered inlets (Galloway, 1967). Some inlets are protected by old beach ridges which line sections of this shore (Fig. 4).

Coastal grasslands cover extensive flat areas of unconsolidated marine sediments from the highlands westward to a broad zone of supratidal flats and mangrove swamps on the eastern coast of Broad Sound and Herbert Creek (Fig. 4). Supratidal flats occupy small patches on the flanks of the relatively steep highlands of the Prince Mountain area (Figs. 2, 4), but are extensive adjacent to the low rolling uplands of the coastal plains south of Fort Cope.

Low hills protrude through broad colluvial-alluvial plains in the valleys of Coonyan, Wadallah, Bark Lagoon, Boundary Flat Lagoons, Halfway, and Block Creeks in the southern part of the coastal plains zone (Figs. 2, 4). The upland area

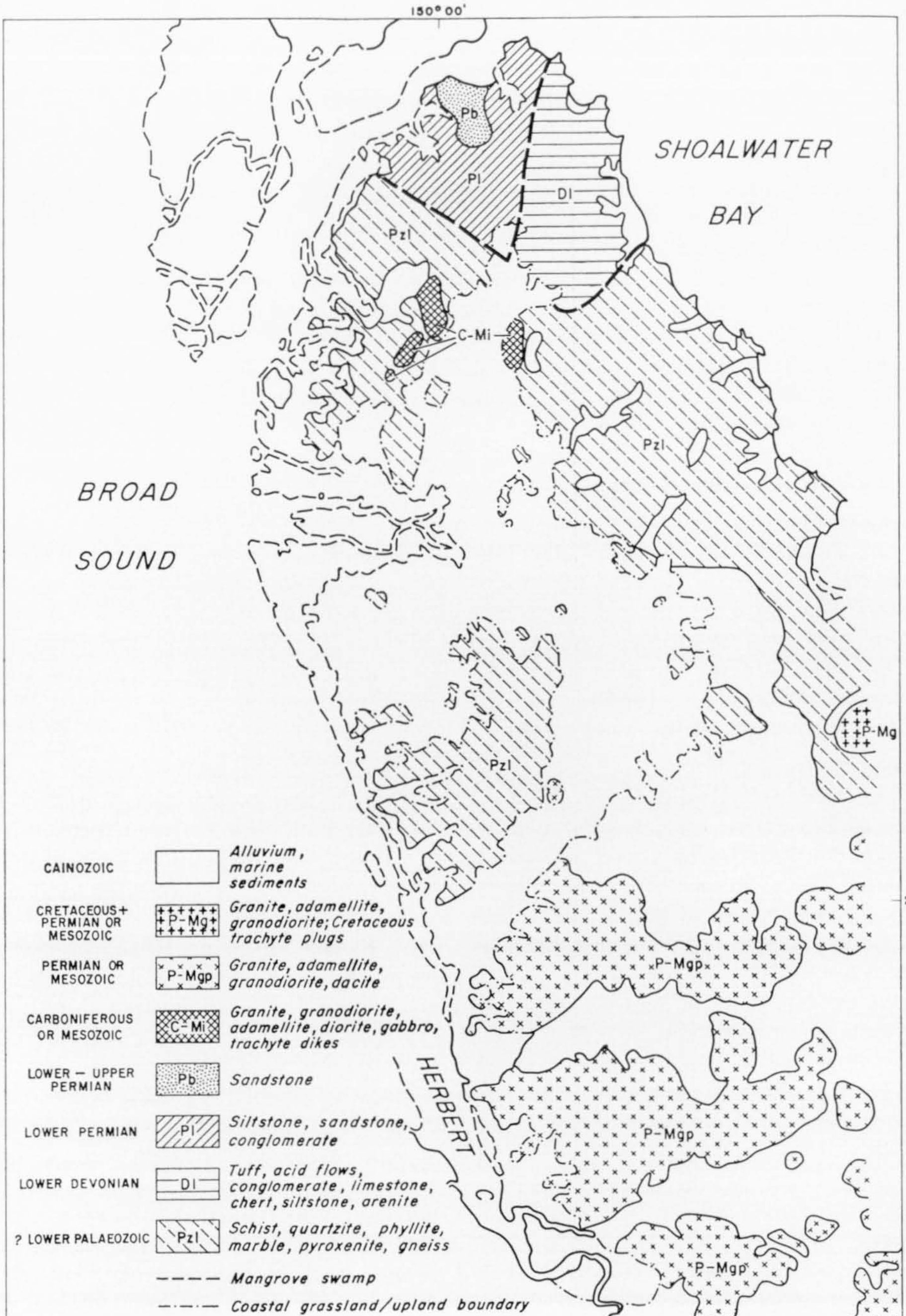


Fig. 3 — Bedrock geology of the Torilla Peninsula.

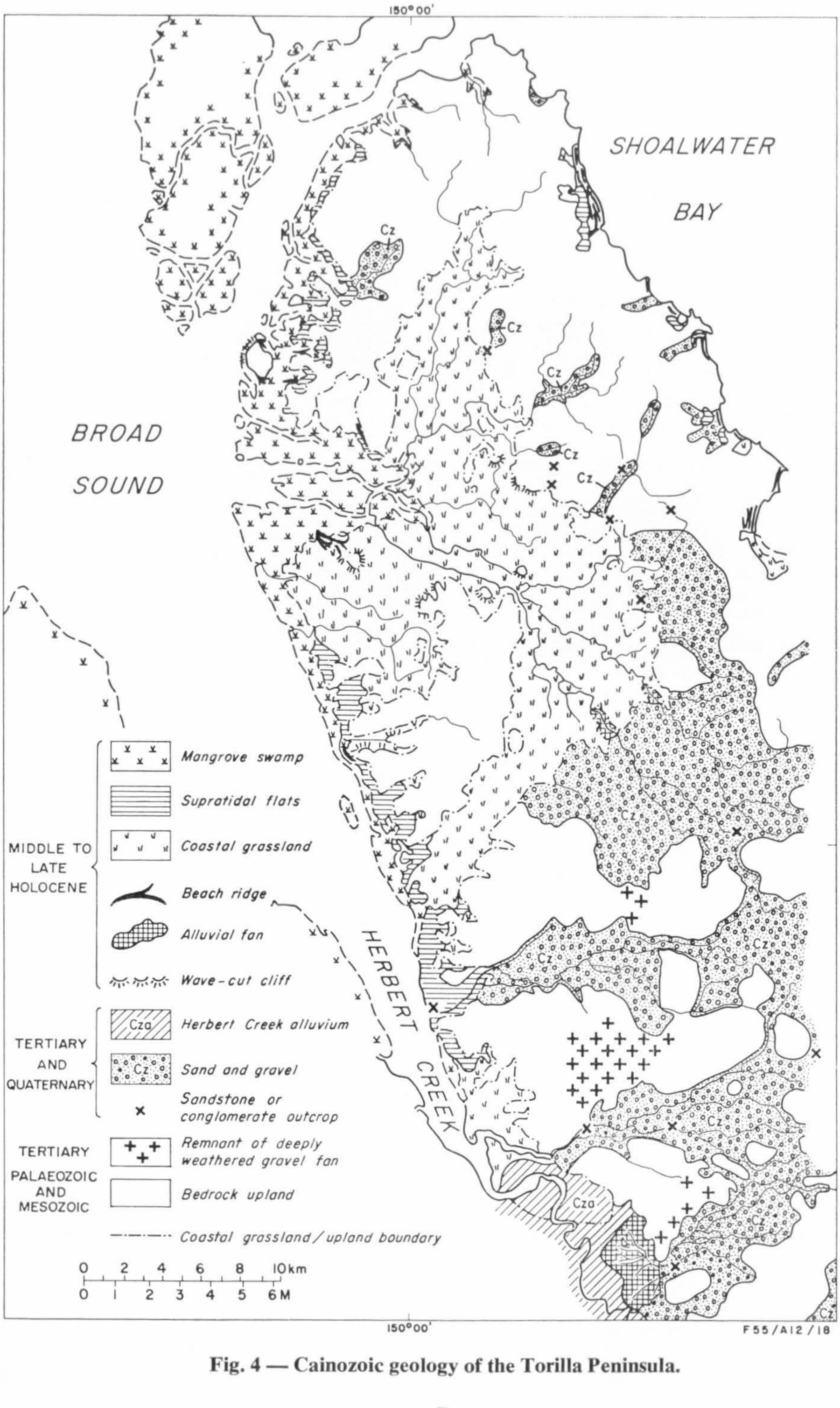


Fig. 4 — Cainozoic geology of the Torilla Peninsula.

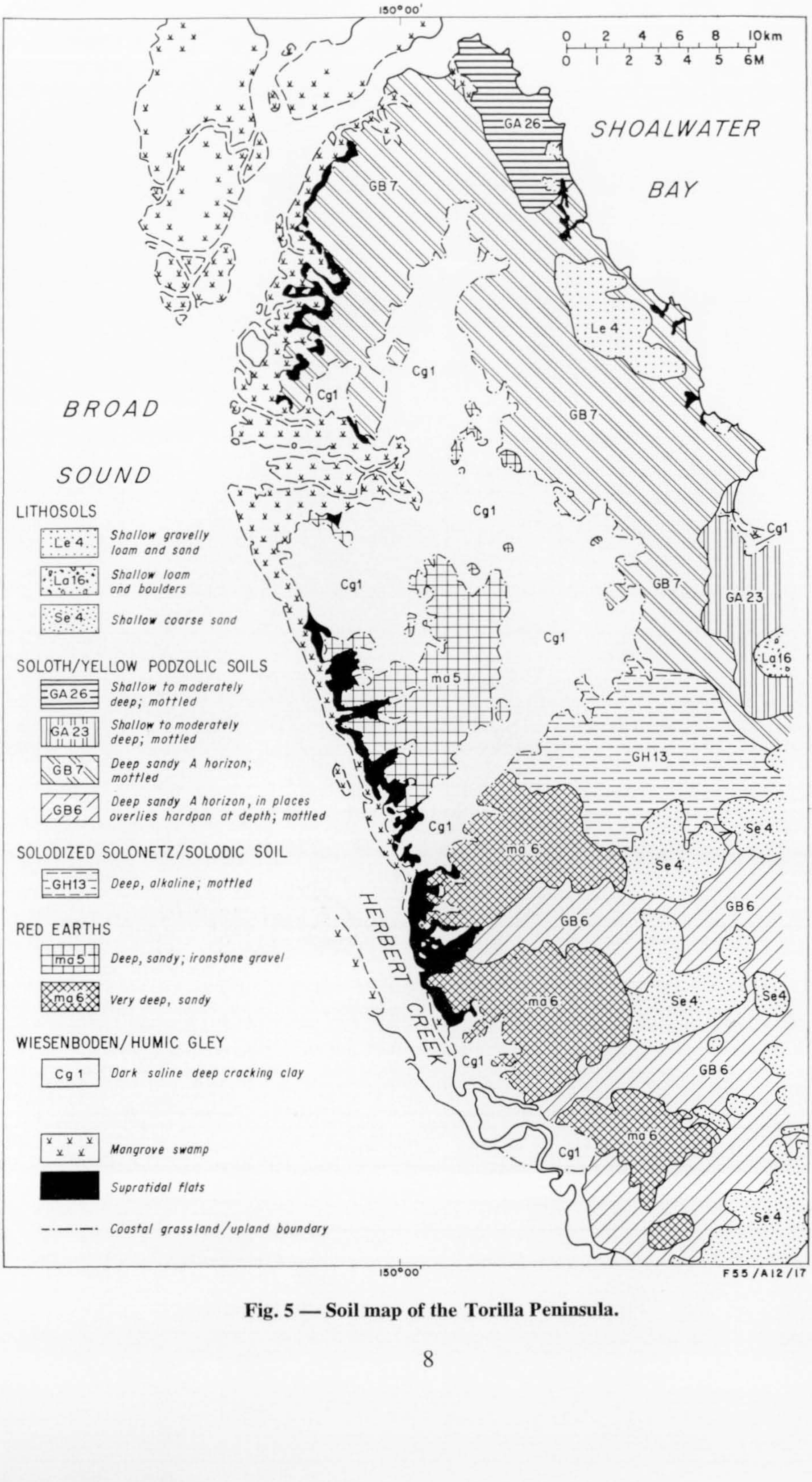


Fig. 5 — Soil map of the Torilla Peninsula.

west of Torilla Plains homestead stands above coastal grassland and supratidal flats and is developed on the ?Lower Palaeozoic metamorphic rocks common in the highlands zone (Fig. 3). The uplands between Wadallah and Block Creeks are underlain by Permian or Mesozoic granite. The Palmer Ridges are a line of fairly rugged granite hills and knobs which extend into the coastal plains from the highlands (Figs. 2, 3).

SOILS

The distribution of soil types on the Torilla Peninsula reflects the Cainozoic history of the area. The soil map (Fig. 5) was compiled from a soil survey of the Fitzroy region by Isbell & Hubble (1967) and from airphoto interpretation. Soil names and symbols used by Isbell/Hubble are retained in this Report.

The red earth soils (ma5, ma6) which cover low uplands in the coastal plains zone are genetically associated with relict soils and old land surfaces (Stephens, 1971). Red earths are porous and massive, but become clayey with depth. Residual ironstone gravel often caps the soil surface, and ferromanganiferous nodules are scattered throughout, or in distinct layers in, red earth profiles. The development of red earths is commonly caused by weathering and truncation of a relict lateritic soil profile under climatic conditions different from those which produced lateritization (Stephens, 1971, p. 13). Red earths form in mild to warm subhumid or humid climates which have alternate wet and dry periods (Stace et al. 1968). Cliff exposures of red earth soil profiles developed on the mottled zone of lateritized bedrock suggest that the red earth uplands in the Torilla Plains area constitute part of an old lateritized land surface (Fig. 5).

