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CHAPTER 5

REEF ISLANDS OF THE COCOS (KEELING) ISLANDS

BY

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INTRODUCTION

Reef islands have developed during the final phase of the Holocene development of the Cocos (Keeling) Islands. The islands are low-lying, and are generally composed of unconsolidated, biogenic sand. In places coral shingle is an important element of the sediments, and in a few localities, as for instance towards the southern end and on the oceanward shore of Pulu Wak Banka, coral rubble, composed of boulders of more than 50 cm diameter, covers the islands seaward margin.

Reef islands often overlie a cemented coral breccia, referred to as conglomerate platform (see previous chapter). Guppy (1889) noted the compositional similarity between this and the material comprising the modern reef flat and reef crest, and as we have demonstrated this platform appears to be an emergent, fossil reef flat dating from the mid-Holocene (Woodroffe et al. 1990a, 1990b). The conglomerate platform underlies many of the islands, although is not found everywhere (Jacobson 1976); it appears to act as an anchor, determining island location. A clinker-like conglomerate, undercut by solution and ringing metallic to the hammer, is found along the lagoonward shore of many islands, and is particularly conspicuous around the perimeter of the lagoonlets or teloks.

In addition to the conglomerate platform there are also cemented deposits of beachrock. Beachrock can be distinguished from conglomerate platform because it is bedded and exhibits a seaward dip (Russell and McIntire 1965, p35); beds are scarped at the landward face, and the deposits are undercut along bedding stratification (Stoddart 1971, p9). In places beachrock overlies conglomerate platform, as on the western shore of Horsburgh Island. In addition there are some isolated cemented deposits which resemble cay sandstone. These are generally less well lithified, and are horizontally bedded; an example occurs on the oceanward shore at the southern end of the airstrip on West Island.

In this section the physical and major vegetation characteristics of individual reef islands are described and mapped. Mapping was undertaken from 1:10,000 colour vertical aerial photographs taken in 1987, supplemented by ground truthing. Elevational information was derived from a series of profiles surveyed across reef islands and related to mean sea level datum. Additional data come from existing surveys and benchmark records.

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The general form of reef islands was summarised diagrammatically by Darwin, who recognised a ledge of conglomerate platform which protruded on the oceanward side of islands, and a ridge, generally sandy, but also of coarser material, which formed the oceanward beach. In common with reef islands on other atolls, Cocos reef islands often show a lower lagoonward beach ridge, in addition to the oceanward beach ridge.

Individual reef islands were described by Guppy (1889). Details of perimeter and island area are given in Table 1; they are examined sequentially below.

REEF ISLANDS

DIRECTION ISLAND

Direction Island (also known as Pulu Tikus, or Rat Island) is a crescent-shaped island. It appears to have been the first island to be inhabited, for it was on Direction Island that the crew, together with the rats, of the *Mauritius* were marooned after their ship was wrecked in 1825. The island was also inhabited for a short period by Alexander Hare and his followers in the same year. It is 1.6 km long and 300 m maximum width, with an area of 0.34 km². It is dominated by coconut woodland, but with a band of *Scaevola* scrub along its eastern margin. This island was the site of the Cable Station, with undersea links to Australia, Singapore and South Africa, which came into operation in 1901 and ceased in 1966. In the late 1960s buildings on the island were either translocated to Home and West Island, or bulldozed into the sea along the oceanward margin, and considerable building rubble is conspicuous along the oceanward shore (Fig. 19a).

The eastern portion of the oceanward shore comprises a prominent ledge of conglomerate platform, extending up to 35 m seaward from the beach (Fig. 14). This conglomerate platform is composed particularly of heads of branching *Acropora*. The oceanward beach ridge is composed of coral rubble and shingle along most of the island, and fragments of *Pocillopora* are especially frequent. This coarse substrate overlies sand, and the island can be seen to be composed of sand just over the ridge crest which reaches a height of around 3.0 m along much of the island, but 3.5 m towards the northern end (Fig. 11). The lagoonward shore is dominated by a broad sandy beach. At the northwestern end of Direction Island there are a series of shingle berms marking periodic accretion, in relation to which Guppy proposed that 'as the reef grows seaward the island also gains on the reef flat by a succession of ridges, thrown up during heavy gales, the remains of which are still to be seen in its interior' (Guppy 1889, p463).

Small outcrops of beachrock are found at the northern and southern ends of the lagoonward beach, indicating minor recession of this shoreline at some stage in the past. There is a strong current running through the inter-island channel at the southern end of Direction Island, and called the Rip. Guppy (1889) proposed that such currents served to give the island its crescentic shape.

WORKHOUSE ISLET

There is presently no permanent land at the site of Workhouse Islet, or Pulu Pasir. However, there has been an island of variable size there in the past. A sand bank 150 ft

by 100 ft was described by van der Jagt in 1829; Guppy (1889) records that in 1888 it was 6 ft high and dominated by one seaward leaning coconut.

PRISON ISLAND

The island north of Home Island is known as Prison Island; it has been known as Pulu Beras (Rice Island) or Pulu Tuan (Master's island), from the time of Alexander Hare. It is now considerably smaller (88x75 m) than it must have been when Alexander Hare moved his household there in 1827 from Home Island. van der Jagt (1831) recorded that it was 20 ft high in 1829, and Guppy (1889) also states that it was 20 ft high in 1888 and was composed of blown sand. It presently reaches a height of 6.7 m, and so has changed little in overall height in this time, though it is now eroding on all sides (Fig. 19b). It contains a mixture of coconut, *Scaevola* and *Tournefortia*. Bunce (1988) implies that much of this erosion has taken place in the 30 years since Pulu Gangsa has been connected to Home Island.

BUTTON ISLETS

Guppy (1889) records that there were a series of islands, termed the Button Islets, on the 1829 map of van der Jagt, between Prison Island and Pulu Gangsa. The sandy reef islands had already disappeared by 1888, with only conglomerate platform remaining (this platform can be seen in the foreground in Fig. 19b).

HOME ISLAND

Home Island has been a centre of habitation since Alexander Hare chose it for his first permanent settlement in 1826. The burial island, Pulu Gangsa, termed Clunie Island by Guppy (1889), was artificially joined to Home Island by placing coconut logs and concrete-filled drums across the channel in the late 1940s (Bunce 1988). In 1888 the channel between the two had been less than 2 ft deep at low tides (Guppy 1889, p464). The island is also known as Water Island, New Selima or Pulu Selma. It is covered by well-managed coconut woodland, with extensive groves of *Calophyllum*. *Casuarina* was reported as widespread on the island in 1888 by Guppy (1889).

The combined islands have a length of 2.6 km, and reach a maximum width of 800 m (Fig. 2). Their area is 0.95 km². Some part of this has been reclaimed from the sea; this is especially true of the landing area north and south of the present jetty, and the part of the village called kampong baru (new village), reclaimed by teams of women earlier this century (Bunce 1988). Oceania House was designed and built by George Clunies-Ross in 1893.

There is considerable survey data available for Home Island. Most of the kampong is 1.20-1.60 m above mean sea level. The island rises generally to an oceanward beach crest that is around 3.30 m (Fig. 11). This beach is covered with coral shingle and coral boulders, but as excavations into the island have shown, these are underlain by sand which is dipping gradually oceanward at 2-6°.

North of the village there is the remnant of a wind-blown dune (see Fig. 11); sand from similar dunes appears to have been removed and used to assist fill in reclaimed areas. The dune presently rises to 5.50 m above mean sea level and contains one of the

few remaining stands of *Pandanus*. The sandy lagoonal shore has been extensively modified; sand has been bulldozed, and there is evidence of a series of seawalls along parts of the shore. The village extended along the southern shore, east of Oceania House earlier this century (Gibson-Hill 1950).

On the oceanward shore of Home Island there is a narrow outcrop of conglomerate platform within which branching corals are especially prominent (Fig. 15). Individual *Porites* blocks within the conglomerate platform reach up to 1.0 m mean sea level. The conglomerate platform is overlain by boulder and shingle deposits. It widens into a broader platform at the southern end of the island. Conglomerate also underlies much of the island, as can be seen on the profiles in Figure 11, and from descriptions in Jacobson (1976).

PULU AMPANG KECHIL

Pulu Ampang Kechil is the small island south of Home Island, and forming the northern outlier of the Ampang Islands (Fig. 3). It was called Scaevola Islet by Guppy (1889). It is dominated by *Scaevola*, although with individual coconut and *Tournefortia*. The island is composed of coral shingle, with a sand spit extending to seaward and to lagoonward. It lies on an outcrop of conglomerate platform which contains some particularly large heads of *Porites* coral of over 1 m diameter.

PULU AMPANG

The Ampang Islands, termed Steward's group in van der Jagt's map of 1829, are a group of several small islands on one outcrop of conglomerate platform. The term Pulu Ampang is generally applied to the northernmost of the group, distinguished as Ampang Major by Guppy. This island is horseshoe shaped 625 m long and 275 m wide, with sandy spits extending into the lagoon around the island margins. *Pemphis* grows on these spits and also occurs along a minor bar cutting off the interior lagoonlet. This lagoonlet dries at low tide, and Guppy recounts that J.C. Ross remembers this feature silting up (Guppy 1899, p466). It appears to have changed little from the account given by Guppy over 100 years ago (Fig. 3)

The conglomerate platform is extensive along the oceanward shore of each of the Ampang Islands (see Fig. 19c). It forms a much flatter surface than on Pulu Ampang Kechil, and rises up to heights on individual coral heads within the platform of 0.76 m mean sea level. Much of the conglomerate platform is inundated at high tide, particularly when there is a large swell. The oceanward beach on Pulu Ampang is composed of shingle overlying sand, with individual boulders at the foot of the beach of diameters up to 1 m. The crest of this ridge has a cover of *Scaevola* scrub, which is replaced 10-20 m inland by coconut woodland (Fig. 3).

PULU WA-IDAS

Pulu Wa-idas, called Ampang Minor by Guppy, is separated from Pulu Ampang to the north by a deep pool, which resembles other inter-island passages except that it does not continue through the conglomerate platform as a channel. The conglomerate platform is fissured, and is evidently eroding at this point, and given time it would appear that a channel will form between these two islands. The island is 75 m from north to

south, and 320 m from oceanward to lagoonward; it is covered with coconut woodland, with a margin of *Pemphis* along its southern side (shown in Fig. 19c).