Duplex soils (soloths, yellow podzolic, solodized solonetz and solodic soils) in equilibrium with the present climate (Stace et al., 1968) have formed on the rolling bedrock highlands and colluvial-alluvial plains of the peninsula. Solodized solonetz/solodic soil (GH13) is restricted to the colluvial-alluvial plain of Coonyan, Wadallah, and Bark Lagoon Creeks. The colluvial-alluvial plains of Boundary Flats Lagoons, Halfway, and Block Creeks are characterized by a soloth/yellow podzolic soil (GB6) which sometimes is underlain by a hardpan at depth.

Lithosols (Le4, La16, Se4) occur on the highest hills of the peninsula and indicate that erosion has been active; only a thin soil cover derived from bedrock remains on the slopes (Stace et al., 1968). These hills are the source of much of the clastic sediment on the broad colluvial-alluvial flats south of Couti Uti homestead, in the valleys of Spencer and Couti Uti Creeks, and on the coastal grasslands (Figs. 2, 4). Differences in bedrock and slope in the Roger Hills, Pine Mountain, and Palmer Ridges have produced a different lithosol in each area.

Dark saline deep-cracking clay (Cg1), also called wiesenboden or humic gley soil (Isbell & Hubble, 1967), covers the surface of the marine plain which has prograded on the eastern shore of Broad Sound (Figs. 4, 5). Coastal grassland grows on the clay, and incorporation of large amounts of plant material causes the surface soil to be dark in colour. The salt-water table fluctuates in the soil, but is generally shallow. Subsoil horizons are mottled, and the clay cracks upon drying. Freshwater runoff from the uplands floods the grasslands during the wet season. The distribution of dark saline deep-cracking clay on the peninsula is a direct consequence of Holocene sedimentation.

The distribution of soil types on the Torilla Peninsula outlines remnants of an old lateritized land surface, colluvial-alluvial plains of groups of streams, areas of active erosion, and the extent of the prograding marine plain.

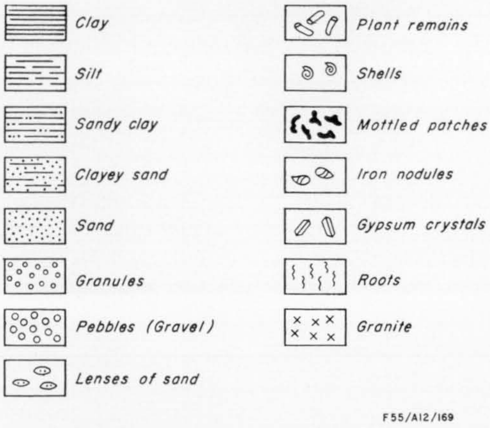
CAINOZOIC ALLUVIUM

Alluvium shed from highlands uplifted on the Torilla Peninsula during Tertiary time (Kirkegaard, Shaw, & Murray, 1970) has been deposited unconformably over Palaeozoic and Mesozoic rocks in the adjacent lowlands during the Cainozoic Era; formation of colluvium and deposition of alluvium may have begun during the Mesozoic Era (Galloway, 1972). The alluvium is unfossiliferous and can only be dated relative to the Mesozoic-Cainozoic unconformity, a Tertiary period of lateritization, and Holocene marine sedimentation.

TERTIARY ALLUVIUM

The period of laterite soil formation which affected the Torilla Peninsula has been dated as probably upper Tertiary in age (Malone, Olgers, & Kirkegaard, 1969). Alluvium which has been lateritized was therefore deposited before or during Tertiary time. Criteria for recognition of lateritized sediment or bedrock are the presence of a ferruginized zone and a mottled zone. The ferruginized zone or true laterite (Connah & Hubble, 1960) has been stripped from much of the peninsula. However, exposures of the mottled zone below Quaternary alluvium and modern soil profiles are common.

Galloway (1972) reported deposition of extensive gravelly fans during late Cainozoic time on the eastern and western flanks of the Normanby and Coast Ranges, which trend southeastward from Pine Mountain. The texture of the well preserved fans on the eastern side of the drainage divide becomes finer toward Shoalwater Bay. Galloway (1972) suggested that these fans extend offshore beyond the western coast of the bay and that they may have been deposited when the sea stood below its present level. The fans on both sides of the ranges are deeply weathered and therefore were deposited before lateritization. The ferruginous crust on fans on the eastern side of the ranges has been dissected, and alluvium younger than the period of lateritization has been deposited in the resulting valleys. Extensive dissection on the western side of the divide has left only deeply weathered gravel remnants of the fans on granite interfluves between Bark Lagoon Creek and Reedy Creek (Fig. 4). The remnants are associated with massive earth soil profiles and overlie thick mottled zones on bedrock (Gunn, 1972). Galloway commented that the landscape on these gravel-capped interfluves, called red earth uplands in this Report (Fig. 13), '. . . . resembles parts of the old weathered



Reference for Figs. 6-8; 10-12; 23.

landsurface of inland Queensland . . . rather than the scenery of the coastal belt . . .' (1972, p. 60).

Unsorted mottled sandy clay lies at the base of BMR Port Clinton 2 (Fig. 7) and is tentatively identified as colluvium or alluvium which was deposited over bedrock near the edge of the red earth upland west of Torilla Plains homestead. Beds of mottled alluvial gravel, sand, and sandy clay overlie that unit and were also penetrated below 4.5 m at the base of BMR Port Lincoln 3 (Fig. 8). Mottled alluvium overlies bedrock at the bottom of BMR St Lawrence 2 (Fig. 12). The extensive alluvial plain of Wadallah Creek is underlain below depths of 5 m by

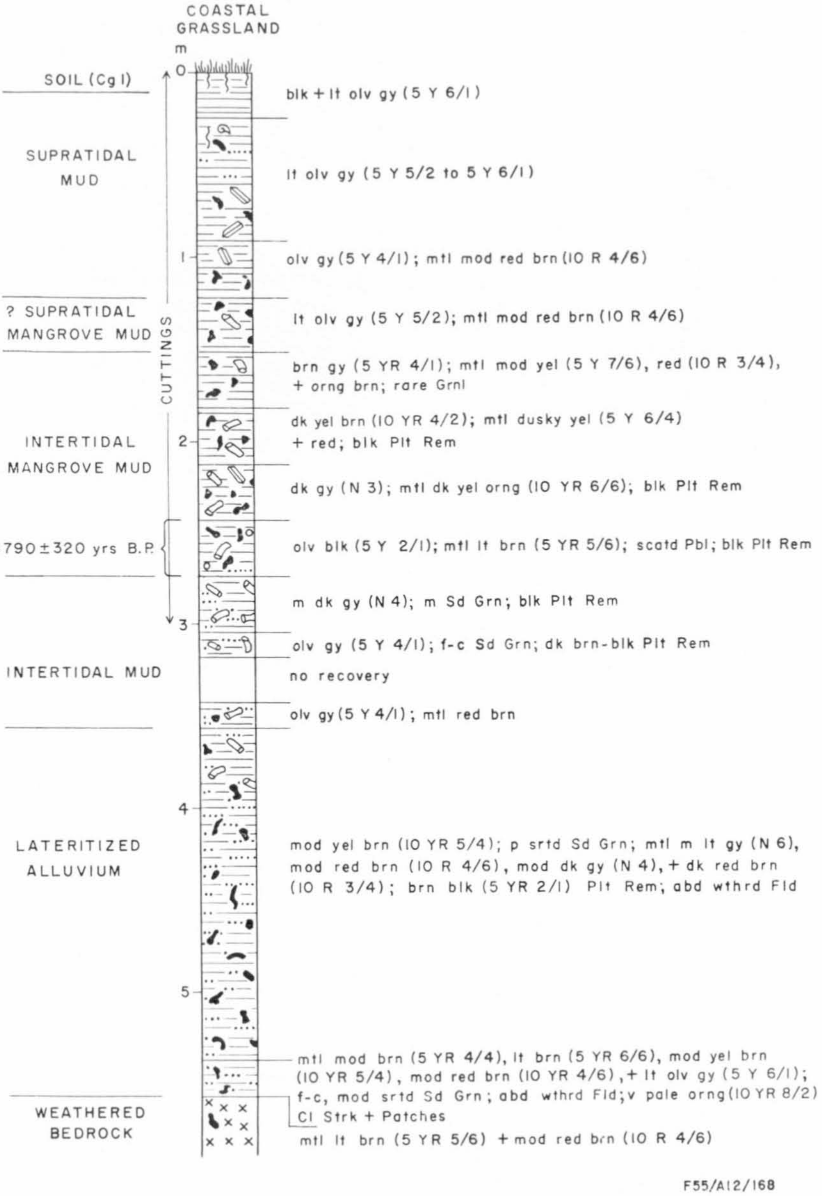


Fig. 6 — Lithological log of BMR Port Clinton 1.

weathered alluvial gravel which is commonly ferruginized (Galloway, 1972). Mottled clayey sand and sandy clay above weathered granite at the base of BMR Port Clinton 1 (Fig. 6) are identified as alluvium because the contact between the granite and sediments is sharp. The abundance of weathered feldspar in the alluvium suggests that the sediments were derived from the granitic source area of the Palmer Ridges and Normanby Range to the south and southeast. Extensive mottling and ferruginization indicate that the ?colluvium and alluvium at these localities have been lateritized. These sediments were deposited before late Tertiary time and may constitute parts of the fans derived from the Normanby Range before lateritization.

Mottled and ferruginized alluvial sand and gravel are exposed in creek beds and on interfluves between The Hollins and Couti Uti homestead. These laterized sediments may have been deposited in fans derived from the Roger Hills (Fig. 2).

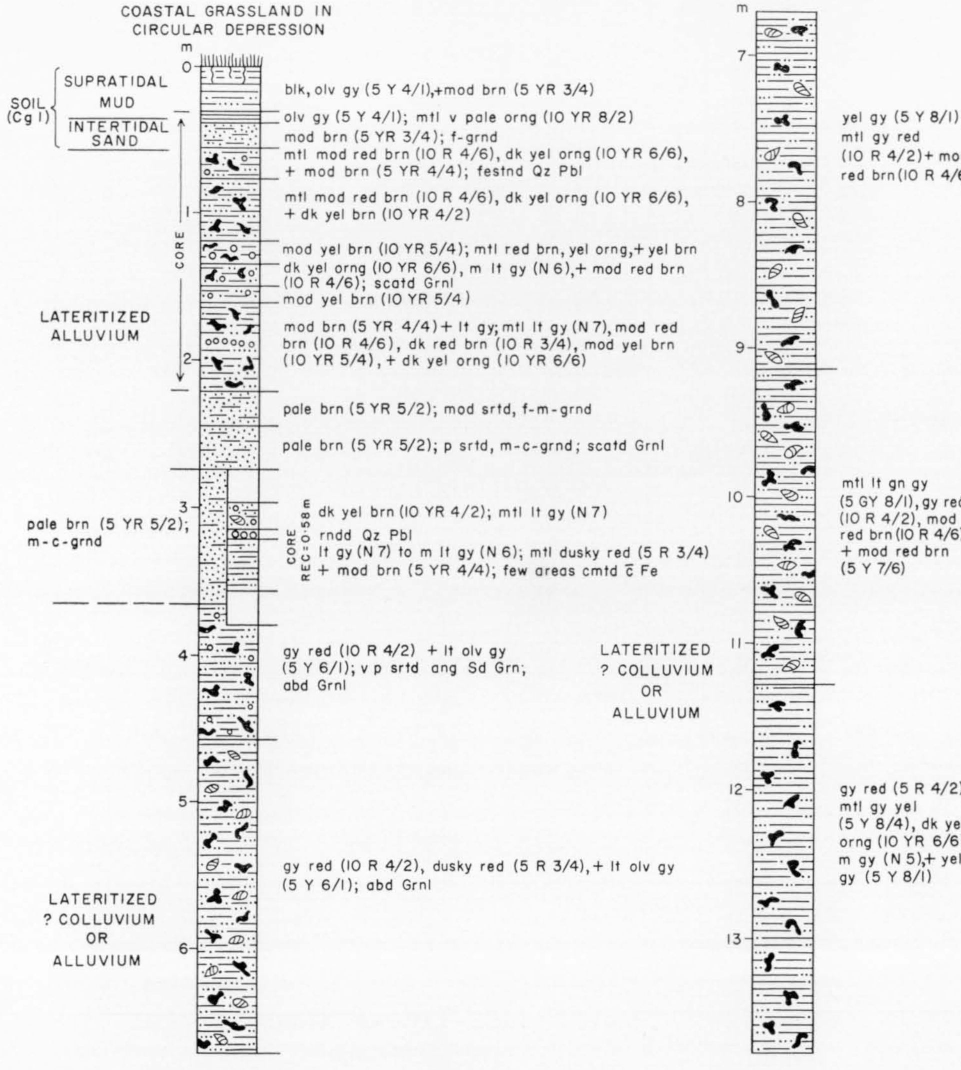


Fig. 7 — Lithological log of BMR Port Clinton 2.

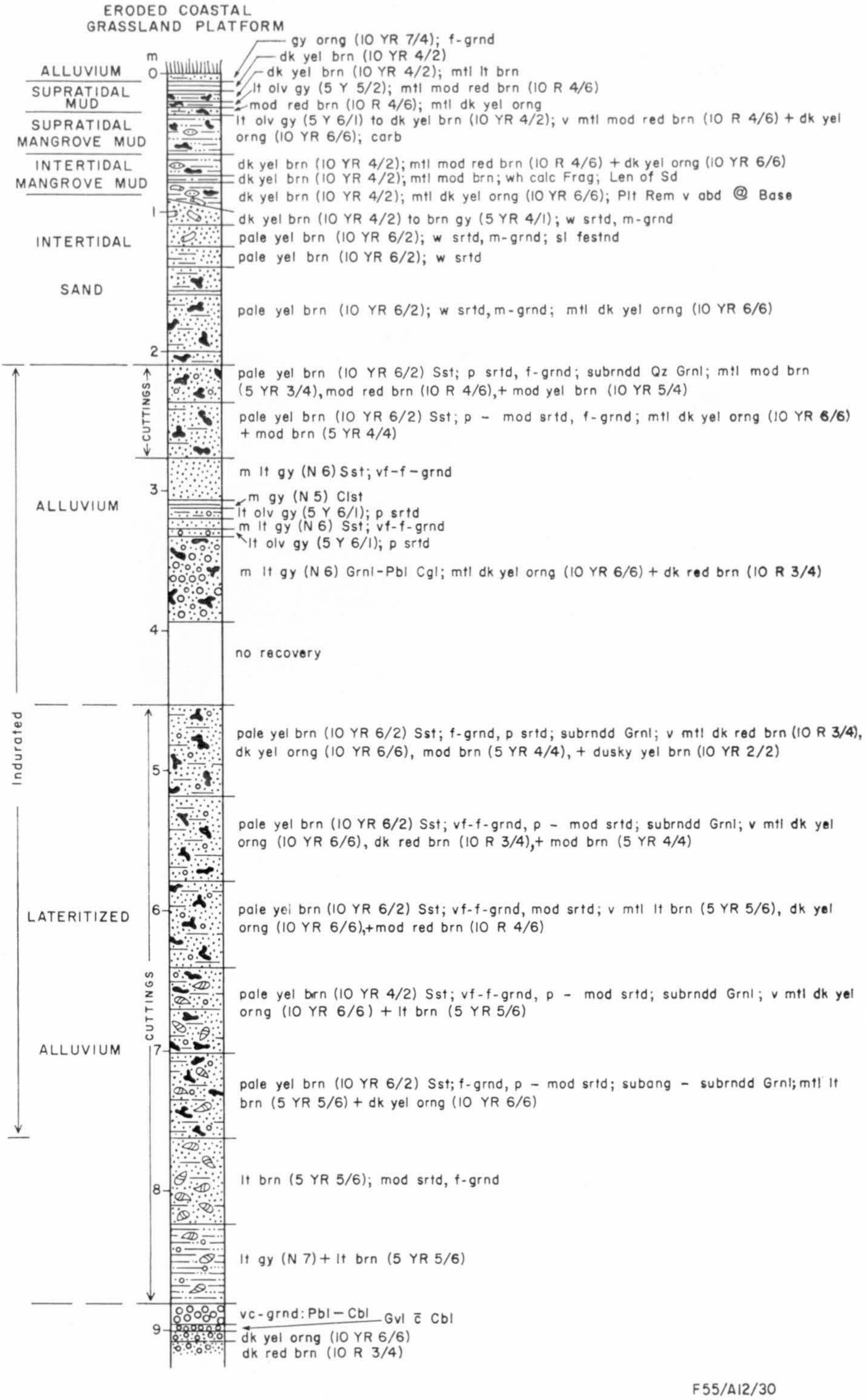


Fig. 8 — Lithological log of BMR Port Clinton 3.

Alluvial fans probably formed on both sides of the drainage divide along the entire length of the Torilla Peninsula before lateritization took place during the Tertiary.

QUATERNARY ALLUVIUM

The formation of colluvium and deposition of alluvium continued after late Tertiary lateritization. Sediments which are neither mottled nor ferruginized are here considered to be Quaternary in age.

Exposures confirm that fresh Quaternary gravel, sand, and clay were deposited unconformably over lateritized Tertiary alluvium in the valleys of Spencer, Couti Uti, Wadallah, Halfway, and Block Creeks (Fig. 9). Quaternary alluvium also overlies lateritized alluvium in BMR Port Clinton 3 (Fig. 8).

Fig. 9 — Circular depression at the edge of a red earth upland (u) southwest of Fernlea homestead. Eroded grassland (g) remains in the circular depression and on the upland edge. Supratidal flats (s), mangroves (m), and intertidal sandbanks (B) are cut by channels.

A sequence of fresh Quaternary sand and sandy clay 19 m thick underlies Holocene marine sediments in BMR Port Clinton 5 (Fig 11); this alluvium was probably deposited by Bark Lagoon Creek. It is underlain by 13 m of fine angular gravel in a clay and sand matrix. The general absence of mottling in the gravel suggests that it may represent a colluvial or alluvial fan which was deposited after lateritization and was subsequently buried by finer alluvial plain sediments.

However, ferruginized Tertiary gravel underlies finer-grained Quaternary alluvium nearby along Wadallah Creek (Galloway, 1972). The gravel at the base of BMR Port Clinton 5 may also be Tertiary in age; the ferruginized and mottled zones may have been stripped from it before the deposition of Quaternary sand and clay.

Block Creek has deposited an alluvial fan during the Quaternary where it flows out of red earth uplands into the valley of Herbert Creek (Fig. 4). Some distributary channels on the fan can be traced on airphotos only to the eastern edge of the flood plain of Herbert Creek, while others are incised into Herbert Creek alluvium. These relations suggest that deposition of at least the youngest part of the alluvial fan has been contemporaneous with seaward progradation of Herbert Creek alluvium during Holocene time.

Marine transgression during the Holocene interrupted the formation of colluvium and deposition of alluvium in the lowlands, but these processes continued in the uplands. With depositional progradation of the marine plain and retreat of the shoreline, late Holocene alluvium is being deposited again in the lowlands over marine sediments. In BMR Port Clinton 3 (Fig. 8) this alluvium consists of 0.1 m of fine sand washed from the uplands by summer freshwater

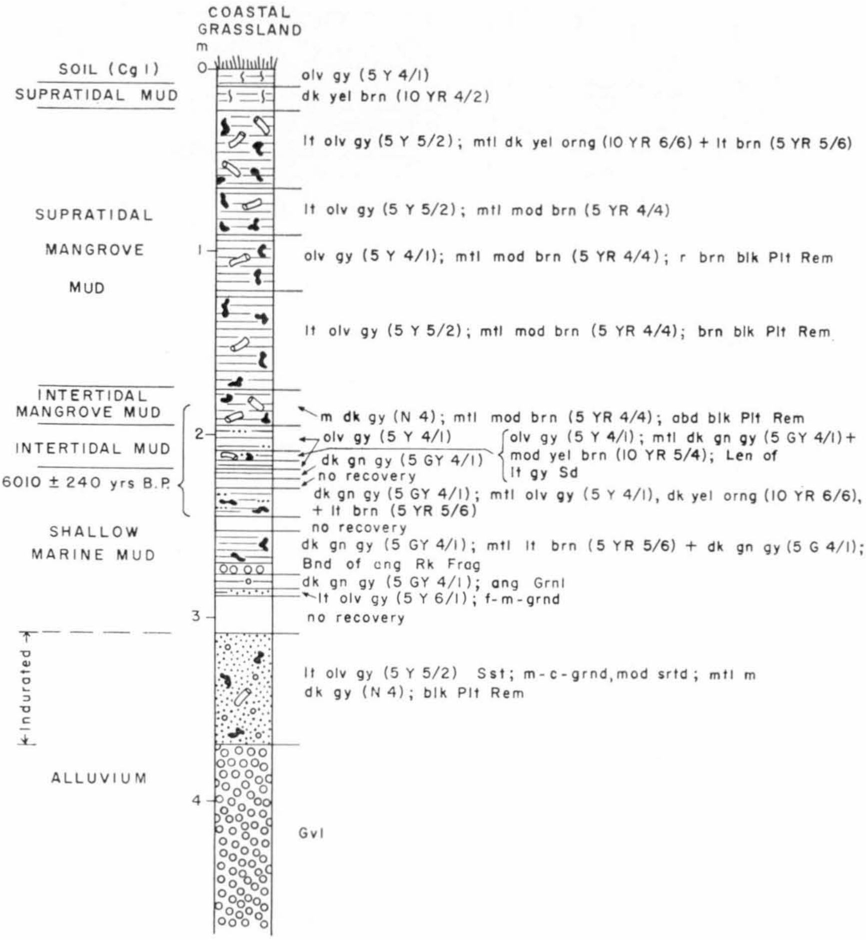


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Fig. 10 — Lithological log of BMR Port Clinton 4.

floods. The flood waters of Coonyan and Wadallah Creeks are depositing alluvial fans over Holocene marine sediments (Fig. 4).

INDURATION OF ALLUVIUM

Some beds of Tertiary and Quaternary alluvium were indurated during soil formation in late Cainozoic time. Ferruginized Tertiary alluvium was cemented in the zone of illuviation during lateritization. Sediments in the mottled zone of the

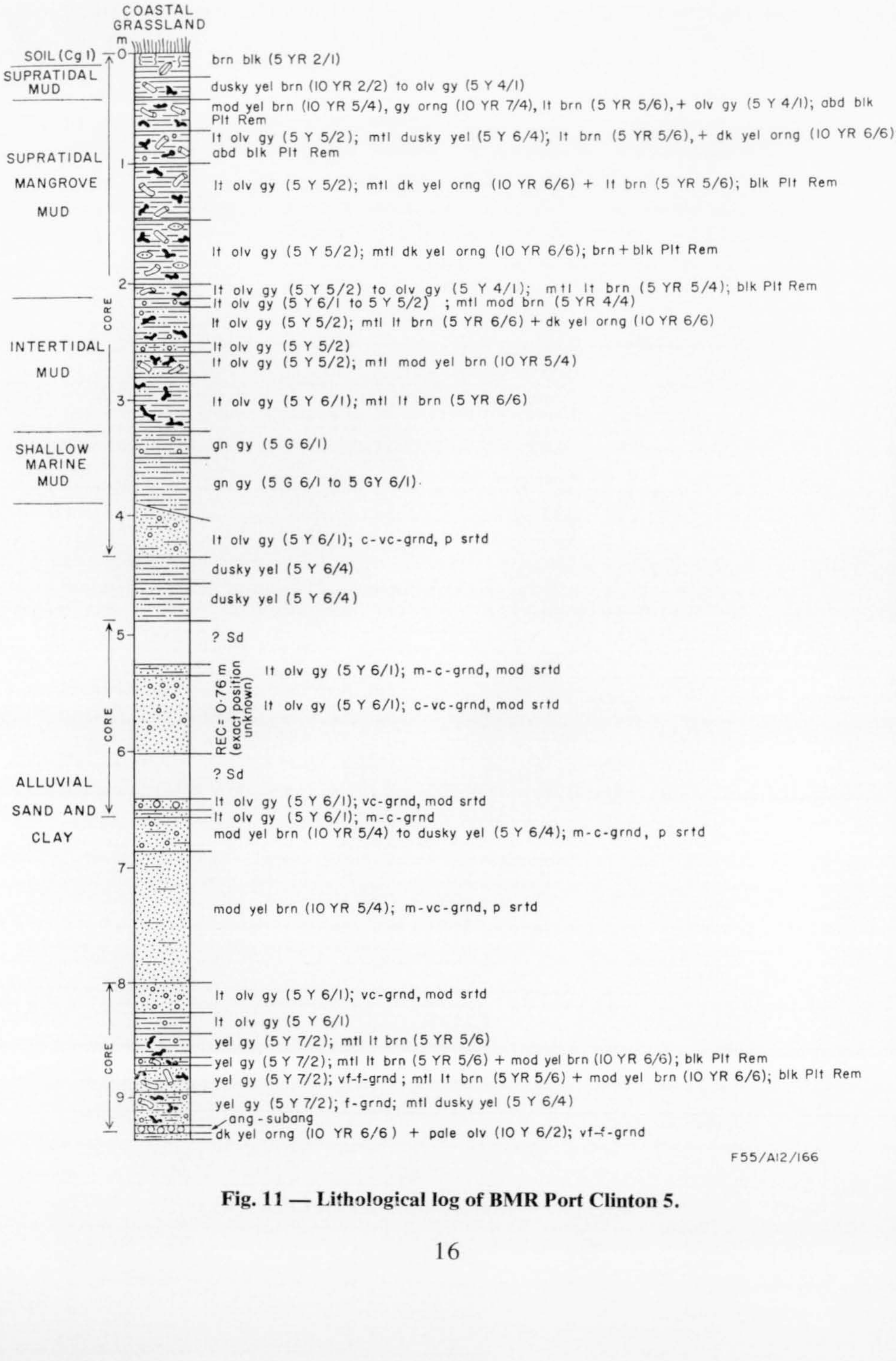


Fig. 11 — Lithological log of BMR Port Clinton 5.