PULU BLEKOK

The southernmost of the Ampang islands is Pulu Blekok, called Pulu Bruko by Guppy. In form it is a mirror image of Pulu Wa-idas, with a fringe of *Pemphis* along its northern margin. It is 230 m from oceanward to lagoonward (Fig. 3). The conglomerate platform, although embayed on the oceanward side at this point, does not show the same indications that a channel will form as to the north of Pulu Wa-idas. Indeed Guppy suggested that the vegetation of the two islands was encroaching, and that over time the two islands would unite (Guppy 1889, p466); they have not done so in the 100 years since he observed them. There is a lagoonlet, largely cut off from the lagoon, on the lagoonward side.

PULU KEMBANG

Pulu Kembang, spelt Pulu Kumbang by Guppy, but not described in any detail, sits on its own outcrop of conglomerate platform. The island is 150 m north to south and 390 m from oceanward to lagoonward; it is predominantly sandy, but it has extensive shingle along the margins flanking inter-island channels, and shingle is found at the beach top, where there is a narrow band of *Scaevola*. Much of the island is covered with coconut woodland, though *Pemphis* occurs on the lagoonward most parts of the sandy spits. The sand on the oceanward beach comprises an abundance of foraminifera; it appears to be actively accreting, particularly at the southeastern corner, where *Pemphis* is colonising this sand.

PULU CHEPELOK/PULU WAK BANKA

The island south of Pulu Kembang is a long island which has several names. It was called Armstrong Island on the 1829 map of van der Jagt; Guppy called it Gooseberry Island. On the recent maps its northern part is called Pulu Chepelok (also spelt Pulu Cepelok), while the southern half is named Pulu Wak Banka. The island is 1.15 km long, and up to 400 m wide. It has prominent spits at the northern and southern ends. There are also a couple of similar features extending into the lagoon in the middle of the island, giving the impression that this island may have comprised two or three islands in the past (Guppy 1899, p466).

The island along its oceanward shore is underlain by an extensive conglomerate platform. This contains large boulders in places; there is a large boulder 1.5 m long and 1 m higher than the general conglomerate platform level, reaching an elevation of 1.50 m mean sea level, at the southern end of the island. The nature of the beach sediments on the oceanward shore changes markedly along the island. There are coarse coral rubble deposits, with boulders up to 1 m in diameter, along much of the southern half of the island, reaching up into the *Scaevola* scrub which is dense along the ridge crest (Fig. 20e). On the other hand, where the island is narrowest, the conglomerate platform is no longer present along the oceanward shore, and instead there is a broad sand beach. The ridge crest rises to 3.5 m mean seal level at the southern end of the island, but is only 2.1 m mean seal level where a profile has been surveyed across the island in the centre. On that profile (Fig. 11), it can be seen that the coral shingle overlies sand, and that the

conglomerate platform also continues under much of the island. Conglomerate forms a thin crust along the margin of the channel along the southern end of the island.

PULU PANDAN

Pandan Island or Pulu Pandan (also called Misery Island) is the clearest example of a horseshoe shaped island (Fig. 3), called an atollon by Guppy (1889). Despite its name, *Pandanus* is no longer conspicuous element of the island's vegetation. It consists of two distinct sandy spits with a shingle veneer, both covered by coconut woodland with *Pemphis* on the lagoonward extremity (Fig. 16). Maximum width is about 800 m, and the island measures 1.8 km from the end of one spit to the end of the other spit. These spits serve to partially enclose a lagoonlet, with a soft muddy floor and cover of seagrass. The southern spit in particular has recently extended into the lagoon, and there is a further shoal of intertidal sand, with an outpost of *Pemphis* on it which represents a continuation of the island.

On the oceanward shore there is a margin of conglomerate platform extending along the island. For much of its extent this conglomerate comprises an upper unit of shingle-sized clasts cemented into a near horizontal layer (Fig. 19d); this overlies some *in situ* fossil microatolls of branching *Porites* at the eastern end of the surveyed transect. The conglomerate platform surface rises to 1.20 m mean sea level, rather higher than on other islands on the eastern rim of the atoll, suggesting that this shingle conglomerate surface may overlie the more conventional conglomerate platform surface. The transect (Fig. 11) illustrates that the island is composed primarily of sand, rising up to a ridge crest of 4.50 m mean sea level, and does not have the shingle or rubble veneer characteristic of the oceanward shore of islands to the north. Shingle does form low elevation ridges along the lagoonward shore, and there are small outcrops of a clinker-like conglomerate around the margin of the lagoonlet.

PULU SIPUT

Pulu Siput (also called Goat Island) is dominated by coconut woodland, and is 660 m oceanward to lagoonward, and 240 m from north to south (Fig. 3). It has formed on an outcrop of conglomerate platform, and the island is predominantly sandy, with foraminiferal sand accumulating at the northeastern corner of the island. Spits, with a cover of *Pemphis*, but also with occasional *Suriana*, extend into the lagoon.

PULU JAMBATAN

Pulu Jambatan is the name given to the island formed largely of coconut woodland, 340 m long, at the lagoonward end of a long, narrow outcrop of conglomerate platform. There is a much smaller island, less than 50 m long, at the seaward end of this conglomerate platform outcrop, apparently without a name, with a vegetation cover of *Scaevola* with some coconut and *Tournefortia* (Fig. 3). The conglomerate platform between these two islands is smooth, and cover with a veneer of pink algal mat. Seaward of the more oceanward island, the platform is highly irregular, and contains much coarser coral boulders.

PULU LABU

Pulu Labu is the island directly north of South Island, separated from it by a narrow channel (Fig. 3). Most of the island, which is 430 m long, is composed of coconut woodland; there is a broad band of *Scaevola* scrub along the oceanward ridge crest, and on the southeastern corner where sand has recently accumulated, *Pemphis* is established. The form of the island is very similar to that of a series of lagoonward promontories on neighbouring South Island, and it is not unlikely that similar islands to Pulu Labu may have existed in the past, but have now been united with South Island.

SOUTH ISLAND

South Island, also called Pulu Atas (meaning top island in reference to it being upwind), Scott Island and Southeast Island, is the windward island of the atoll. It was chosen as the site for the first settlement by Captain John Clunies Ross in 1827, who dredged a boat channel through the southern lagoon to the centre of the island. The long lagoonal shore is the preferred site for a number of Home Islanders pondoks (weekender shacks), and was also home to a regiment of Kenyan soldiers, the Fifth African Rifles, who were stationed at the southwestern end near the highest point termed 'Gunong', as coastwatchers in World War II.

The island is 9.5 km long, and reaches a maximum width of 1.1 km and is mapped in Figures 5 and 6. Much of the oceanward shore of South Island is formed of a dune (see Fig. 19f). Windblown sand reaches up to 6.3 m on profile I and profile J (Fig. 11). A dune reaches up to 11 m at the 'Gunong' at the southwestern corner of the island. A coral rubble veneer reaches 4.7 m mean sea level on profile H. The vegetation of the dunes is primarily *Scaevola*, though with considerable *Tournefortia*, particularly as isolated shrubs within blowouts along the dune crest. Guppy (1889) recorded that *Pandanus* was found along this dune crest, but it is not a conspicuous element of the vegetation now. While dunes, which are rare on coral atolls, characterise much of the shoreline of South Island, there is also a substantial outcrop of conglomerate. This takes two forms; conglomerate platform occurs in irregular outcrops along much of the eastern part of the island, often rising up to 1.20 m mean seal level. There are also outcrops of conglomerate ramp, a highly worn form of conglomerate platform, which has been bevelled back to a steep ramp-like profile (Fig. 19e). The latter superficially resembles beachrock, which can also be found at sites along the oceanward shore of South Island, but is not imbricated, and on inspection can be seen to have been bevelled to form the dipping outcrop, rather than deposited in dipping stratification. Similar conglomerate ramps are described on Diego Garcia, an atoll in the Chagos group (Stoddart 1971, p18).

The interior of the island is now covered by thick, overgrown coconut woodland which has degenerated from the organised and harvested coconut plantations of the heyday of the Clunies Ross estate. On the oceanward shore and over the narrow necks of the island, there is dense, impenetrable *Scaevola* scrub. Little remains, except isolated stumps of the *Pisonia* and *Cordia* stands which were once widespread on the island. There is a large stand of *Calophyllum* at the southwestern corner of the island (Fig. 5).

The lagoonward shore of South Island is highly irregular. The lagoonal flats are composed of mud or sandy mud, and there are irregular linear shoals, covered by *Pemphis* and inundated at high tide, partially enclosing some of the larger lagoonlets, termed Teloks (Fig. 20c). It is said to have been silting rapidly, which may have lead to

the abandonment of the first settlement there; though there can be little doubt that the southern flats of the lagoon must have been shallow even at that time, and access cannot have been easy. The western end of the island has a series of recurved spits; these are not as distinct as those of West Island; nevertheless they were interpreted by Guppy (1889) to indicate that the island had been extending to the west.

Upon first impression this elongate island appears to have been made up from several islands which have been joined together. There are two areas, traversed by profiles H and I respectively, which resemble infilled passages between these former islands. These are covered mainly by *Scaevola* scrub, with few coconuts; those coconuts which do grow there are stunted, and stressed. There is no freshwater lens developed beneath these narrow areas. Soil is absent or poorly developed, and the lagoonward portion of the island is composed of clinker coral shingle. Darwin interpreted these as former channels, and his interpretation was aided by a map that Leisk, the manager in charge of the islands at the time of his visit, told Darwin he had seen. Guppy was rather dismissive of the likelihood that the channels had been infilled as recently as Darwin implied, pointing out that they were closed, and the island one entity even in the map shown in van Keulen's Atlas of 1753 (Guppy 1889, p467). We examine this issue in more detail below.

PULU KLAPA SATU

Pulu Klapa Satu, the island directly west of South Island, is about 125 m long and 75 m wide (Fig. 5). It sits on a long linear exposure of conglomerate platform, which in common with the other islands of the southern passage, is relatively free of large coral clasts, and contains largely sand-sized grains cemented together. In petrography it resembles beachrock, but lacks the stratification which distinguishes the latter.

PULU BLAN AND PULU BLAN MADAR

Pulu Blan and Pulu Blan Madar, also known as Burial Island and East Cay, sit on the same outcrop of fine-grained conglomerate platform. They are composed of sand with some shingle, and carry a vegetation of coconut and *Scaevola*. The oceanward shore of Pulu Blan Madar rises up to a height of 1.20 m mean sea level.

PULU MARIA

Pulu Maraya or Pulu Maria lies on an outcrop of fine-grained conglomerate platform just west of the eastern end of West Island (Fig 8), and is named after one of two European children who disappeared without trace from the island shores in the 1860s. The island is predominantly sandy though with a series of shingle berms on the oceanward shore. It is dominated by coconut woodland, with a fringe of *Scaevola*, replaced with *Pemphis* along the lagoonward flanks.

WEST ISLAND

West Island, also known as Ross Island, or Pulu Panjang (Long Island), is the island upon which the airstrip was built, initially in 1944, but seeing little action in the war, and revamped for use by Qantas in 1951. It was first settled in 1826 by some of

Alexander Hare's followers, probably in the vicinity of Rumah Baru, and has been inhabited discontinuously since. It was home to more than 7000 troops from Britain, Canada, Australia and India in 1944, and has been associated with the airstrip and contains an Australian expatriate population at present.

The island is 12.6 km long and reaches up to just less than 1 km wide at its maximum width. It is mapped in Figures 6, 7 and 8. Most of the 6.2 km² was covered by coconut plantation, but much is now covered by buildings, the airstrip, or radio transmitter and receiver aerials. The coconut woodland has ceased to be cleared regularly, and has become largely overgrown, and penetrable with difficulty.

The island comprises three broad sections, connected by narrow sections which may have been former inter-island passages. These lead into the two large lagoonlet areas, Telok Jembu (Fig. 20a) and Telok Kambing (Fig. 20b). Much of the western shore is a sandy beach, with a dune, reaching more than 7 m high, at Beacon Heights, which has been excavated. Groynes have been constructed in front of the settlement to stop northwards movement of sediment, but accumulation within them indicates little net movement. There are extensive outcrops of beachrock, particularly at the southern end of the island, and adjacent to the Quarantine station, at those sites which appear to mark former passages. There is a large area of conglomerate platform at the southwestern end of the island, and isolated outcrops at the westernmost point and to the northwest. The outcrop to the southwest is one of the more elevated outcrops on the atoll rising up to 1.20 m mean sea level, with a further cemented shingle conglomerate up to 1.80 m mean sea level outcropping on the beach behind the conglomerate platform. There are a number of dipping arcuate ridges within this platform, especially at the southwestern corner, resembling the bassett edges recorded on the Great Barrier reef islands (Stoddart et al. 1978).

The easternmost end of the island is characterised by a number of sand spits and ridges, suggesting gradual buildout of the island into the southern passage. Radiocarbon dating of coral shingle from shallow pits in those shown in Figure 9, in the previous chapter, indicates that these spits have been built progressively. The ages are shown on an aerial photograph of the spits in Figure 17.

HORSBURGH ISLAND

Named after James Horsburgh, the British hydrographer, who compiled detailed sailing directions of this part of the Indian Ocean in 1805, Horsburgh Island is also known as Pulu Luar (Outside island). It is 1.7 km long and 0.9 km wide, covering an area of over 1 km² (Figs. 9 and 18).

It was almost continuously inhabited from 1826 until after World War II. Initially Alexander Hare put people on the island to grow vegetables and fruit for other islands. This tradition was maintained by the Clunies Ross proprietors, and George Clunies Ross kept deer on the island for hunting. In 1941, gun emplacements were installed on the southern point of the island and manned by Ceylonese troops.

This island sits partly on an outcrop of conglomerate platform. The conglomerate differs from that on other islands; on the eastern shore of Horsburgh it is generally narrow, and often bevelled into a conglomerate ramp. On the western shore there is a broad platform which consists of a series of strata dipping seaward at up to 5°, which

resemble beachrock. The platform appears to combine conglomerate platform and beachrock, and suggests that islands here may have formed almost contemporaneously with the development of the emergent reef flat.

Along the southern shore there is a broad sandy beach, in places with outcrops of beachrock which indicate that in the past the shoreline has had a slightly different orientation in this part of the island. The northern shore of the island is particularly exposed and consists of a bevelled conglomerate platform ledge, and boulder deposits over the top. A particularly noteworthy feature of this island is the small lagoonlet which occurs within the interior of the island to the northeast. This feature, blocked off from the sea by a boulder rampart, presently contains brackish water, and a stand of mangrove *Rhizophora apiculata*. Associated with the mangroves are *Cordia* stumps and *Sesuvium*. In his account of Horsburgh in 1888, Guppy (1889) describes the inland lakelet, but does not record mangroves growing there naturally; indeed he makes the point that mangrove propagules are regularly brought to the shores of Cocos, but have not colonised (Guppy, 1890). Guppy indicates that mangroves were planted there by John George Clunies Ross (Guppy 1890, p278). In a photograph of the lakelet, taken in 1941, the mangroves can be still seen (Gibson-Hill, 1950).

Much of the northern part of Horsburgh is composed of shingle or rubble, while the southern part is predominantly sand. Coconut scrub is especially open over the southern part of the island with a sward of grass and the sedge *Fimbristylis*, but forms denser coconut woodland to the north. *Scaevola* scrub is widespread over the island; to the south it is relatively open, but to the north it is dense, and made almost impenetrable by a tangle of *Turnera*, *Triumfetta*, *Wedelia*, *Premna* and the parasitic *Cassytha*.

NORTH KEELING ISLAND

North Keeling Island is named after Captain William Keeling who is believed to have sighted the island in 1609. It was sketched, showing coconuts, by the Swedish captain Ekeberg in 1749 and appears on the chart reproduced by Dalrymple the English hydrographer in 1787. Fitzroy examined and mapped it from *H.M.S. Beagle* in 1836, but made no landing. Unlike the South Keeling Islands, North Keeling has been visited relatively infrequently by naturalists, and therefore does not have the same history of description. It was first described in detail by Guppy (1889) who was there for 6 days in 1888. Wood-Jones (1912) spent a few hours ashore in June 1906, and the most detailed account, especially of the fauna is that of Gibson-Hill (1948, 1950) who visited for 1 day in January and 2 days in early July in 1941.

The island has not been inhabited for any continuous period, and is presently relatively little changed in comparison with the South Keeling Islands. It was visited from Cocos by the Clunies-Ross family, and Home Islanders (up to 40-60) stayed there for up to three months over the November-February period cutting firewood. The Emden beached on the southern shore of North Keeling after being routed by the Sydney in 1914; and the longest period of settlement was probably during the salvage of the Emden October 1915 to January 1916.

The island is 2.0 km long and 1.3 km wide, with a reef crest around all of the island, except the northwestern corner (Fig. 10). Reef island is almost continuous around the perimeter of a shallow lagoon, reaching a maximum width of 320 m and a minimum width of 50 m. There is one major opening into the lagoon on the southeastern corner of the atollon. This is the windward side, and the opening has no channel through the reef,

but is a shallow conduit which drains almost totally at lowest tide. The lagoon is shallow, reported as nowhere deeper than 8 feet by Guppy. Its surface sediments are muddy sands, except for two sandy spits which trail in through the entrance. These did not appear on Fitzroy's chart of the island; Guppy added them in his sketch of the island, but shows them scrolled back on themselves. As can be seen in Figure 10 they are presently linear features which extend flanking the channel. Much of the lagoon is covered with sea grass.

The island varies from sand to rubble. On the northern shore there is a broad sandy beach. This continues along the western shore but with varying amounts of shingle. On the profile (Fig. 10) the sandy beach rises up about 4 m above mean sea level. A pit shows some shingle fragments, but indicates that the majority of the substrate is sand. This becomes coarser to the south, where rubble outcrops on the beach, and there is an erosional cliff cut into this rubble. The southern shore of the island is composed of a spectacular steep shingle beach, with a series of berms identifiable. Much of the eastern shore is composed of a series of shingle berms, these are particularly well-developed just south of the channel into the lagoon, but continue to the north as well. Guppy (1889) recorded that pumice from the eruption of Krakatoa had advanced the shore into the lagoon; no evidence of this can be seen today.

There are also outcrops of coral conglomerate. A broad platform of conglomerate extends out over the reef flat at the eastern part of the island, almost closing the channel into the lagoon completely. Along much of the southern and eastern shore the conglomerate outcrops at the foot of the beach but contains a series of parallel rubble ridges, dipping and stratified like beachrock. These appear to be the lines described by Guppy (1889) as old reef margins, and upon which he based his argument that the reef built out by a series of jumps rather than prograding gradually. Similar boulder conglomerates have been described from other reef settings; they closely resemble the adjacent beach in structure and composition and we call them beach conglomerate, believing that they mark the position of former beach lines rather than reef crests (Fig. 20f). At the site of the southern transect (Fig. 10) there are a number of algal terracettes veneering these old beach deposits. Beach conglomerate overlies conglomerate platform in some places (Fig. 10).

The vegetation of the island was conveniently divided into four zones by Gibson-Hill (1950). Much of the island is dominated by *Pisonia* forest (see Williams, this volume, Chapter 6). Coconuts are a conspicuous element of all stands of *Pisonia*, and over much of the island we have chosen to map this as *Pisonia* and coconut woodland. *Tournefortia* is a conspicuous element of the vegetation of the eastern shore, dominating the crest of the shingle or rubble ridges. In some cases *Tournefortia* is monospecific, north of the channel into the lagoon it occurs with *Scaevola* also. Around the margins of the lagoon, *Pemphis* forms a thicket. *Cordia* is also important in this location, and it was to cut this latter species that the Clunies-Ross sent workers. It may have been less important when Gibson-Hill visited because of this history of cutting. Where *Cordia* forms a lagoonal fringe at present it is often fairly even-aged, and much may have grown back since cutting ceased. The final area that Gibson-Hill identified are cleared areas; the grassy and *Sesuvium* covered area to the northwest of the lagoon is the most extensive area of this type.

There has been considerable speculation as to how North Keeling has developed. In particular it seems unusual because the remaining entrance to the lagoon occurs on the most windward side, rather in the shelter that might develop on the leeward. Indeed the island is quite the inverse of the horseshoe shape that Guppy considers the typical style of

development on the main atoll. This has led a number of observers, starting with Fitzroy, to suggest that the island developed from a series of formerly unconnected islands.

REEF ISLAND MORPHOLOGY

The surveyed traverses (Fig. 11 and 12) show three basic cross-island profiles, the simplest of which was first described by Darwin (1842) and illustrated by a woodcut in the chapter on Keeling atoll (this illustration is in fact a section across Whitsunday atoll and not Cocos (Keeling)). Darwin notes that the highest part of the islets is close to the outer beach and that "from the outer beach the surface slopes gently to the shores of the lagoon". Such simple asymmetric profiles are common on West and South Islands and across the centre of the small horseshoe shaped islands on the atoll's eastern side.

The second type of profile is basin shaped, again with a prominent seaward ridge which slopes inland to a central depression before rising to a lower lagoonward ridge. Such profiles are illustrated from Direction Island and the southern end of Home Island (Fig. 11). The third profile type is more complex being composed of a series of subdued ridges and swales between the ocean and lagoonward ridges. This form suggests a more complicated accretionary history.