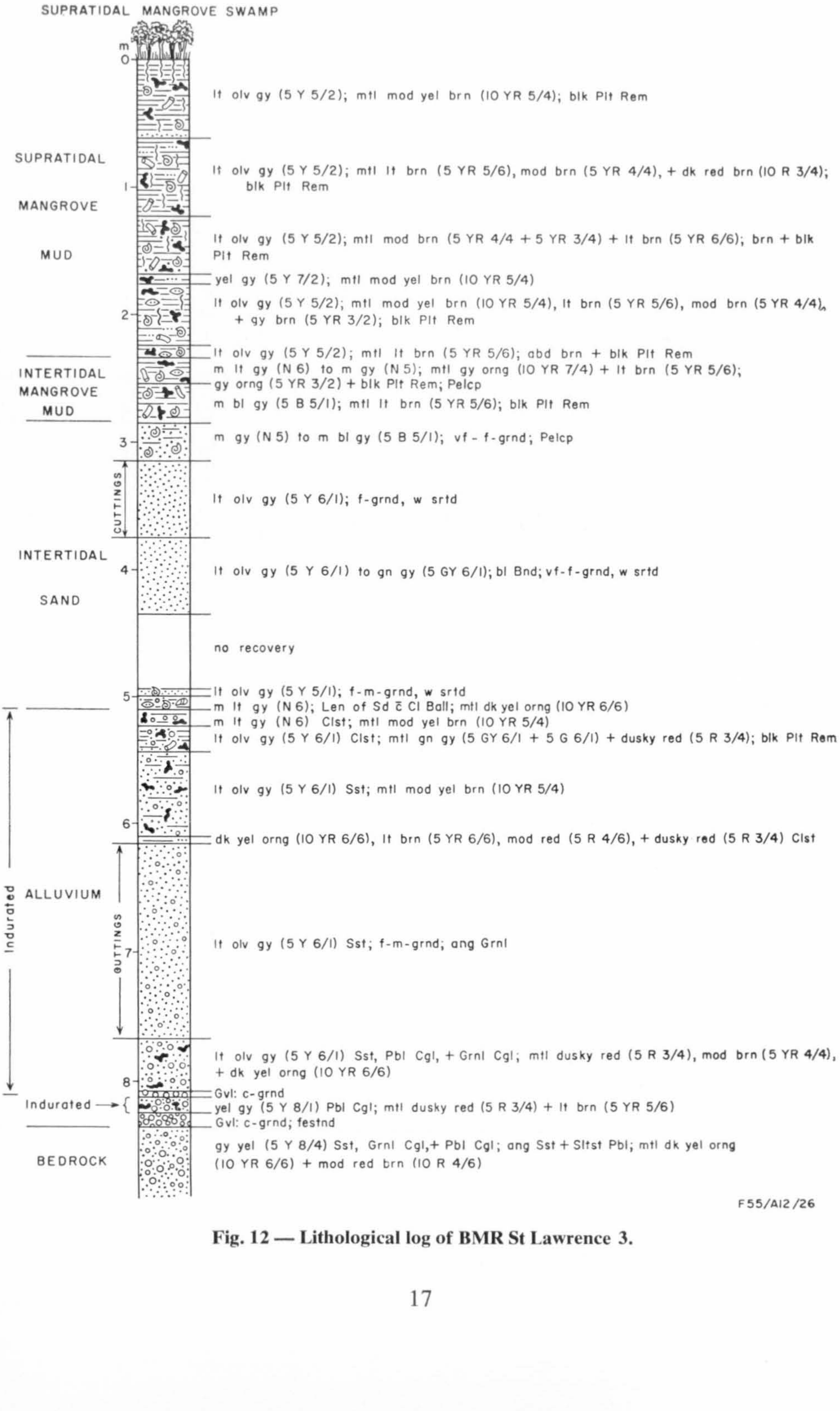
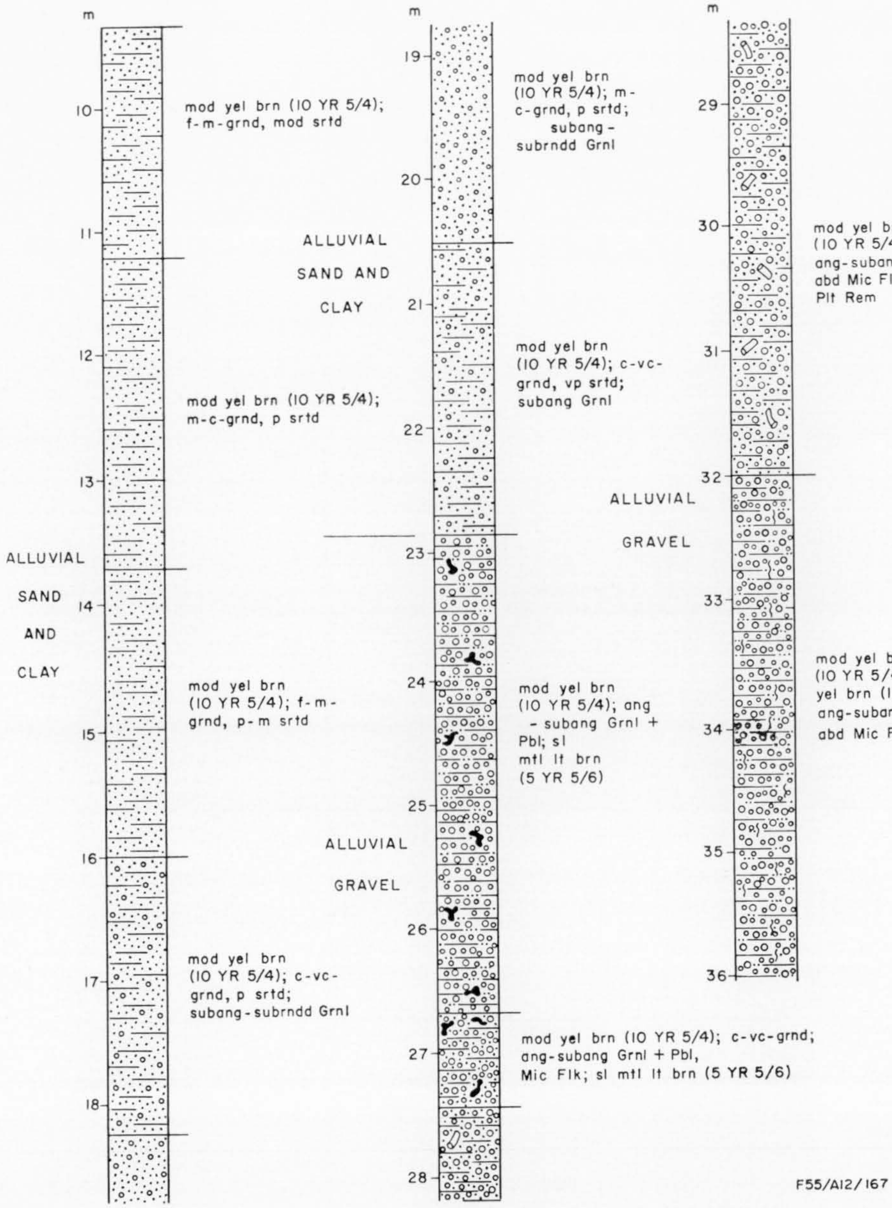


Fig. 12 — Lithological log of BMR St Lawrence 3.


m
10
11
12
13
14
15
16
17
18
mod yel brn (10 YR 5/4); f-m-grnd, mod srtd
mod yel brn (10 YR 5/4); m-c-grnd, p srtd
ALLUVIAL SAND AND CLAY
mod yel brn (10 YR 5/4); f-m-grnd, p-m srtd
mod yel brn (10 YR 5/4); c-vc-grnd, p srtd; subang-subrndd Grnl
m
19
20
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27
28
mod yel brn (10 YR 5/4); m-c-grnd, p srtd; subang-subrndd Grnl
ALLUVIAL SAND AND CLAY
mod yel brn (10 YR 5/4); c-vc-grnd, vp srtd; subang Grnl
ALLUVIAL GRAVEL
mod yel brn (10 YR 5/4); ang - subang Grnl + Pbl; sl mtl lt brn (5 YR 5/6)
mod yel brn (10 YR 5/4); c-vc-grnd; ang-subang Grnl + Pbl, Mic Flk; sl mtl lt brn (5 YR 5/6)
m
29
30
31
32
33
34
35
36
mod yel brn (10 YR 5/4); ang-subang Grnl, abd Mic Flk; blk Plt Rem
ALLUVIAL GRAVEL
mod yel brn (10 YR 5/4) to dk yel brn (10 YR 4/2); ang-subang Grnl, abd Mic Flk
F55/A12/167

Fig. 12 (contd.)

relict lateritic profile may have become indurated during lateritization or during a later period of soil formation. In the southern part of the Torilla Peninsula a siliceous hardpan underlies modern soils developed in colluvium derived from granite (Isbell & Hubble, 1967; Galloway, 1972; Gunn, 1972). Much Tertiary and Quaternary alluvium was probably indurated in such soil hardpans as groundwater levels changed with climatic fluctuations during Quaternary time. Sandstone 0.75 m thick is interbedded with Quaternary alluvium in the bed of Couti Uti Creek (Fig. 4). The presence of numerous root channels, small pieces of fossilized wood, disturbed bedding, and small blebs of clay indicate that the sandstone was indurated as a soil hardpan. Quaternary alluvium, indurated to sandstone and conglomerate, is also exposed in the beds of Wadallah, Halfway, and Block Creeks.

Induration of alluvium has been selective. In BMR Port Clinton 3 (Fig. 8) the lower 1.6 m of Tertiary alluvium is unconsolidated, but the upper 2.6 m of mottled Tertiary alluvium and overlying fresh Quaternary alluvium has been indurated to sandstone. In an exposure of Tertiary alluvium between Spencer and Couti Uti Creeks only sediments in the lower part of the mottled zone are indurated. Unconsolidated gravel underlies indurated sandstone in BMR Port Clinton 4 (Fig. 10), an unconsolidated gravel is interbedded with conglomerate and sandstone in BMR St Lawrence 2 (Fig. 12). In contrast, the entire alluvial sequence of ?Tertiary gravel and Quaternary sand and clay in BMR Port Clinton 5 (Fig. 11) is unconsolidated. Selectivity of induration from bed to bed and from place to place may be explained by differences in sediment texture, groundwater circulation, and the timing of sediment deposition relative to long-term water-table fluctuations.

Cook & Mayo (in press) identify an indurated surface which slopes gently seaward from the eastern edge of the Torilla Plains into Broad Sound. The surface is covered by Holocene marine sediments which thicken from several metres below the Torilla Plains to 10 m below Broad Sound. Some occurrences of indurated alluvium cited above are probably exposures of this pre-Holocene weathering surface.

CIRCULAR DEPRESSIONS

Shallow circular to elliptical depressions up to 400 metres across have developed on remnants of the lateritized Tertiary land surface now covered by red earth soils. (Figs. 9, 13, 14). Streams draining the red earth uplands commonly originate in and flow through circular depressions which also form isolated or overlapping basins without tributary or exit streams (Fig. 13). The circular depressions occur on flats 15 to 30 m above sea level; they are absent from higher areas of red earth uplands where the relief is greater. The surface of the red earth uplands stands about 3 to 6 m above the floors of the depressions and slopes gently down into them. The depressions are flooded during the wet season, and a few between Boundary Flat Lagoons and Halfway Creek are occupied by shallow marshy lakes much of the year; more than 1 m of slightly clayey well sorted sand covers the floor of the lake at the site of BMR St Lawrence 1 (Burgis, 1972). Other depressions are grassed and wooded. Dense ti-tree grows at their edges on sediments deposited in them, but the vegetation changes abruptly to tall eucalypt woodland on the surrounding red earth soils (Figs. 9, 14). Marine sediments were deposited in some of the circular depressions at the seaward edges of red earth uplands during the Holocene transgression.

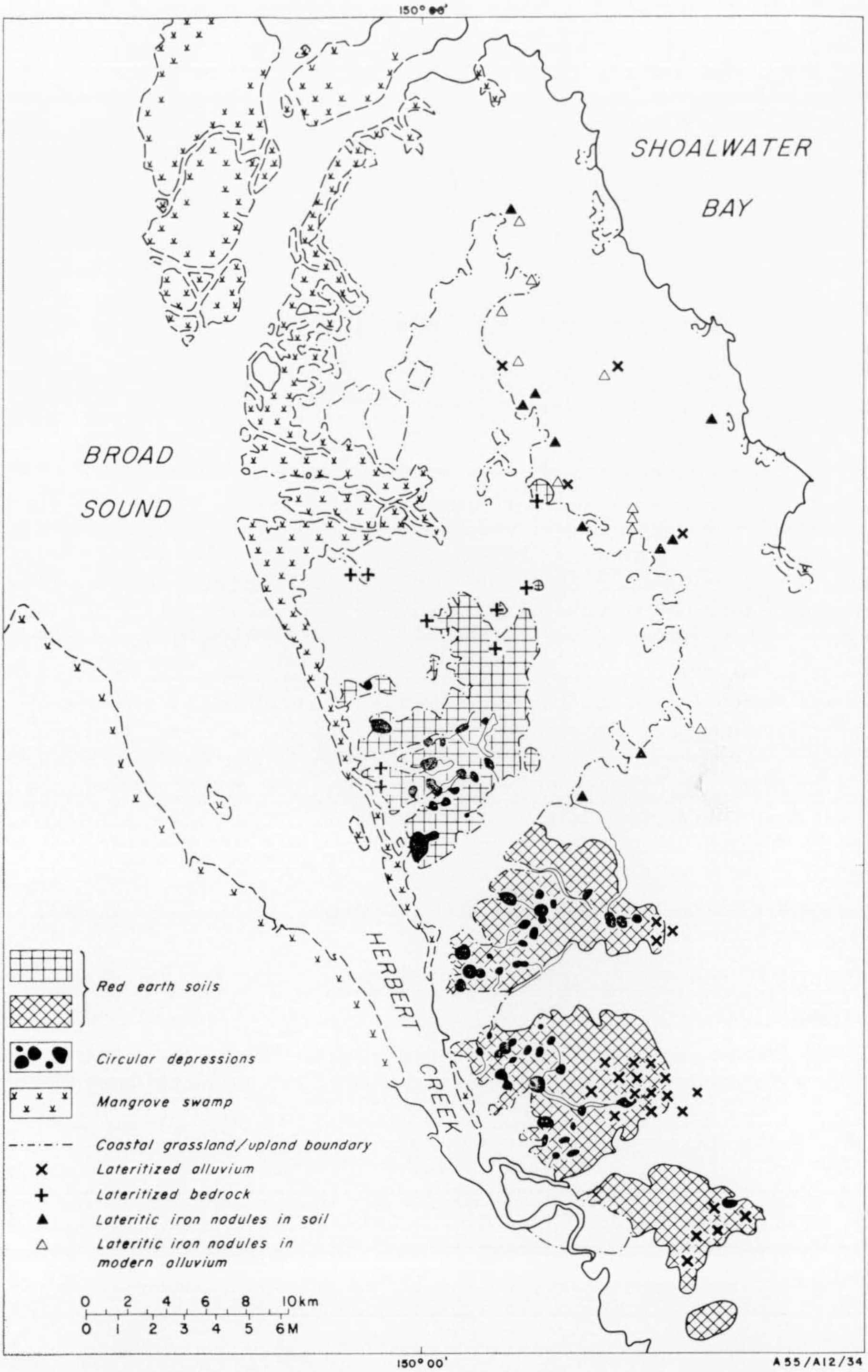


Fig. 13 — Distribution of red earth and circular depressions on the Torilla Peninsula.