A characteristic feature of the islands on Cocos is their plan shape, which Guppy (1889) described as semi-crescentic or horseshoe shaped with their convexities to seaward. "The crescentic form is possessed in various degrees by different islands; some of the smaller ones are perfect horse-shoe atollons and enclose a shallow lagoonlet, others again exhibit only a semi-crescentic form, whilst the larger islands have been produced by the union of several islands of this shape." Examples of the first type would include Pulu Ampang, of the second type Direction Island and of the third type South Island.

To Guppy the islands fitted into an evolutionary sequence all stages of which are represented on Cocos "from the islet recently thrown up on the reef to the perfect horse-shoe atollon". Critical in Guppy's interpretation are the lagoonward recurving extremities of the islands which he believed were formed from material brought in by uni-directional currents through the interisland passages and "heaped up in such a manner as to prolong the extremities of each island lagoonward in the form of two horns". In the case of the larger islands a crescentic form results, while for the smaller islands a more perfect horseshoe shape is first attained. After the two horns are stabilised by vegetation, and providing there is an adequate supply of sand, the horns would tend to approach each other and ultimately they would be joined by a bar enclosing a lagoonlet on the island's lagoon side, Guppy called this occluded island form an atollon, and noted that Horsburgh Island "represents the last condition of an atollon, the earlier stages being illustrated by Pandan Island and Pulu Ampang Major".

This view of island evolution differed from that of Darwin who envisaged a difference in formative processes between islands on the windward and leeward sides of the atoll (Darwin 1842). On the windward side, the islands "increase solely by the addition of fragments on their outer side". Thus the gently sloping surface on the western side of the windward island predates the high ridge to seaward, and is lower because waves had further to go from the reef edge and "had less power to throw up fragments". On the leeward islands, Darwin recognised a combination of two processes operating. First, waves from seaward formed the high ocean ridge, and second "little

waves of the lagoon, heap up sand and fragments of thinly branched corals on the inner side of the islets on the leeward side of the atoll". As a result "these islets are broader than those to windward, some being even eight hundred yards in width, but the land thus added is very low".

Both Darwin and Guppy, as well as subsequent workers; recognised the association of islands with the conglomerate platform and the fact that the unconsolidated sands and gravels which go to make up the island commonly rest on a solid foundation of conglomerate platform. Indeed Guppy went so far as to suggest that where bare level patches of conglomerate are exposed on the windward side of the atoll these were "the foundation of the islets that have long since swept away" (Guppy 1889, p462).

In our view, the evidence for such an assertion is generally lacking, except in those places where linear or arcuate bands of beachrock or beach conglomerate are firmly cemented onto the conglomerate platform. Examples of such exposures are found along the northwestern side of Horsburgh Island, adjacent to the Quarantine Station on West Island, around the southwestern corners of West and South Island and on North Keeling Island. We believe that these outcrops are residuals from the earliest phase of island building and represent shorelines developed concurrently with the formation of the conglomerate platform at the time of higher sea level. A radiocarbon date of 3030 ± 85 years B.P. from a coral boulder in beach conglomerate to the southwest of North Keeling gives some support to this argument. Landward erosion of these shorelines has subsequently occurred. In some other locations high beachrock or beach conglomerate is found congruent with the present shoreline. In such cases the position of the initial shoreline has been maintained.

While the association of islands and conglomerate platform is the norm, Guppy (1889) also recognised that conglomerate platform is not everywhere present beneath the islands being "absent in those situations where ancient passages have been filled up with sand and reef debris, and also in those places where recent additions have been made to the land surface" (p. 462). Our drilling and field data confirm the validity of this comment, particularly with respect to the "horns" and "bars" of the horseshoe islands and atollons, as well as the extensive area of lagoonward recurving spits at the western end of South Island and eastern end of West Island. Radiocarbon dates recording the development of the last area are shown in Figure 17.

REEF ISLAND FORMATION

Reef islands post-date the conglomerate platform, and it has been demonstrated that the conglomerate platform was deposited 4000-3000 years ago, as shown by the narrow range of radiocarbon ages from within it (Woodroffe et al. 1990a, 1990b, this volume; see chapter 4, Fig. 2). The platform has been interpreted as a former reef flat, deposited under a sea level around 1 m above present, and the islands have formed in the last 3000 years during the time that the sea has fallen to present level.

Some indication of island age has already been given for Home Island (Woodroffe et al. this volume, see last chapter Fig. 3). Samples of coral shingle from a trench through island sediments (shown in Fig. 20d), indicate an age range of 1400-1800 years B.P.

Nevertheless there remains a series of different possible models of island formation, both in terms of oceanward or lagoonward accretion, and in relation to the

gradual or episodic nature of deposition of sediment. In order to examine the chronology of island formation in greater detail, three transects of pits were examined on West Island (Fig. 13) and samples of coral shingle submitted for radiocarbon dating.

The radiocarbon dates shown in Figure 13 confirm that the islands contain few sediments greater than 3000 years old. The date of 4280 ± 70 on transect O (T2) came from a depth around mean sea level which would be within conglomerate platform elsewhere. There is no lithified platform at this site, but the date appears to indicate a similar chronology of deposition. Although this transect is across a narrow neck of island flanking a telok (see Fig. 12), termed a barachois in relation to the atoll of Diego Garcia, a date of 3030 ± 70 elsewhere on the transect indicates island formation at an early stage at this site.

Transect P (T1) has been dated in some detail. The oldest date 2710 ± 90 years B.P. comes from pit 7 to lagoonward. There is then a progressive decrease in age towards the ocean. Thus contrary to Darwin's expectation, the island appears to have built out towards the ocean even here on the leeward side of the atoll. Dates from pit 3 are stratigraphically consistent and indicate rapid vertical build up. The dominant mode of accretion is horizontal.

A similar trend of older dates to lagoonward, and younger ages to oceanward is seen for transect L (T3), which also ranges from 3000 years B.P. to present. This is particularly significant because this eastern part of West Island has been extending further eastward over the last 1500 years (see Woodroffe et al., this volume, Fig. 9). Radiocarbon ages on individual spits are shown in Figure 17. The main part of this southern section is evidently 3000 years old, like the northern section of West Island.

North Keeling is morphologically distinct from the South Keeling Islands and may have developed differently. It is not unusual in other Pacific and Indian Ocean atoll archipelagoes for the smaller reef platforms to be occupied by one island which is low in the middle, with a lagoon that may or may not be connected to the open ocean. The history of development of these is not known in detail, although there are some radiocarbon dates available from table reefs, or reef-top islands, of this type in Tuvalu (McLean and Hosking 1991).

We have three further radiocarbon dates from North Keeling. A coral from conglomerate on the northeast of the island dated 3840 ± 85 years B.P., similar to but at the older end of the range of dates for conglomerate platform from the South Keeling Islands. An age of 3060 ± 60 years B.P. was derived for coral shingle in a pit in the centre of the island, suggesting little time difference between the formation of the beach at the margin of the reef platform, and the formation of the island. The final date was on a boulder exposed within an erosional scarp in the rubble beach on the southwest of the island, which gave an age of 1620 ± 80 years B.P. Guppy (1889) suggested that the boulders on this beach indicated that it was prograded by coral blocks piled up during a cyclone; this age implies that cyclones may have occurred over the last 1500 years or more. We note that this equates with a phase of island building on other parts of the Cocos (Keeling) Islands.

The radiocarbon ages suggest continual addition to islands over the last 3000 years, but we have insufficient dates to indicate whether this accretion was gradual or whether it occurred in a series of episodes. At this stage we have no dates which allow us to address the morphological issues raised by Guppy. Nevertheless reef islands are geologically young and morphologically dynamic; sediment is continuing to be produced

and supplied to islands and the islands are continuing to change through the addition of sediment at some points, but its erosion from elsewhere.

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Table 1. Perimeter and area of the Cocos reef islands

Island	Perimeter (km)	Area (km ²)
Horsburgh Island	4.4	1.04
Direction Island	3.4	0.34
Prison Island	0.4	0.02
Home Island	6.7	0.95
Pulu Ampang	1.8	0.06
Pulu Wa-idas	0.7	0.02
Pulu Blekok	1.1	0.03
Pulu Kembang	1.6	0.04
Pulu Wak Banka	2.4	0.22
Pulu Pandan	3.9	0.24
Pulu Siput	2.2	0.10
Pulu Labu	1.3	0.04
South Island	28.5	3.63
Pulu Klapa Satu	0.5	0.02
Pulu Blan Madar	0.7	0.03
Pulu Blan	0.8	0.03
Pulu Maria	0.7	0.01
West Island	38.5	6.23

Table 2. Radiocarbon dating results on reef island sediments, West Island and North Keeling Island.

Beta No.	Sample No.	Island	Depth of sample (cm)	Material	Conventional radiocarbon age
59845	NKI-60	North Keeling	60	Coral shingle	3060 ± 60
59846	WI-T1-P2 95	West Island	95	Coral shingle	570 ± 60
59847	WI-T1 P3 85	West Island	85	Coral Shingle	1990 ± 70
59848	WI-T1 P3 120	West Island	120	Coral Shingle	2010 ± 60
59849	WI-T1 P3 160	West Island	160	Coral Shingle	2110 ± 60
59850	WI-T1 P4 140	West Island	140	Coral Shingle	2130 ± 60
59851	WI-T1 P7 75	West Island	75	Coral Shingle	2710 ± 90
59852	WI-T1 P2 60	West Island	60	Coral Shingle	3030 ± 70
59853	WI-T1 P4 140	West Island	140	Coral Shingle	4280 ± 70
59854	WI-T1 P1 200	West Island	200	Coral Shingle	420 ± 50
59855	WI-T3 P2 70	West Island	70	Coral Shingle	1970 ± 70
59856	WI-T3 P4 55	West Island	55	Coral Shingle	3100 ± 70

Note: Radiocarbon ages determined by Beta Analytic have not been corrected for δC^{13} or for environmental reservoir effect. These corrections are of similar magnitude (c 400 years), but cancel each other out. Thus these Beta dates are more-or-less comparable to the environmentally-corrected ages given in the previous chapter.

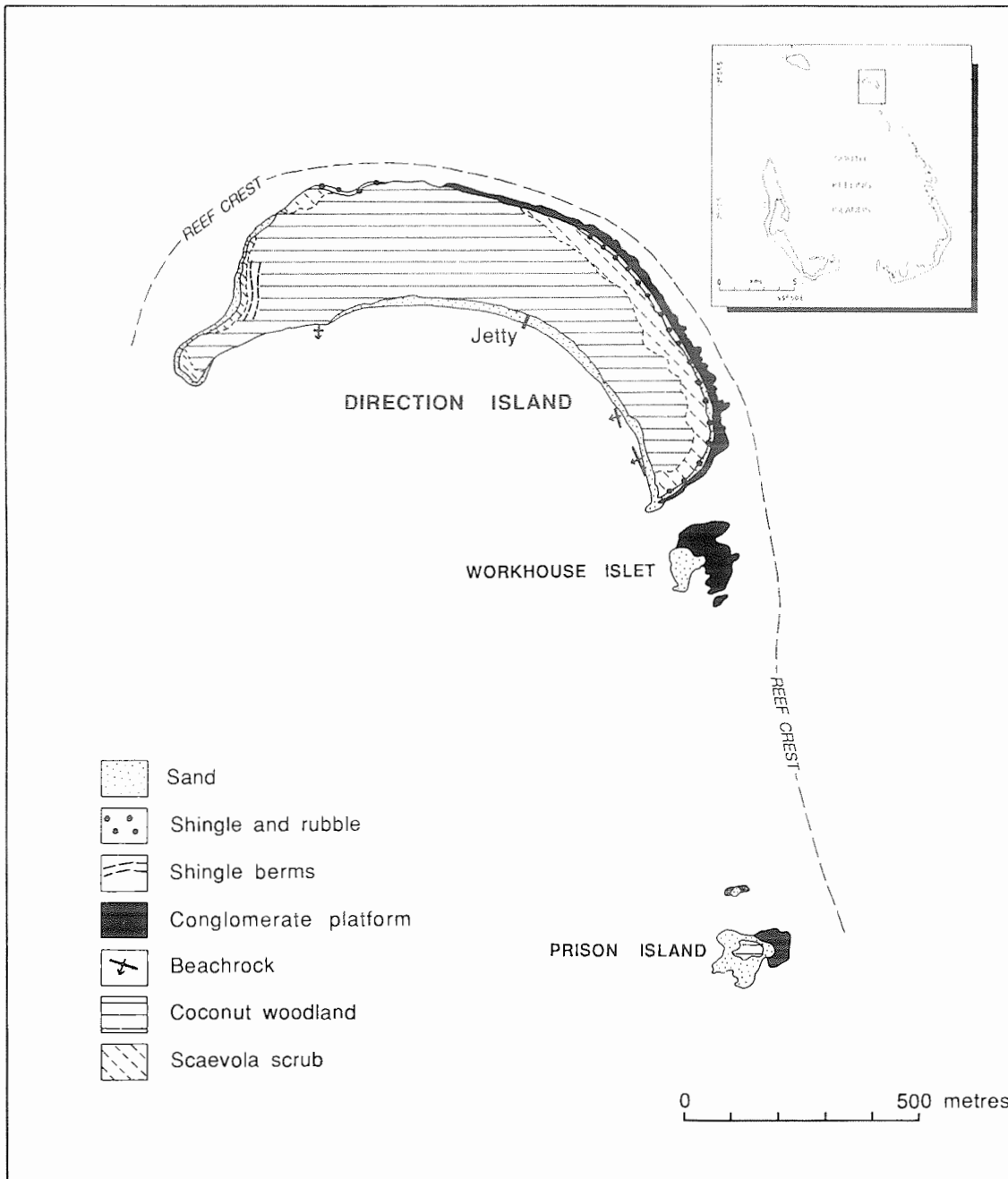


Figure 1. Direction Island, mapped from 1987 aerial photography.

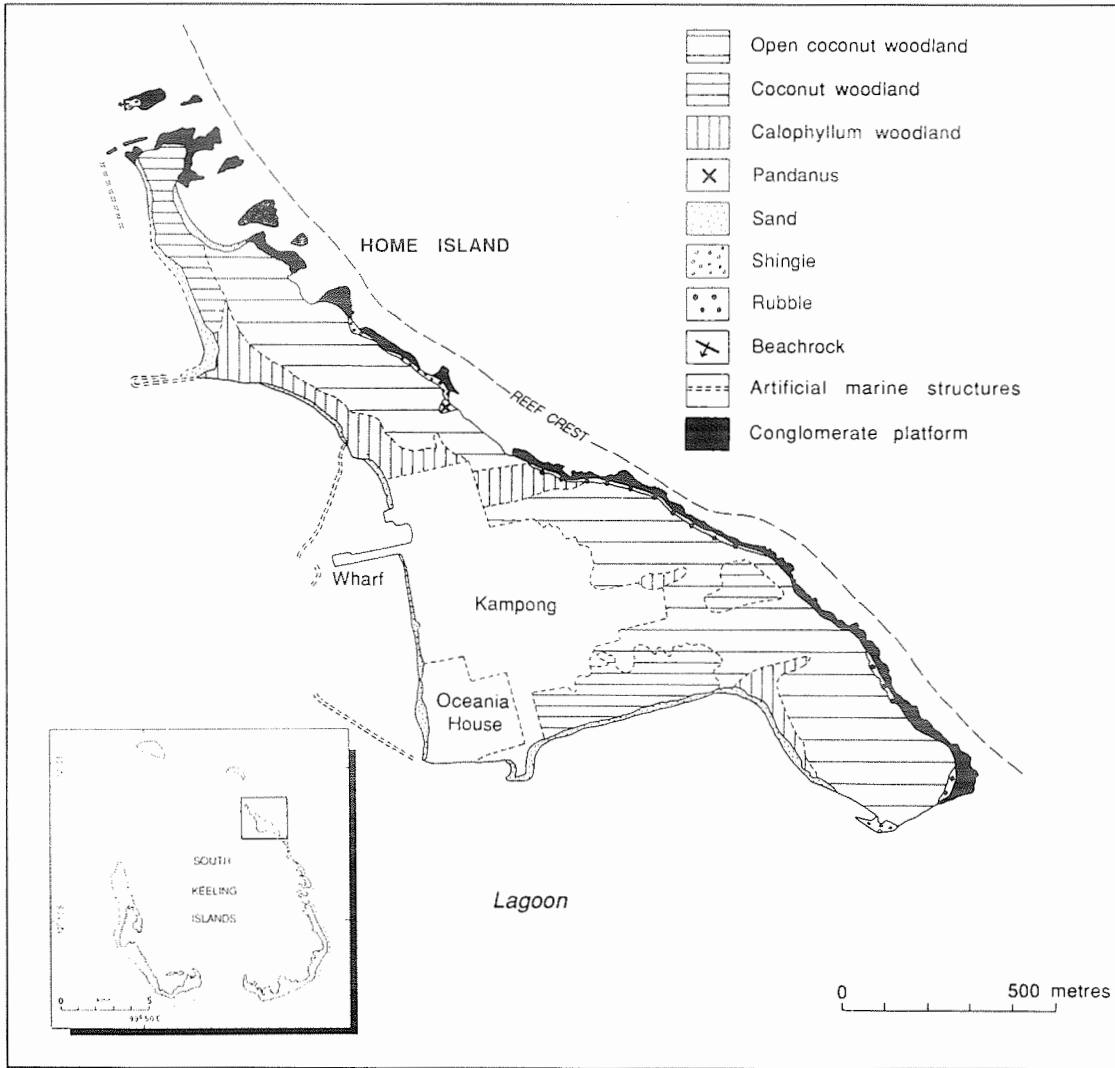


Figure 2. Home Island mapped from 1987 aerial photography.

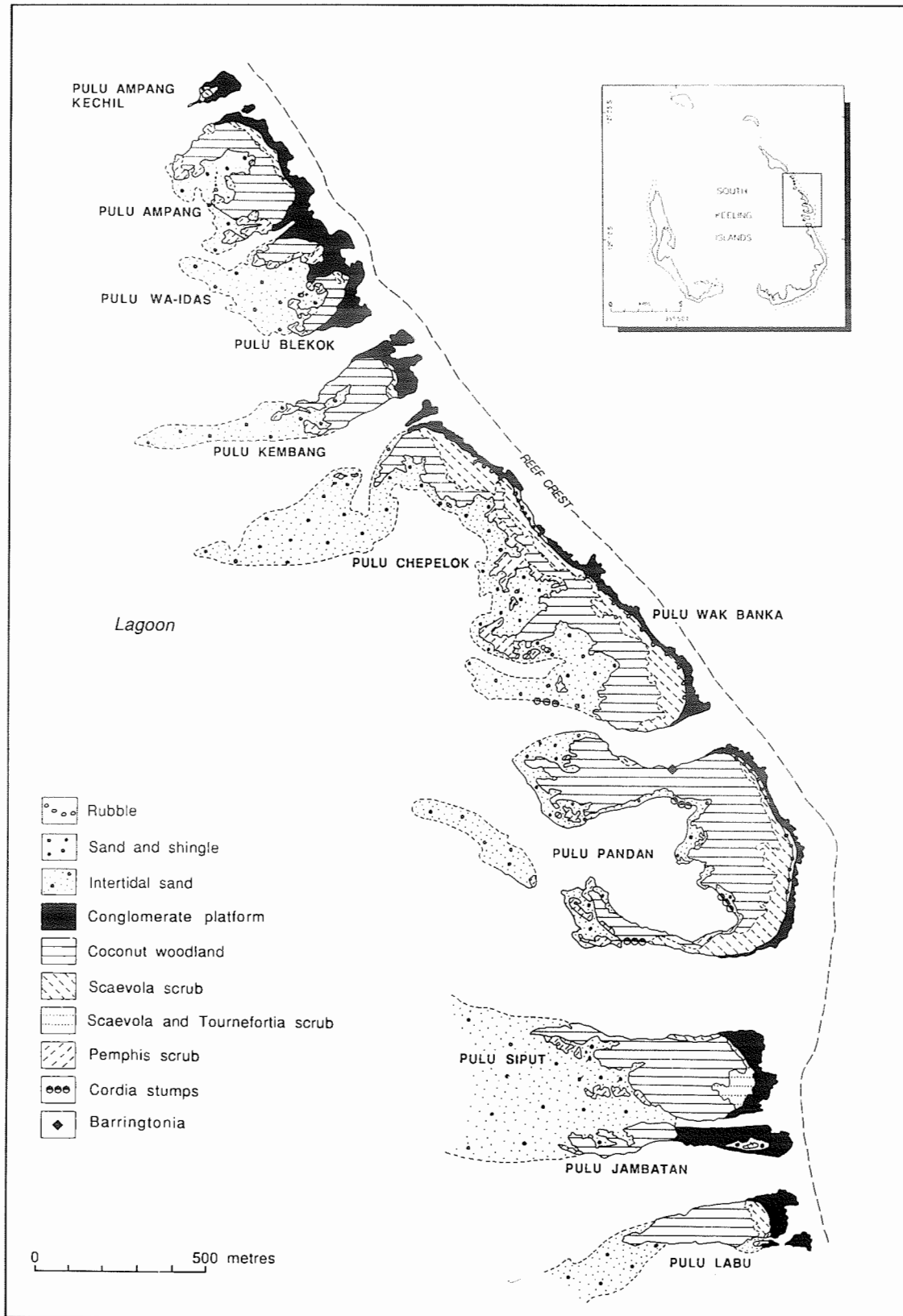


Figure 3. Islands of the eastern rim of the atoll from Pulu Ampang to Pulu Labu, mapped from 1987 aerial photography.