Fig. 14 — Overlapping circular depressions at the edge of a red earth upland (u) southeast of Fernlea homestead. Grassland (g) is being eroded to supratidal flats (s) at the seaward end of the circular depressions. Mangroves (m) grow in the distance.

The association of circular depressions with red earth uplands (Fig. 13) suggests that lateritization or weathering of a relict lateritic soil profile caused their formation. Similar enclosed depressions are scattered across the lateritized Tertiary Koolpinyah Surface of the Adelaide-Alligator area in the Northern Territory (Williams, 1969) and occur on some deeply weathered land systems of the Leichhardt-Gilbert and Isaac-Comet areas of Queensland (Perry et al., 1964; Story et al., 1967). Trendall (1962) suggested that the depressions may have been formed by solution during lateritization. However, Vann (1963) attributed the development of shallow flat-bottomed depressions (Baixas) in Amapa, Brazil to the mass-wasting of a relict lateritic soil profile. Baixas form by the coalescence of steep-sided flat-bottomed gullies which are broadened by groundwater sapping at the top of the mottled zone. An Amapa landscape of depressions and gullies (Vann, 1963, figs. 5-9) is morphologically similar to areas of red earth uplands east of Broad Sound where broad flat-bottomed stream valleys join circular depressions scattered along their courses. The development of red earth soils on these uplands proves that the lateritic profile in the Broad Sound area is relict. Furthermore, mottled sandy clay was penetrated below the sand which covers the floor of the circular depression at the site of BMR St Lawrence 1 (Burgis, 1972), and probably represents the mottled zone of the lateritic profile exposed in cliffs at the edges of the red earth uplands. The evidence suggests that circular depressions were formed by gullying and groundwater sapping in a strict lateritic profile.

Teardrop lakes in the Tabasco lowlands of southeastern Mexico are morphologically similar to circular depressions of the red earth uplands east of Broad Sound (compare West et al., 1969, fig. 30 with Fig. 9 in this Report). Teardrop lakes commonly occupy the heads of first-order streams draining flat interfluves; no channels enter the lakes, but streams issue from the narrow downstream ends of the shallow teardrop-shaped basins. Some circular depressions on the red earth uplands east of Broad Sound occupy similar positions at the heads of stream valleys. The Tabasco lowlands have been lateritized, but relict and actively forming lateritic profiles could not be distinguished. West et al. (1969) attributed the development of teardrop lakes to a combination of gullying and groundwater sapping at the top of the mottled zone. They suggested that during periods of low sea level during the Quaternary, headward erosion of gullies was dominant over groundwater sapping. As sea level rose and the rate of stream dissection decreased, groundwater sapping became dominant over gully erosion, and the heads of streams were consequently broadened into teardrop lakes. West et al. (1969) suggested that teardrop lakes are young landforms related to sea-level rise.

Circular depressions on the red earth uplands east of Broad Sound may have formed during Tertiary lateritization or during Quaternary weathering of the relict lateritic profile at times when the rate of groundwater sapping at the top of the mottled zone exceeded the rate of gully erosion. Some circular depressions may have formed by the coalescence of broadening gullies, while others probably developed by widening of the heads of streams. The development of circular depressions may have been episodic and related to base-level changes from late Tertiary to Holocene time. The presence of Holocene marine sediments in some circular depressions indicates that those basins had formed before the sea reached its maximum Holocene extension.

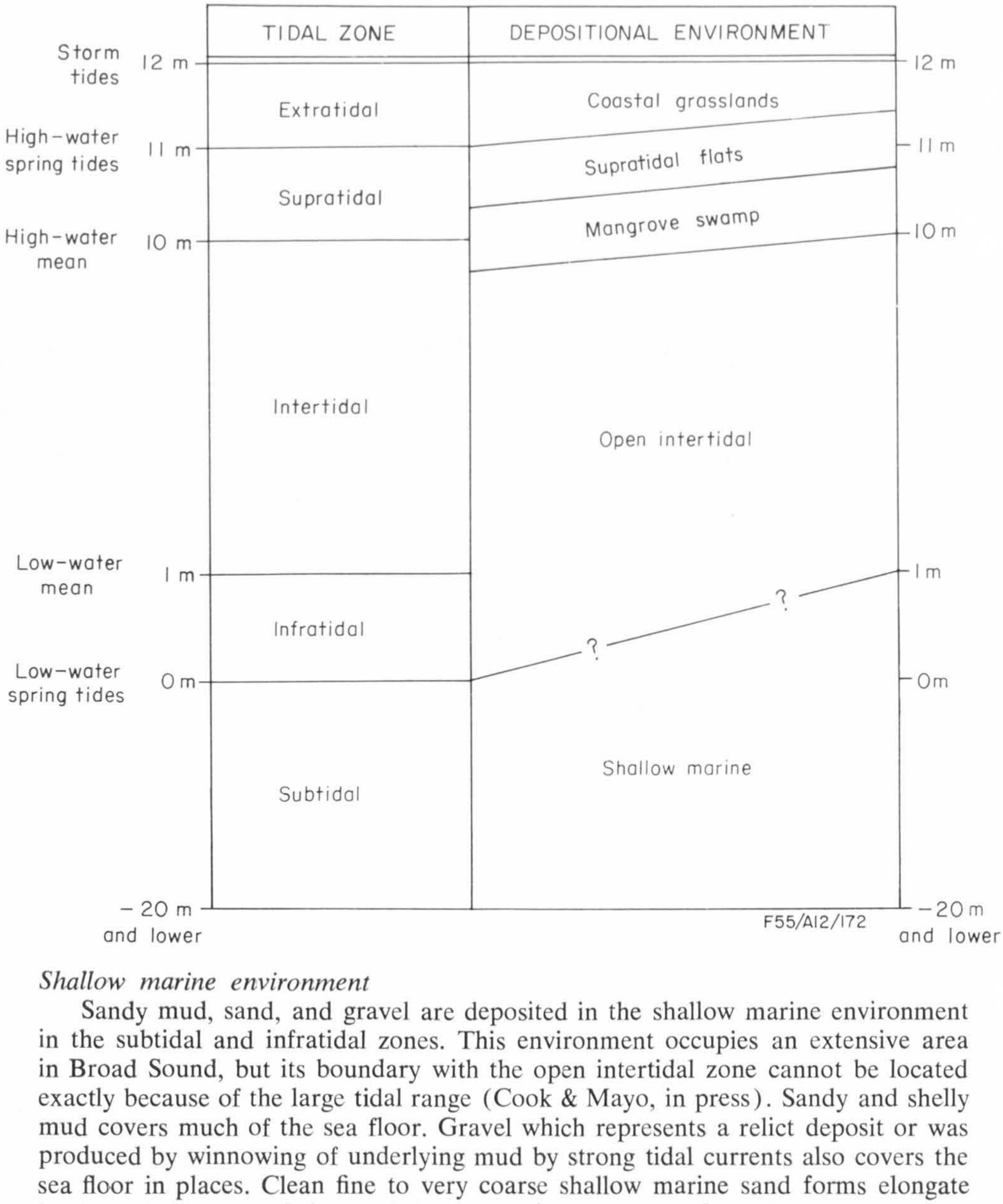
HOLOCENE SEDIMENTATION

The coastal grasslands on the Torilla Plains (Fig. 4) are underlain by a sequence of marine sediments which averages 2.6 m thick (Tables 1, 2) and overlies older Cainozoic alluvium or Palaeozoic or Mesozoic bedrock. Radiocarbon dates on mangrove wood and shells identify the sequence as Holocene in age, and the vertical profile seen in auger and drill holes was produced by seaward retreat of the shoreline. Lithological criteria established from the study of modern depositional environments in the Broad Sound estuary (Table 4) were applied to recognize sedimentary facies in the subsurface.

Modern Depositional Environments

Cook & Mayo (in press) point out that the high tidal range is the most important direct or indirect control on sedimentary processes in Broad Sound. Therefore they have classified modern depositional environments primarily by their positions in the tidal range (Table 3). The biota also influences depositional conditions, and consequently mangrove swamp is found in both the intertidal and supratidal environments. Depositional conditions strongly influence the lithology of sediment characteristic of the various environments. The coarsest material is deposited in seaward environments, and the finest in landward environments (Cook & Mayo, in press).

TABLE 3. SCHEMATIC RELATION OF TIDAL ZONES AND DEPOSITIONAL ENVIRONMENTS IN THE BROAD SOUND ESTUARY (AFTER COOK & MAYO, IN PRESS).



Shallow marine environment

Sandy mud, sand, and gravel are deposited in the shallow marine environment in the subtidal and infratidal zones. This environment occupies an extensive area in Broad Sound, but its boundary with the open intertidal zone cannot be located exactly because of the large tidal range (Cook & Mayo, in press). Sandy and shelly mud covers much of the sea floor. Gravel which represents a relict deposit or was produced by winnowing of underlying mud by strong tidal currents also covers the sea floor in places. Clean fine to very coarse shallow marine sand forms elongate banks and ridges parallel to and shaped by tidal currents (Cook & Mayo, in press) and interfingers southeastward with intertidal sand.

Open intertidal environment

Elongate banks and ridges of clean, fine to medium quartz and calcareous sand cover much of the extensive open intertidal environment in Herbert Creek (Fig. 15). The ridges are up to 10 km long, 1 km wide, 10 m high, and have have been shaped by strong tidal currents (Cook & Mayo, in press). Ripples and

Fig. 15 — View north along the Torilla Peninsula showing circular depressions (c) on red earth uplands, alluvial flats (a), supratidal flats (s), mangroves (m), and intertidal sand banks (B) in Herbert Creek. Two circular depressions contain remnants of grassland (g).

Fig. 16 — Island Bluff (I) and Fort Cope (F) from the northwest. Young mangroves (im) grow on intertidal sand banks (B). Mangrove swamp (sm) grows in the supratidal zone seaward of coastal grassland (g) which is cut by supratidal channels. Vegetated cheniers (b) have been built on the western end of Fort Cope. Wooded uplands (u) west of Torilla Plains homestead lie in the background.

Fig. 17 — Barren to sparsely vegetated supratidal flats on the eastern shore of Herbert Creek. Supratidal mud in the left foreground is broken by desiccation cracks. The wooded upland (u) is edged by a strip of eroded grassland (g). Mangrove swamp (m) grows in the right distance.

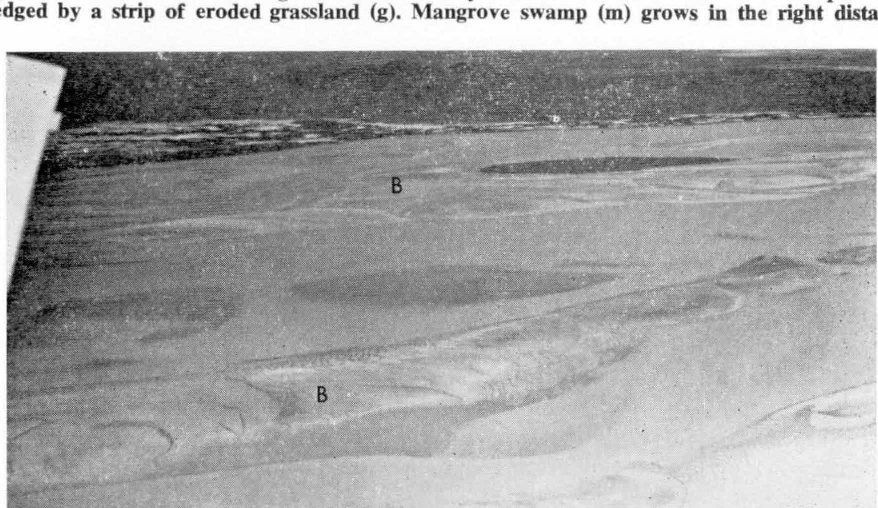


Fig. 18 — Intertidal sand banks (B) are exposed at low tide in Herbert Creek. Coastal grassland (g), a vegetated crescentic chenier (b), and supratidal flats (s) are adjacent to a wooded upland (u) at the Torilla Plains boat landing (left foreground). A narrow band of intertidal mud (i) has been deposited seaward of supratidal mangrove swamp (m).