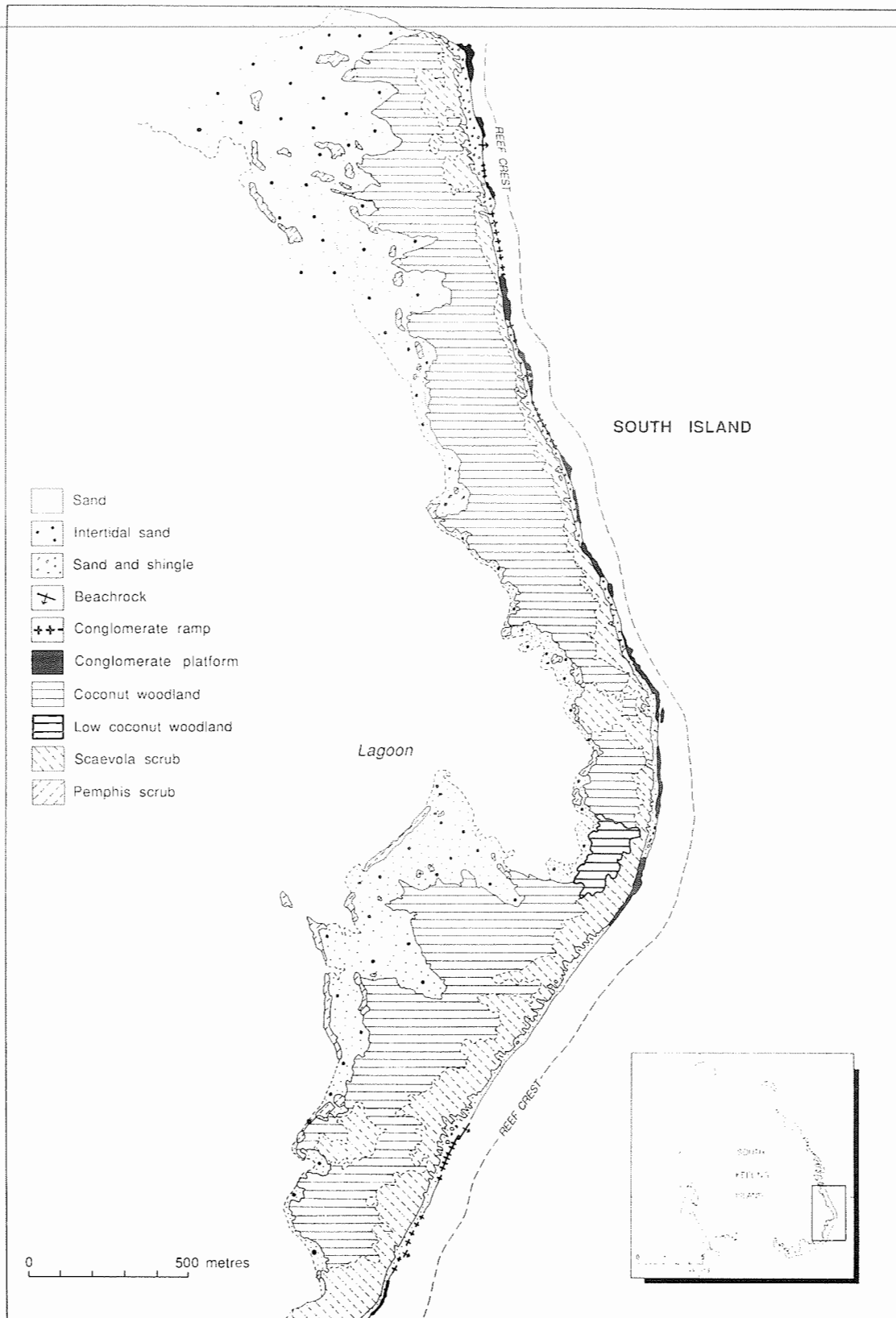


Figure 4. South Island, northern section, mapped from 1987 aerial photography.

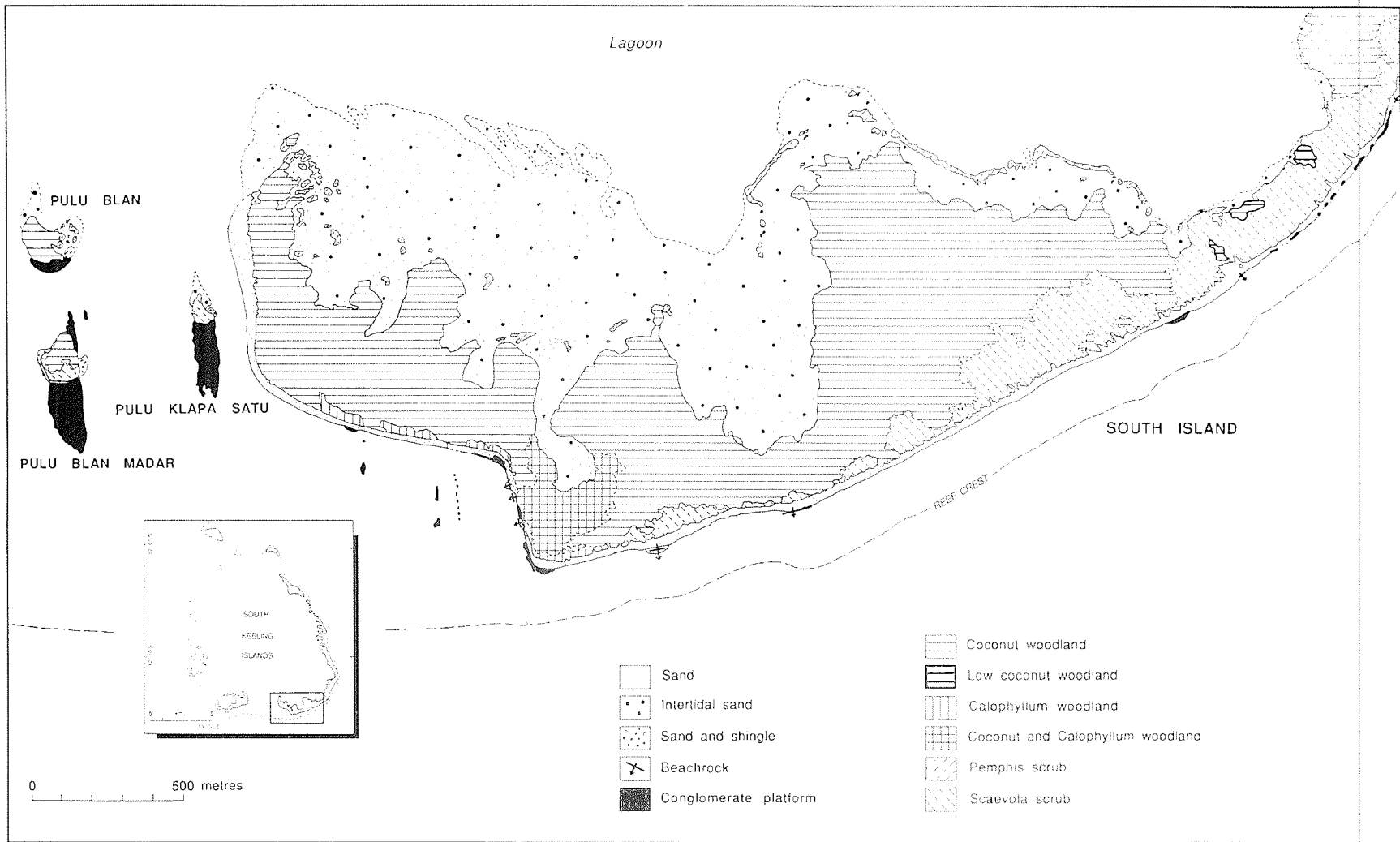


Figure 5. South Island, southern section, mapped from 1987 aerial photography.

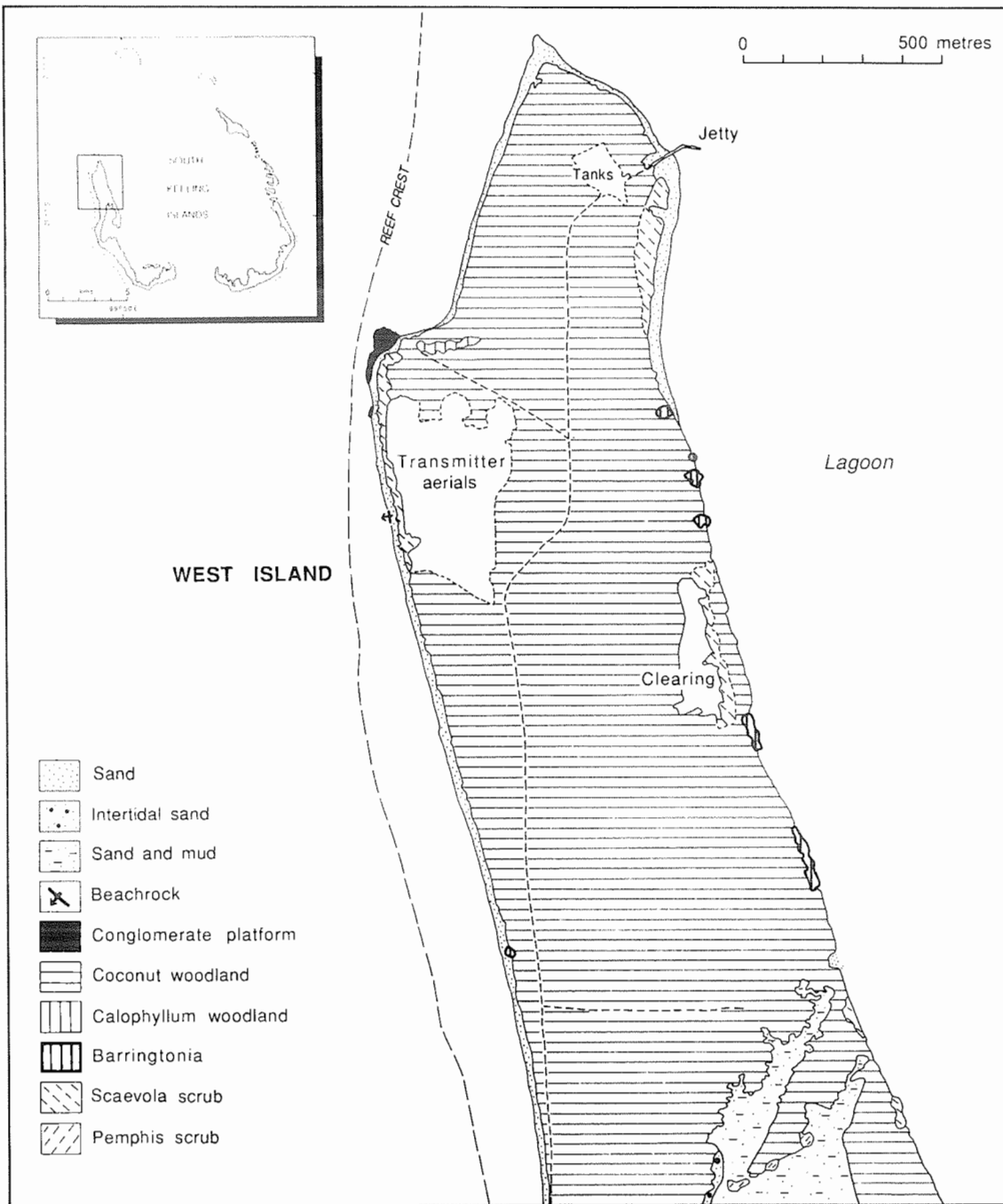


Figure 6. West Island, northern section, mapped from 1987 aerial photography.

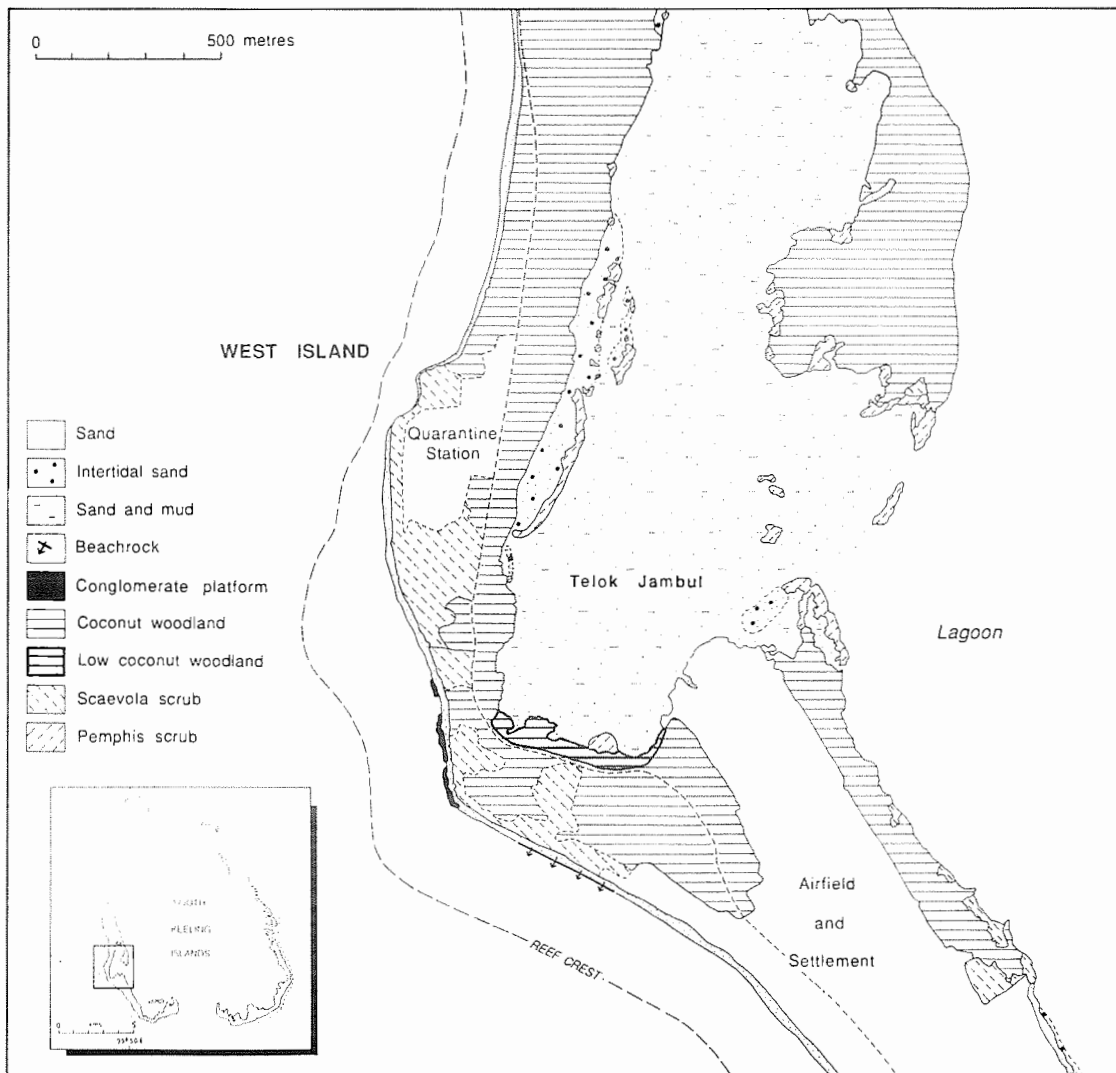


Figure 7. West Island, central section, mapped from 1987 aerial photography.

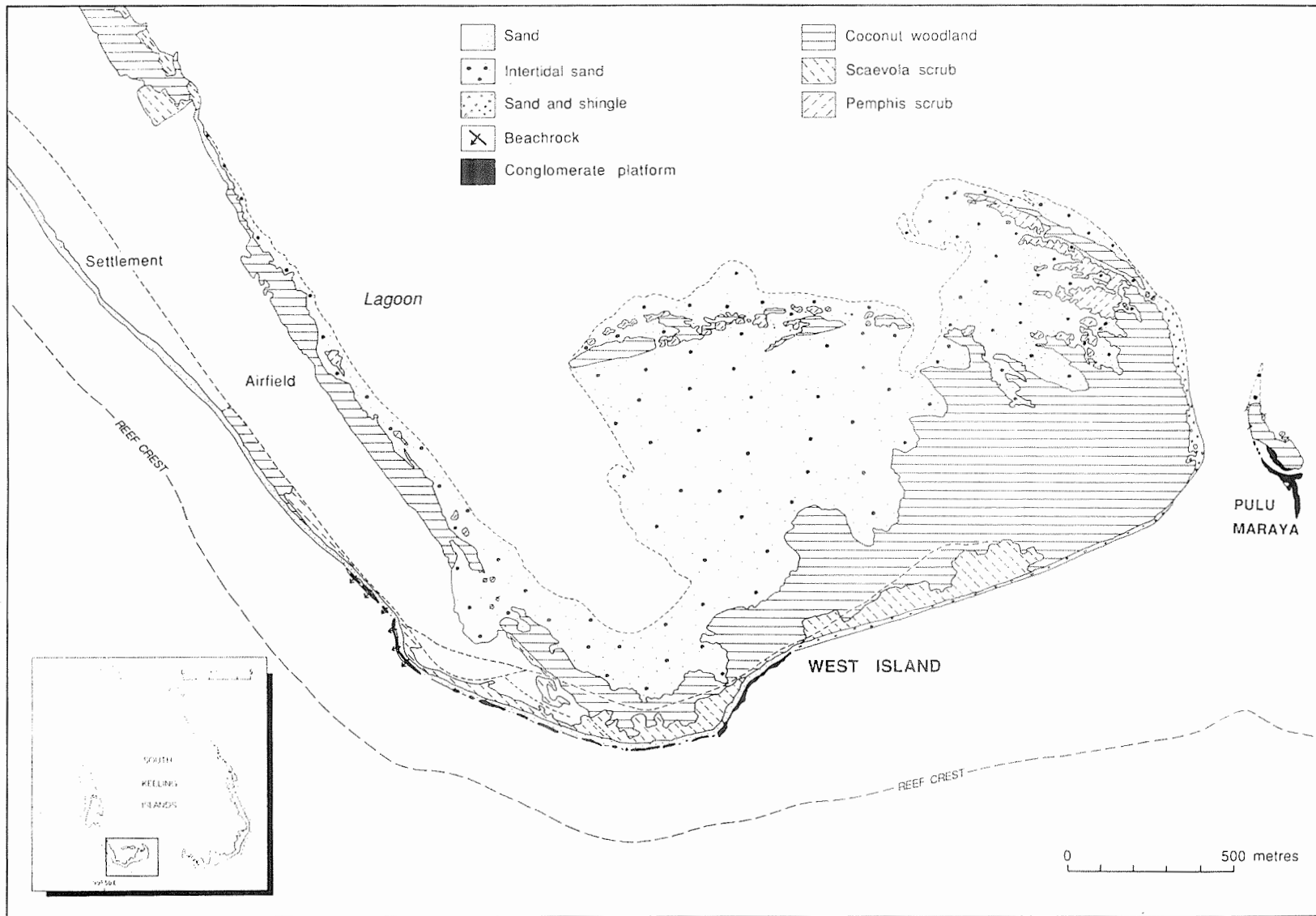


Figure 8. West Island, southern section, mapped from 1987 aerial photography.