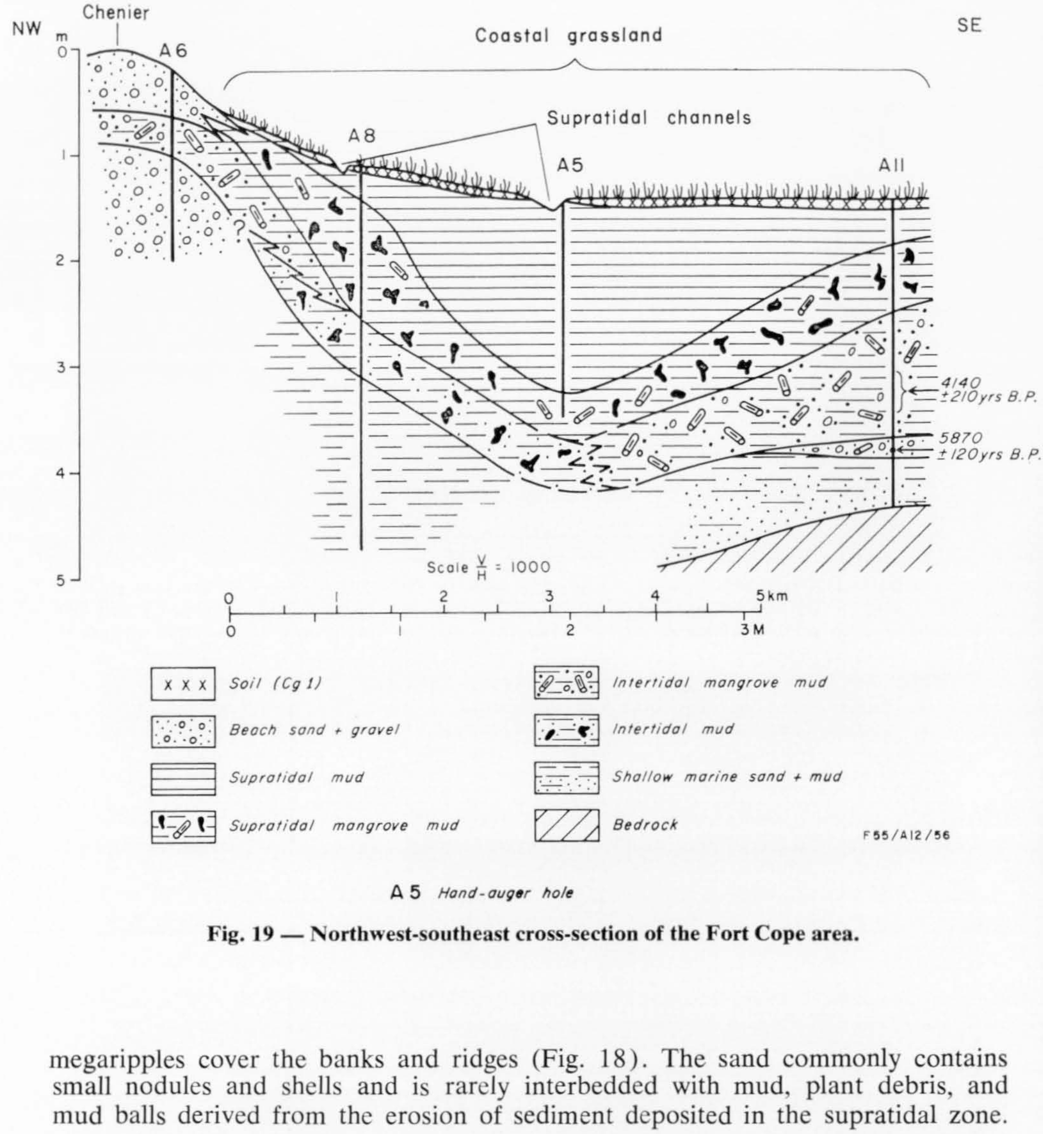


Fig. 19 — Northwest-southeast cross-section of the Fort Cope area.

megaripples cover the banks and ridges (Fig. 18). The sand commonly contains small nodules and shells and is rarely interbedded with mud, plant debris, and mud balls derived from the erosion of sediment deposited in the supratidal zone.

A zone of laminated mud up to 90 m wide lies in the open intertidal environment between the sand banks and ridges and the mangrove swamp from Fort Cope south to Fernlea homestead (Fig. 18). The mud is eroded from the adjacent mangrove swamp and supratidal flats and redeposited immediately seaward of them. Consequently it is the same light olive-grey colour as most of its parent material and contains large amounts of plant debris. Crab burrows and thin interbeds of sand are loci of oxidation in the mud and become mottled red, orange, and brown.

TABLE 4. CHARACTERISTICS OF SEDIMENTS DEPOSITED IN MODERN MARINE ENVIRONMENTS

Depositional environment	*Lithology*	*Colour*	*Mottling*	*Sedimentary structures*	*Organic remains*	*Nodules*	*Comments*
Supratidal flats	Mud	lt olv gy (5 Y 5/2, 5 Y 6/1)	sl mtl orng + red	laminated burrows, desiccation cracks	r to com partly oxidized plant remains	r	Oxidizing conditions, algal mats, salt crust, gypsum crystals, rare interbeds of sandy and mud + quartz pebbles
Mangrove swamp — Supratidal Zone	Mud	lt olv gy (5 Y 5/2)	v mtl red, orng + brown	burrows	com to abd partly oxidized plant remains	—	Oxidizing conditions, rare interbeds of sandy mud
Mangrove swamp — Intertidal Zone	Mud to sandy mud	gy to dk gy	—	burrows	abd black plant remains	—	Reducing conditions
Open Intertidal	Sand (f to m-grnd)	pale to dk yel brn (10 YR 6/2 to 10 YR 4/2) or lt olv gy (5 Y 6/1)	—	ripples + megaripples	r to com shells + plant remains	r to com	Rare interbeds of mud + mud balls
	Mud	lt olv gy (5 Y 5/2, 5 Y 6/1)	sl mtl red orng + brn	laminated, burrows, depositional dip	abd plant remains	r	Interbeds of sand; mud balls
	Sandy mud	gn-gy (5 GY 6/1, 5 G 6/1) to dk gn-gy (5 GY 4/1, 5 G 4/1); lt olv gy (5 Y 5/2, 5 Y 6/1)	—	—	com to abd shells	com to abd	Locally indurated
	Sand (f to vc-grnd)	mod yel brn (10 YR 5/4)	—	—	com to abd shells	com to abd	
Shallow marine	Gravel	—	—	—	abd shells + coral	abd	Lt olv gy (5 Y 6/1, 5 Y 5/2) mud or sand matrix in places; partly indurated

Mangrove swamp

A zone of mangrove swamp 0.2 to 4.5 km wide lines most of the eastern shore of Broad Sound (Figs. 16, 17, 18). Small patches of mangrove swamp occupy sheltered inlets on the western coast of Shoalwater Bay. The vegetation is composed of several genera, including *Rhizophora* and *Avicennia*.

Mangroves grow in the intertidal and supratidal zones in areas which lie near the level of mean high water (Table 3). In both zones mangroves reduce wave and current energy, and they trap fine sediment (Cook & Mayo, in press). Consequently, the texture of material deposited in the intertidal and supratidal zones of the swamp is similar. However, frequent inundation of mangroves growing in the intertidal zone produces reducing conditions in the substrate, while less frequent flooding of the supratidal zone allows oxidation of sediment deposited in that part of the swamp. Therefore, differences in colour, mottling, and the preservation of organic remains distinguish intertidal from supratidal swamp sediments.

Grey to dark grey mud is deposited under reducing conditions in the intertidal zone of the mangrove swamp. The mud is sandy where material is washed into the mangroves from intertidal sand banks. Black plant remains are abundant. Mangroves which grow in the intertidal zone commonly have adapted to a poorly aerated substrate by sending stilt roots out from their trunks above ground level to provide oxygen (Australian Conservation Foundation, 1972).

Most of the mangrove swamp in the Torilla Plains area lies in the supratidal zone and is flooded only by spring tides. Oxidation of abundant plant remains produces extensive red, orange, and brown mottling in the light olive-grey mud deposited in this part of the swamp. Mangroves which grow in the supratidal zone generally send roots into the better aerated soil at or below ground level.

Buried mangrove mud deposited in the intertidal zone of the swamp may be oxidized as the water table fluctuates with time. Oxidation of the dark sediment and abundant plant remains would produce a light-coloured mottled unit very similar to mud deposited in the supratidal zone of the swamp. Consequently some units recognized in the subsurface as supratidal mangrove mud may have been deposited in the intertidal zone of the swamp and subsequently oxidized.

Supratidal flats

In this Report the term 'supratidal zone' refers to the area between the level of mean high water and high-water spring tides (Cook & Mayo, in press) (Table 3). This usage follows that of Shinn et al. (1965) and of Lucia (1972, p. 160) who defined the supratidal zone as ' . . . . that area of tidal-flat sedimentation out of reach of the daily tides. Its elevation could be higher or lower than the mean high-tide mark. This environment is covered only by spring or storm tides and lies exposed subaerially for long periods of time'.

Mangroves grow in the lower, more frequently inundated part of the supratidal zone, but their landward growth is limited by the dryness and high salinity of the less frequently inundated supratidal flats in the higher part of the zone (Coleman et al., 1966). Supratidal flats lie landward of mangrove swamp along much of the eastern coast of Broad Sound and occur in some inlets on the western shore of Shoalwater Bay.

Mud is carried in suspension onto the supratidal flats by high spring tides and is deposited in laminae across a surface commonly covered by algal mats which grow when the flats are flooded. A hard cracked crust veneered with some patches of salt forms on the surface during the long period of subaerial exposure after each spring tide (Fig. 17). Sediment deposited on the supratidal flats is also washed from the uplands during wet-season floods. Sand, quartz pebbles, and iron nodules characteristic of the uplands are deposited in supratidal mud at the edges of uplands.

The supratidal flats are generally barren of vegetation, but small patches of grass grow in the higher parts of the supratidal zone (Fig. 17). Plant remains are washed landward from the mangrove swamp by tides, and seaward from the uplands by freshwater floods, and are deposited in supratidal mud. Oxidizing conditions prevail on the supratidal flats. Consequently, plant remains and the roots of dead grass decay to produce orange and red mottling in the light olive-grey mud. The degree of mottling and abundance of oxidized plant remains are the main criteria for distinguishing supratidal mangrove mud from supratidal mud (Table 4). Supratidal mangrove mud is very mottled and contains abundant plant remains because a thick cover of trees grows on it; supratidal mud is only slightly mottled because little vegetation grows on it and relatively small amounts of plant material are deposited with it. Some algal material is also incorporated into supratidal mud (Cook, 1973).

Coastal grasslands

The coastal grasslands lie landward of supratidal mangrove swamps and supratidal flats is the extratidal zone (Table 3, Fig. 16). They are inundated only rarely by storm tides; sea water is usually confined to supratidal channels which extend far into the coastal grasslands. Fresh water may also flood the coastal grassland during the wet season, but it is commonly restricted to the anastomosing drainage system which is deeply incised into the grasslands (Cook & Mayo, in press). Modern sedimentation is largely restricted to the fluvial and supratidal channels. A thin dark saline deep-cracking clay soil (Cg1) has formed on the coastal grasslands and supports a thick growth of couch grass (probably *Sporobolus* sp.). Some landward areas of the coastal grasslands stand above the extratidal zone and are not inundated by storm tides (Cook & Mayo, in press).

Alluvial plains

Streams which have built alluvial plains among the uplands continue to deposit poorly to moderately sorted fine-grained angular sand to coarse angular gravel. The alluvium of some streams contains iron nodules eroded from the relict lateritic soil profile (Fig. 13), and abundant plant remains. Streams stop flowing or dry up during the dry season. Their coarse load reflects high-energy flow conditions during the wet season.

Holocene Depositional Progradation

The stratigraphy of sediments below the coastal grasslands and presence of coastal landforms up to 20 km inland from Broad Sound on the Torilla Plains record retreat of the shoreline. Seaward growth of the coastal plains on the eastern shore of Broad Sound has been dated as middle to late Holocene. Evidence from the western shore of Broad Sound indicates that the sea stabilized at its present level in that area about 5000-6000 years ago (Cook & Polach, 1973). Therefore, growth of the Torilla Plains has probably been caused by depositional progradation rather than by eustatic lowering of sea level.

Stratigraphic evidence of progradation

Superposition of marine facies deposited in progressively higher tidal zones proves that sediment below the Torilla Plains was deposited during retreat of the sea.

Inland sites on coastal grassland

Intertidal mud was deposited over lateritized alluvium in BMR Port Clinton 1 (Fig. 6) during or after the Holocene transgression. Mangrove swamps then grew at the site, first in the intertidal zone and subsequently in the supratidal zone. Supratidal mud flats developed, and when the area passed into the extratidal zone, soil (Cg1) formed on the supratidal mud under couch grass cover.

The thick sequence of Quaternary alluvium in BMR Port Clinton 5 (Fig. 11) was buried by shallow marine mud during or after the Holocene transgression. Intertidal mud was then deposited until mangrove swamp grew at the site in the supratidal zone. Supratidal flats developed as conditions became too dry and saline for mangrove growth, and as the sea retreated farther couch grass colonized the extratidal zone.

The vertical profiles of both drill holes record retreat of the shoreline.

Fort Cope area. Shallow marine sand and mud were deposited over bedrock lowlands in the Fort Cope area during or after the Holocene transgression (Figs. 19, 20). Sand and gravel at the base of auger hole 6 and above shallow marine sediments in auger hole 11 may represent beaches on the flanks of uplands which

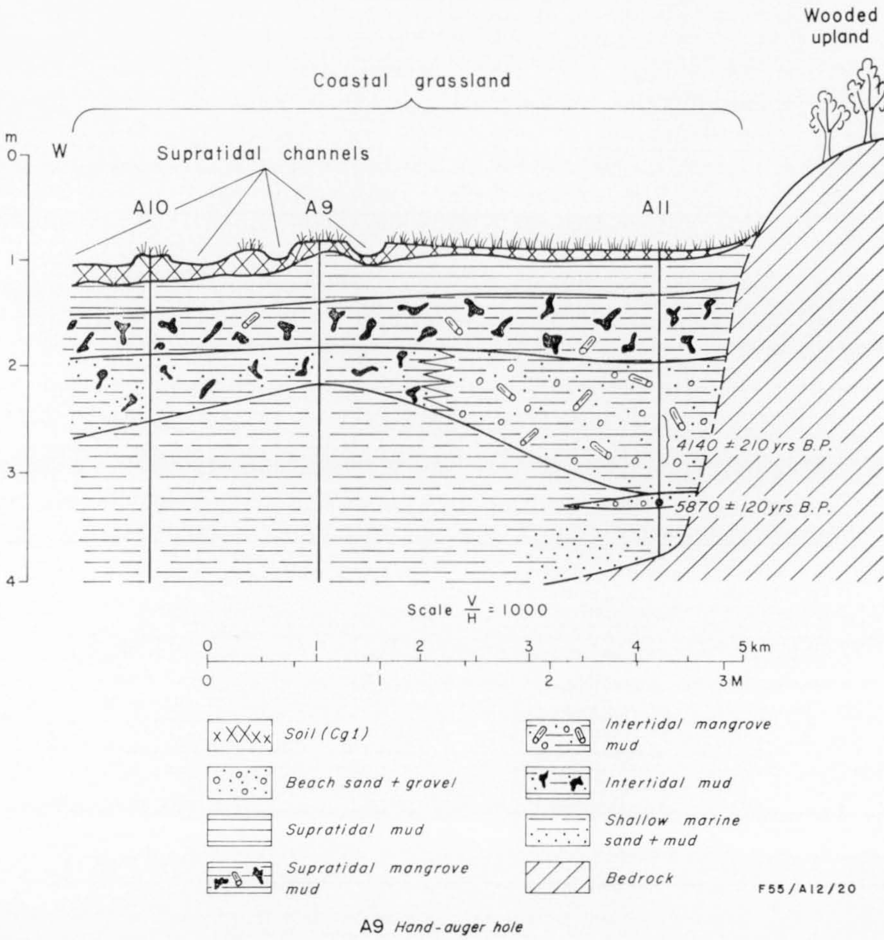


Fig. 20 — East-west cross-section of the Fort Cope area.

stood as islands. Mangrove swamp developed over shallow marine and beach sediment in the higher part of the intertidal zone on the shores of the islands (A6, A7, A11), while mud and sandy mud were deposited in the lower part of the intertidal zone (A8, A9, A10). The growth of intertidal mangrove swamp around Fort Cope was interrupted by the formation of a chenier which rests on swamp sediment (A6). Cook & Polach (1973) attributed the development of cheniers on the west coast of Broad Sound to the periodic erosion of the mangrove swamp caused by decreased sediment supply from rivers to the estuary. The rate of erosion exceeds the rate of deposition, mangrove thickets are depleted, and winnowing of mangrove mud concentrates shells and sand into a beach ridge landward of the mangrove zone. Mangroves growing in the supratidal zone then spread across the Fort Cope area. As conditions became drier and more saline, the mangroves died. Barren supratidal flats developed, and supratidal mud filled a depression between the islands (A5). Grass colonized the higher supratidal flats as marine inundation became infrequent, and soil has formed on the supratidal mud under grassland.

The vertical profile of shallow marine sand and mud overlain in turn by intertidal sand and mud, mangrove mud, supratidal mud, and soil proves that the shoreline has retreated across the Fort Cope area.

Torilla Plains boat landing. Intertidal sand and mud were deposited over indurated, lateritized alluvium on the shore of the upland east of the Torilla Plains boat landing after the Holocene transgression (BMR St Lawrence 2, A1) (Figs. 18, 21). Lateritized material on the western flank of this island was reworked during intertidal deposition (A4), and storm waves or tidal currents produced a lens of shells and gravel on intertidal sediments (A1). The subsequent growth of intertidal mangrove swamp across the area was interrupted by the formation of a chenier (A2, A3) during a period of meagre sediment supply to the estuary. Mangroves re-established themselves in the intertidal zone and now grow in the supratidal zone at the boat landing (A1, BMR St Lawrence 2). Mud is being deposited west of the chenier in the higher part of the supratidal zone on supratidal flats (A1), but east of the chenier the flats extend into the extratidal zone and are covered by couch grass (A4). Mangrove-swamp sediments are being eroded with the consequent deposition of intertidal mud at the base of the scarp at the boat landing (BMR St Lawrence 2). The upward sequence of intertidal, mangrove, and supratidal sediments demonstrates that the section at the boat landing was produced by retreat of the shoreline.

The vertical profiles in other auger and drill holes along the seaward edge of the upland west of Torilla Plains homestead are very similar to the stratigraphic sequence at the boat landing. In auger hole 12 (Fig. 2) intertidal mud is overlain by intertidal mangrove, supratidal mangrove, and supratidal mud (Burgis, 1972). The deposition of intertidal sand and mud at the site of auger hole 13 was followed by the growth of supratidal mangrove swamp and the development of supratidal flats before the area passed into the extratidal zone (Burgis, 1972). In BMR Port Clinton 4 shallow marine mud overlies indurated alluvium and is succeeded in turn by intertidal, intertidal mangrove, supratidal mangrove, and supratidal mud on which soil has formed under grassland (Fig. 10). In BMR Port Clinton 3 (Fig. 8) and auger hole 14 (Burgis, 1972) intertidal, mangrove swamp, and supratidal sediments were deposited over indurated alluvium and are overlain in turn by late Holocene alluvium washed from the adjacent upland during wet-season floods. Dark soil (Cg1) developed on supratidal mud at the site of auger hole 14 before

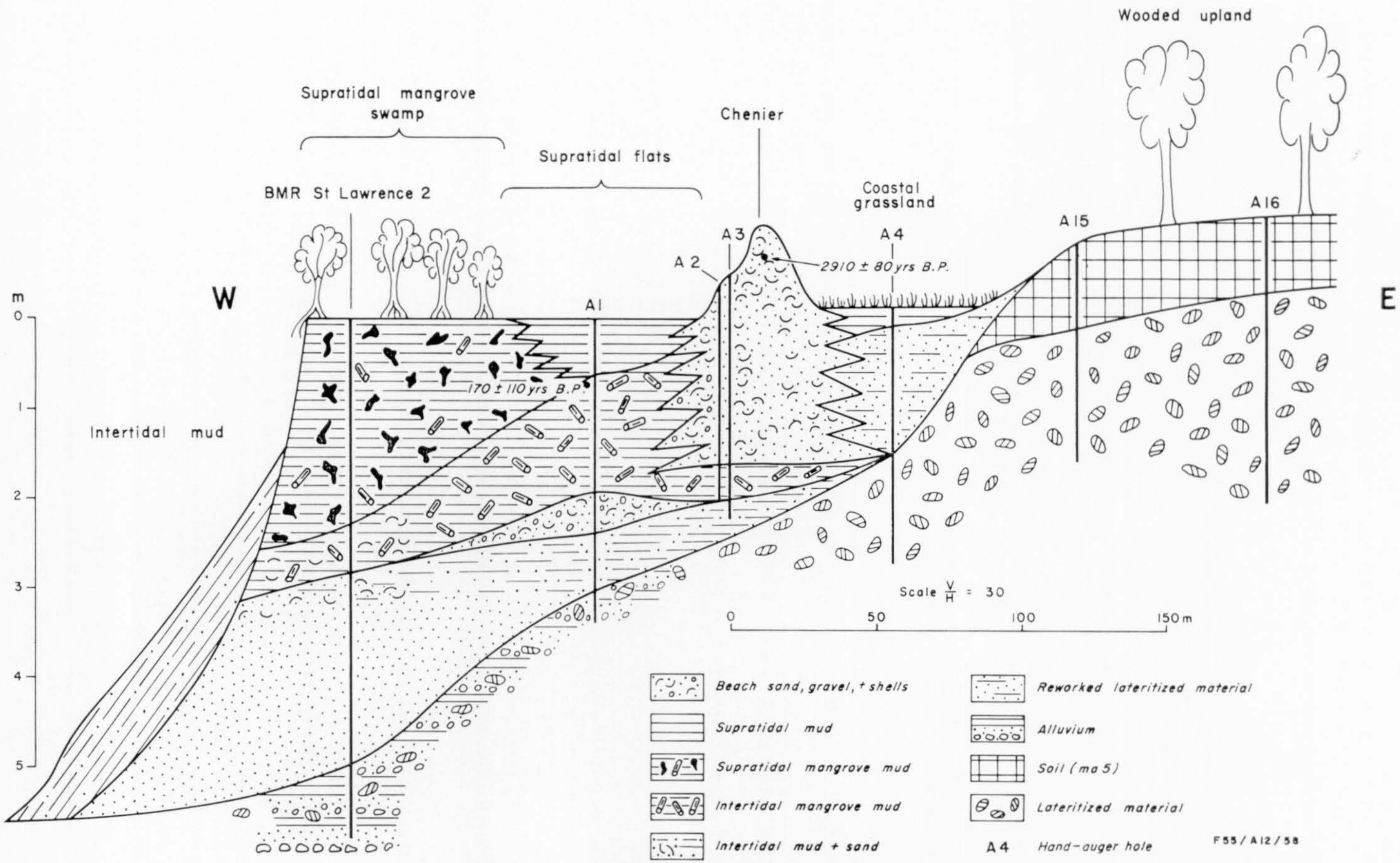


Fig. 21 — Cross-section at the Torilla Plains boat landing.

the late Holocene alluvium was deposited. BMR Port Clinton 2 (Fig. 7) was drilled west of Torilla Plains homestead on a red earth upland in a circular depression which was flooded during the Holocene transgression. Intertidal sand and supratidal mud were deposited in the depression over lateritized alluvium, but the Holocene sequence is very thin because of the greater elevation of this site. The stratigraphic sequences in all of these holes illustrate retreat of the shoreline.

Geomorphic evidence of progradation

The presence of landforms shaped by coastal processes inland on the Torilla Plains and the alluviation of the coastal grasslands indicate that the shoreline has retreated seaward across the Torilla Plains.

Coastal landforms. The boundary between the coastal grasslands and wooded, flat to rolling uplands marks the maximum Holocene transgression (Fig. 4). Subsurface data show that the coastal grasslands grow on a time-transgressive unit of supratidal mud which becomes younger seaward to merge with sediment being deposited on modern supratidal flats. The area covered by couch grass and dark saline deep cracking clay soil (Cg1) (Fig. 5) is coincident with old supratidal flats which passed into the extratidal zone as the sea retreated.

The uplands commonly slope sharply 1 to 2 m down onto the flat grasslands, but in places wave-cut cliffs up to 5 m high have been cut into lateritized bedrock at the coastal grassland/upland boundary (Fig. 4). Cliffs near the mouth of Spencer Creek stand above coastal grassland 15 km inland from the present shoreline and were cut during the maximum extent of the sea. Cliffs were also eroded around the edges of the upland west of Torilla Plains homestead and around Torilla Hill and Fort Cope.

Cheniers rise 1 to 2 m above coastal grassland around Fort Cope (Figs. 4, 19) and are clearly abandoned beach ridges which formed as the shoreline retreated. The radiocarbon age of the chenier (2910 ± 80 years B.P.) at the Torilla Plains boat landing (Figs. 18, 21) shows that it is also a relict beach ridge; supratidal mud has been deposited on its flanks since its formation. Middle to late Holocene cheniers are more common on the western coast of Broad Sound (Cook & Polach, 1973). Cheniers are associated with modern depositional environments west of Prince Mountain on the eastern shore of Broad Sound, and beach ridges line the shore of inlets on the western coast of Shoalwater Bay (Fig. 4); the ages and stratigraphic relations of these ridges are unknown.

Incision of channels into the coastal grassland (Figs. 16, 22) also reflects withdrawal of the sea. As supratidal flats passed into the extratidal zone and became grassed, freshwater and supratidal channels were cut into the old supratidal sediment to carry water to and from the retreating shoreline.

Alluviation of the coastal grassland. Coonyan and Wadallah Creeks are depositing alluvial fans over the Holocene marine sediments which underlie the coastal grasslands (Figs. 4, 22). The fans are northwestward extensions of the broad colluvial-alluvial plain which occupies the valleys of these creeks, and they stand a few metres above the coastal grasslands. The fan being built by Wadallah Creek is 2 km long and 0.5 km wide. The disruption of drainage lines at its toe reflects the youth of the fan; the channel of Wadallah Creek which crosses it has no direct connexion with channels cut into the coastal grasslands (Fig. 4), and fan sediment has partly buried meanders of channels incised into old supratidal flats during middle to late Holocene time.

Couti Uti Creek is also depositing alluvium on the coastal grasslands. Dark organic soil (Cgl) which developed on supratidal mud is buried by 0.6 m of fine sand and silt where the stream flows onto the grasslands.

TABLE 5. RADIOCARBON AGES OF MATERIAL FROM THE TORILLA PLAINS

Laboratory Number	*BMR Registered Number*	*Material Dated*	*Locality*	*Depth Below Surface*	*Radiocarbon Age (Years B.P.)*	*Comments*
SUA—139	71636214	Wood	BMR Port Clinton 4	1.8—2.4 m	6010±240	Wood from shallow marine, intertidal, and intertidal mangrove mud
SUA—137	71636212	Wood	Auger hole 11	2.4 m	5870±120	Wood from beach sand and gravel
SUA—138	71636213	Wood	BMR Port Clinton 1	2.4—2.7 m	5790±320	Wood from intertidal mangrove mud
SUA—133	71636208	Wood	Auger hole 11	1.6—2.0 m	4140±210	Wood from intertidal mangrove mud
SUA—127	71636039	Oyster shells	Near auger holes 2 & 3	0.41 m	2910±80	Chenier near boat landing
SUA—136	71636211	Wood	Auger hole 7	1.8—2.1 m	2470±150	Wood from intertidal mangrove mud
SUA—126	71636059E	Mangrove Wood	0.5 km north of boat landing	Near surface	1740±80	Mangrove stump partly buried by supratidal mud
SUA—134	71636209	Wood	Auger hole 7	0.9—1.5 m	1130±170	Wood from intertidal mangrove mud
ANU—899	71636067	Mangrove Wood	Near auger hole 1	0.61 m	170±110	Probably contaminated; wood from intertidal mangrove mud

The deposition of fluvial sediments over the Holocene marine sequence proves that alluviation of the coastal grasslands has only recently begun. The phase of fluvial sedimentation of the coastal lowlands which had occupied much of the previous Cainozoic history of the Torilla Peninsula has now resumed.

Age of the depositional progradation

Radiocarbon dating of wood from sediments below the Torilla Plains (Table 5) shows that the Holocene transgression reached its maximum extent about 6000 years ago. Wood from the base of intertidal mangrove mud in BMR Port Clinton 1 (Fig. 6) dates early growth of mangrove swamp 2 km west of the uplands at 5790 years B.P. By that time mud had been deposited in the lower part of the intertidal zone at the site, and the sea had already retreated slightly from its maximum shoreline at the coastal grassland/upland boundary. Therefore the maximum Holocene transgression is slightly older than 5790 years B.P. in the Torilla Plains area.

Sedimentation during retreat of the shoreline began at approximately the same time in more seaward sites. Wood deposited in the subtidal, open intertidal, and intertidal mangrove zones at the site of BMR Port Clinton 4 (Fig. 10) dates at 6010 years B.P. and wood deposited in a lens of beach sand and gravel over shallow marine mud in auger hole 11 (Figs. 19, 20) gives an age of 5870 years B.P.

Sedimentation has continued across the Torilla Plains area through middle and late Holocene time. Intertidal mangrove swamp was well established at auger hole 11 (Figs. 19, 20) 4140 years B.P. and grew at auger hole 7 at least from 2470 to 1130 years B.P. (Fig. 23). The chenier at the Torilla Plains boat landing was built about 2910 years B.P. (Fig. 21) and 0.5 km north of the boat landing supratidal mud has been deposited over a mangrove stump which died 1740 years B.P. A date of 170 $\pm$ 110 years B.P. for intertidal mangrove wood near auger hole 1 (Fig. 21) is regarded as suspect: observations indicate that sedimentation on modern supratidal flats is slow, and 60 to 280 years is too little time for deposition of the 0.6 m of supratidal mud which overlies intertidal mangrove mud at this site.

Retreat of the eastern shoreline of Broad Sound across the Torilla Plains may have been caused by eustatic lowering of sea level, depositional progradation, or uplift of the Torilla Peninsula. Jardine (1928) cited the presence of marine shells on the surface of the coastal grasslands as evidence of a drop in sea level of 4.5 to 6.0 m in the Torilla Plains area in recent time. Fairbridge (1950), Hopley (1968, 1971), and Gill & Hopley (1972) presented evidence from northern Queensland and Victoria for a high Holocene stand of the sea and a subsequent eustatic lowering to the present sea level. However, data from southern Queensland and New South Wales led Thom et al. (1969, 1972) to question whether the sea has stood above its present level along the eastern coast of Australia during Holocene time. Bird (1971) concluded that the sea stood at or slightly above its present level about 5500 years B.P. near Cairns and that the coastal plain there has prograded seaward since that time.

Several sequences of roughly parallel cheniers stand above the grassed prograding coastal plains on the western shore of Broad Sound in the Waverly Creek, Hoogly, and Charon Point areas (Cook & Polach, 1973), (Fig. 1). Radiocarbon dates on oyster shells from two chenier sequences indicate that the oldest cheniers were built about 5000 years ago; younger cheniers have formed since then during periods of meagre sediment supply to the estuary. Cook & Polach

(1973) considered that stability of sea level is a prerequisite for chenier development and reported no significant seaward change in the elevations of the cheniers. Therefore, they concluded that the sea reached and stabilized at its present level along the western coast of Broad Sound about 5000 years ago; sea level has not fluctuated by more than 1 m since that time. Depositional progradation rather than eustatic lowering of sea level is thought to have been responsible for the construction of the chenier plains on the western coast of Broad Sound.

The oldest cheniers dated by Cook & Polach (1973) are separated from uplands by strips of marine sediments, some of which were deposited before the cheniers were built. Therefore, the maximum Holocene transgression on the western shore of Broad Sound probably occurred before chenier development began about 5000 years ago.

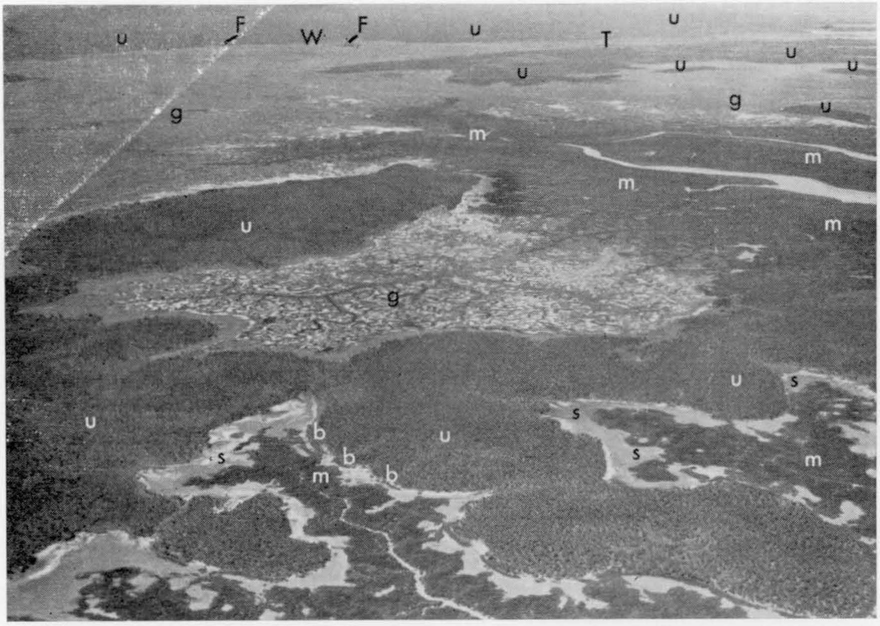


Fig. 22 — Alluvial fans are being deposited over Holocene marine sediments at the edge of the uplands (u) near Waratah (W) and Torilla Plains (T) homesteads. Coastal grassland (g) cut by supratidal channels covers the Torilla Plains. Beach ridges (b) flank uplands (u) in the foreground. Supratidal flats (s) and mangrove swamp (m) line the shore of Broad Sound.

The sea has been stable at its present level on the western coast of Broad Sound during the middle and late Holocene. The Torilla Plains have been built seaward during that time. Consequently retreat of the shoreline across the coastal grasslands on the eastern side of the estuary was probably caused by depositional progradation rather than by eustatic lowering of sea level. There is no evidence of Quaternary tectonism on the Torilla Peninsula, but localized small-scale uplift of the area may have produced a relative lowering of sea level and progradation of the Torilla Plains.

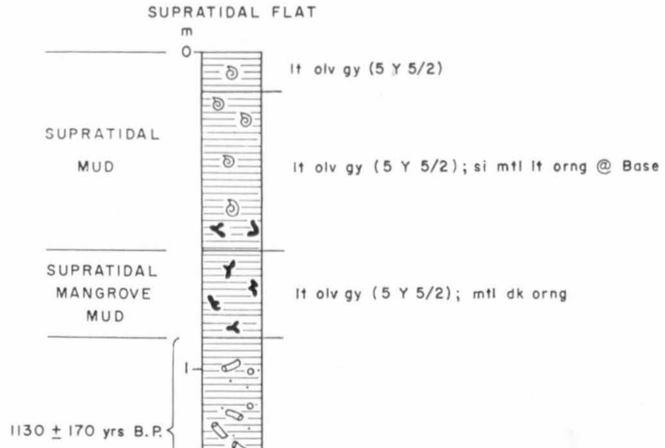


Fig. 23 — Lithological log of auger hole 7.

Erosion of the coastal grasslands

High spring tides which flood modern supratidal flats have eroded coastal grassland along the eastern coast of Broad Sound from auger hole 10 south almost to Halfway Creek (Fig. 2). Islands of grassland surrounded by erosional scarps up to 1 m high are scattered across the supratidal flats, and remnant strips of grassland 10 to 20 m wide with similar scarps on their seaward edges lie between the uplands and supratidal flats (Fig. 17). High spring tides have also partly eroded grassland which covers the floors of circular depressions in the seaward edges of the red earth uplands (Figs. 9, 14, 15). Grassed supratidal mud deposited during progradation of the Torilla Plains is now being eroded as modern supratidal flats expand landward.

The present shores of the Broad Sound estuary are lined by adjacent areas of modern erosion and modern deposition (Cook & Mayo, in press). Zones of erosion are characterized by a low cliff cut into sediments supporting mangrove swamp and are more common in the upper reaches of the estuary. Zones of deposition are often characterized by the growth of young mangroves seaward of the main swamp (Fig. 16). Mangrove swamp which lines much of the coast in the area where grassland is being eroded terminates seaward in a wave-cut cliff (Fig. 21). A band of intertidal mud derived from the erosion of mangrove mud is being deposited seaward of the cliff (Fig. 18). Northward this zone of erosion passes into a depositional coastline in the Fort Cope area; there the wave-cut cliff is absent, the band of intertidal mud pinches out, and young mangroves are pioneering into the intertidal zone. Holocene sediments eroded from one area of the Broad Sound coastline are being deposited elsewhere along it. Erosion of coastal grassland and mangrove swamp between auger hole 10 and Halfway Creek is thus simply a reflection of this process of sedimentary cannibalism (Cook & Mayo, in press) which prevails in Broad Sound today. The distribution of erosional and depositional areas probably reflects the pattern of tidal currents in the estuary.

The shape of the Broad Sound estuary changed as the shoreline prograded during the Holocene. With construction of the Torilla Plains, Herbert Creek has now attained a funnel shape which Cook & Mayo (in press) feel '. . . equilibrates the forces of tidal erosion and depositional progradation.' The rate of deposition exceeded the rate of erosion until Herbert Creek reached this shape; erosion and deposition are now in balance along its shores until a marked change in the tidal range or rate of sedimentation takes place (Cook & Mayo, in press).

CAINOZOIC HISTORY

Alluvium and colluvium were shed from highlands on the Torilla Peninsula during the Tertiary and were deposited in fans on the flanks of the ranges possibly when the sea stood below its present level. The fans extended into the lowlands which are now covered by grassed coastal plains.

Lateritic soil profiles developed on bedrock, alluvium and colluvium during upper Tertiary time. Some alluvium was indurated in the ferruginous zone during lateritization, and a thick mottled zone developed.

Alluviation of the lowlands resumed during the Quaternary. The top of the lateritic profile was removed by erosion in the highlands, and mottled Tertiary alluvium was buried by Quaternary sediments. However, remnants of the Tertiary lateritized land surface were preserved on low uplands in the coastal plains zone. Reweathering of the relict lateritic profile on these uplands under Quaternary climatic conditions has produced red earth soils. Circular depressions in the red earth uplands were produced by groundwater sapping at the top of the relict mottled zone, possibly during periods of Quaternary sea-level rise. Evidence of early and middle Pleistocene sea-level changes has not been recognized on the Torilla Peninsula.

The alluviated lowlands in the Torilla Plains area and the floor of Broad Sound were exposed to weathering during the last low stand of the sea in the late Pleistocene. Some marine sediments and Tertiary and Quaternary alluvium were indurated as soil hardpans before this surface was inundated again during late Pleistocene and early Holocene time.

The sea transgressed across the alluviated lowlands to its maximum extent at the coastal grassland/upland boundary about 6000 years ago. It stabilized at its present level, sea cliffs were cut at its shore, and depositional progradation began. The intertidal, supratidal, and extratidal environments migrated seaward as the shoreline retreated. Shallow marine sediments deposited during or immediately after the Holocene transgression were buried by intertidal sand and mud, which were in turn buried by intertidal and supratidal mangrove mud as mangrove swamps followed the sea westward. Cheniers were built landward of the mangrove swamp during periods of low sediment supply to the estuary. Supratidal flats developed as aridity and high salinity killed mangroves, and supratidal mud was deposited across the marine plain with retreat of the sea. As areas extended into the extratidal zone, couch grass colonized the supratidal mud, soil formed under the coastal grassland, and supratidal and fluvial channels were incised into the Torilla Plains. Alluviation of the lowlands has resumed in late Holocene time with the deposition of alluvial fans over Holocene marine sediments.

Progradation of the Torilla Plains during middle and late Holocene time has changed the shape of the estuary so that today the rates of deposition and tidal erosion are in equilibrium. Sediment eroded from coastal grassland and mangrove swamp along one section of the shoreline is deposited in adjacent areas.

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APPENDIX 1

ABBREVIATIONS USED IN LITHOLOGICAL LOGS

Abundant	abd
And	+
Angular	ang
At	@
Band (ing) (ed)	Bnd, Bndg, Bndd
Black (ish)	blk
Blue (ish)	bl
Brown (ish)	brn
Calcite (areous)	Calc, calc
Carbonaceous	carb
Cement (ed)	cmt, cmtd
Clay (ey)	Cl, cl
Claystone	Clst
Coarse	c
Cobble	Cbl
Common (ly)	com
Conglomerate (ic)	Cgl, cgl
Crystal (line)	Xl, xl
Dark (er)	dk
Decrease (ing)	Decr, decr
Feldspar (thic)	Fld, fld
Fine (ly)	f
Flake (y)	Flk, flk
Fragment (al)	Frag, frag
Grade (ed) (ing)	grd, grdd, grdg
Grain (ed)	Grn, grnd
Granule	Grnl
Gravel	Gvl
Green (ish)	gn
Grey (ish)	gy
Gypsum (iferous)	Gyp, gyp
Igneous	ig
Iron	Fe
Ironstained	festnd
Large	lrg
Layer	Lyr
Lens (ticular)	Len, len
Light	lt
Lower	low
Matrix	Mtx
Medium	m
Mica (ceous)	Mic, mic
Moderate	mod
Mottled	mtl
Near	nr
Nodule (ar)	Nod, nod
Olive	olv

Orange	orng
Pebble (y)	Pbl, pbl
Pelecypod	Pelcp
Pink (ish)	pk
Plant	Plt
Plant remains	Plt Rem
Platy	plty
Poor (ly)	p
Quartz (itic) (ose)	Qz, qtz, qzs
Quartzite	Qzt
Rock (y)	Rk, rk
Round (ed)	rnd, rndd
Sand (y)	Sd, sd
Sandstone	Sst
Scattered	scatd
Silt (y)	Slt, slt
Siltstone	Sltst
Slight (ly)	sl
Small	s
Sorting (ed)	Srtg, srtd
Stain (ing) (ed)	Stn, Stng, stnd
Streak (y)	Strk, strk
Subangular	subang
Subrounded	subrndd
Thick	tk
Thin	tn
Upper	up
Variety (ous)	Var, var
Very	v
Weathering (ed)	Wthrg, wthrd
Well	w
White (ish)	wh
With	č
Wood	Wd
Yellow (ish)	yel

R73/1842