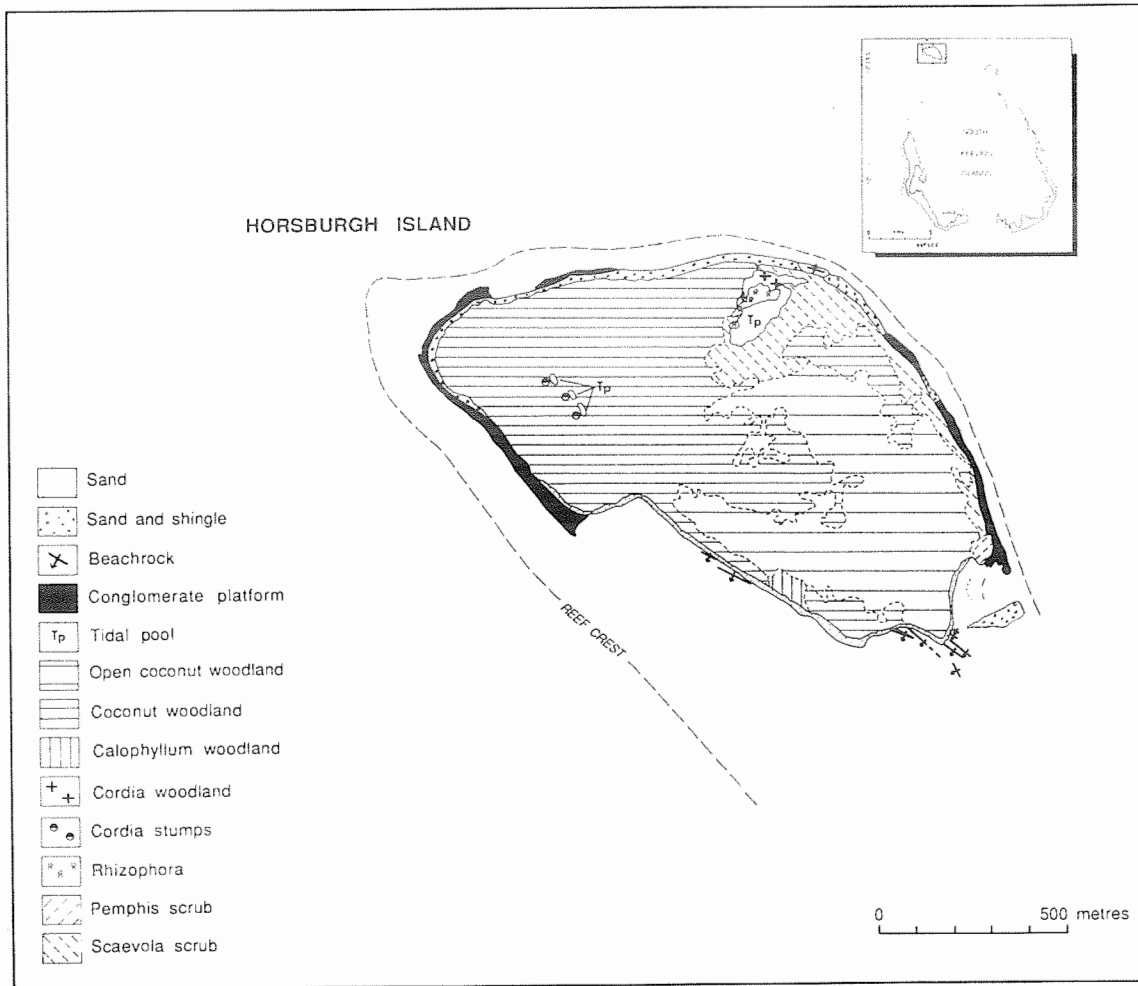


Figure 9. Horsburgh Island, mapped from 1987 aerial photography.

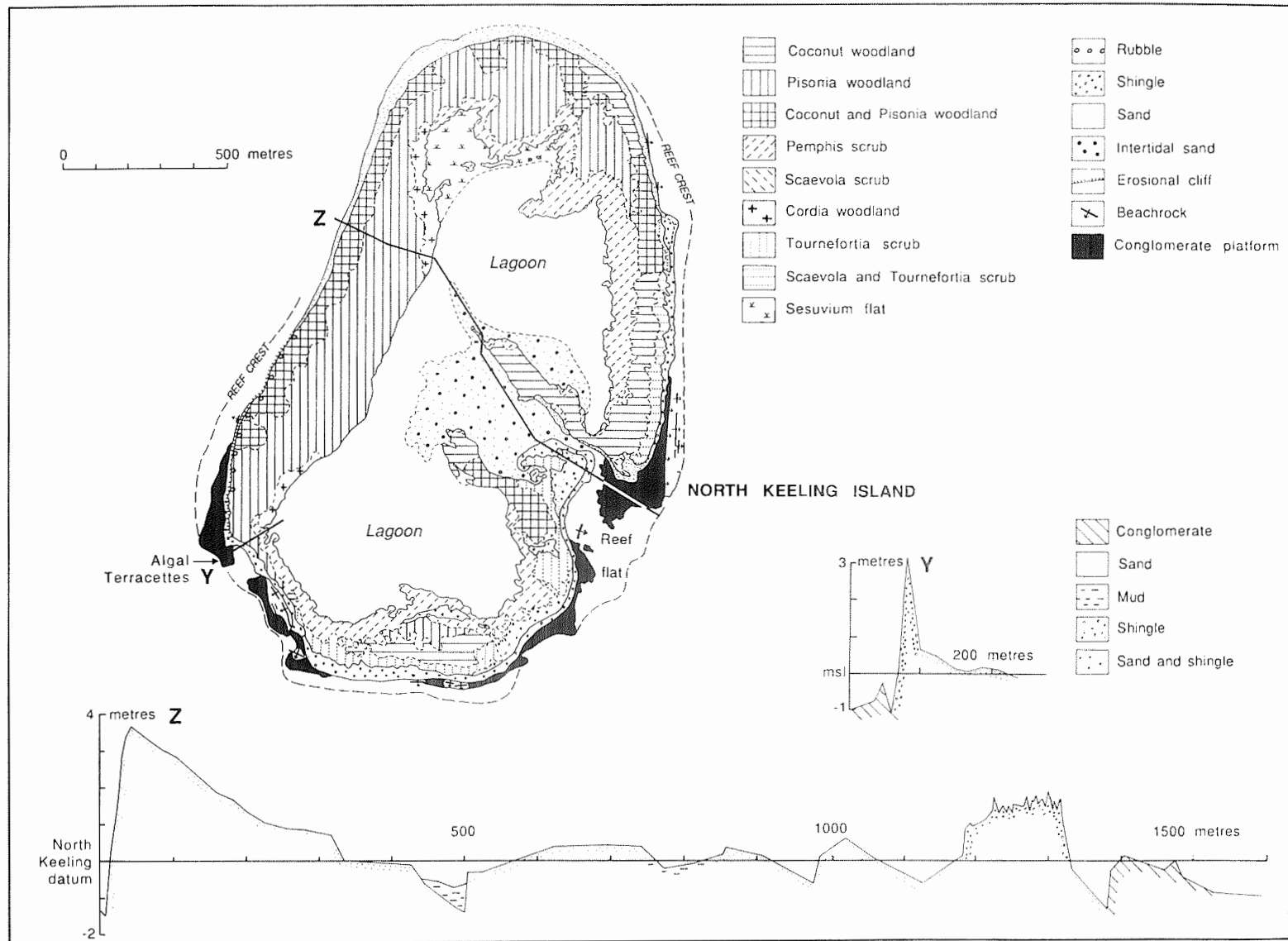


Figure 10. North Keeling Island, mapped from 1987 aerial photography, with surveyed sections.

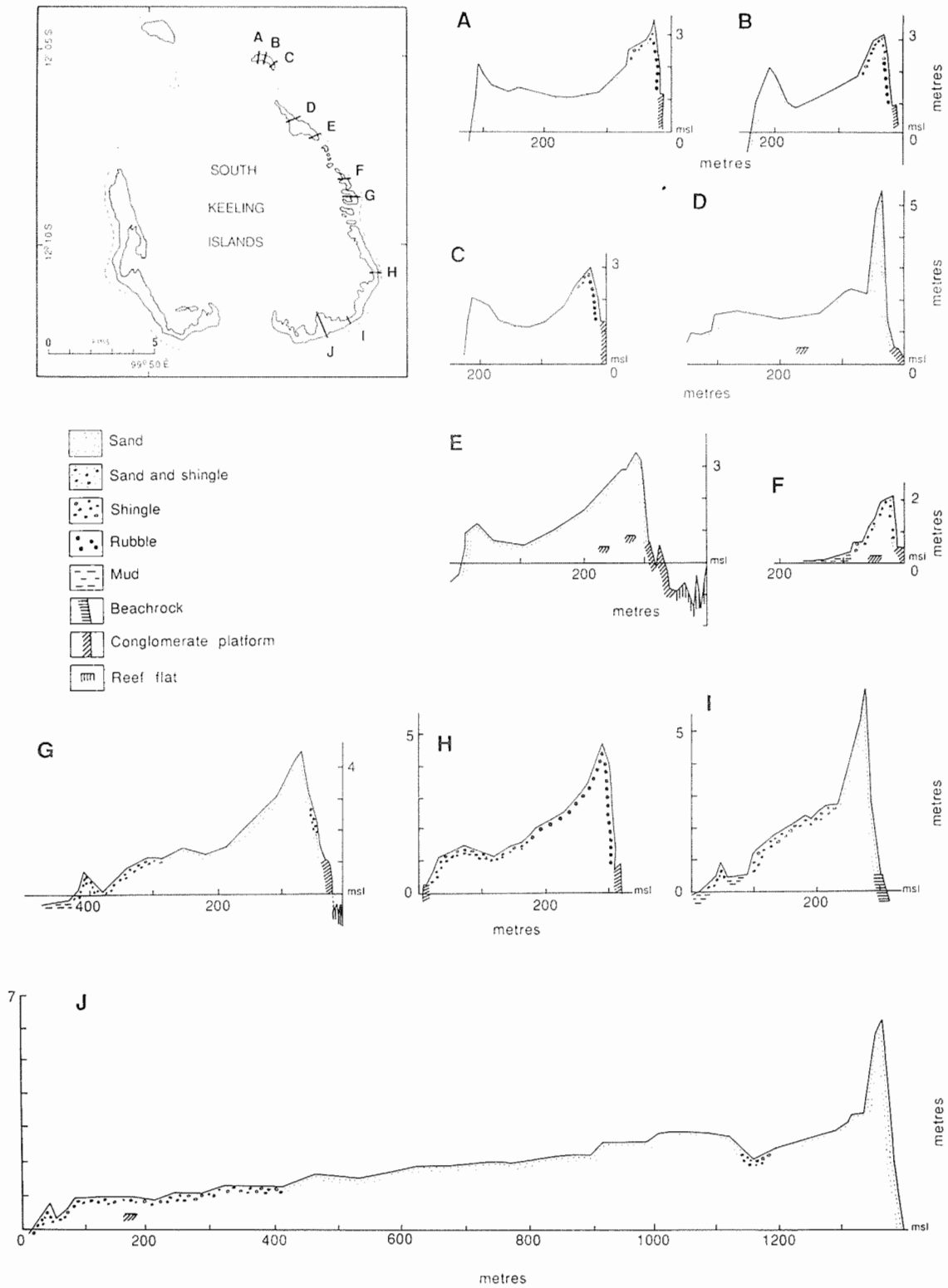


Figure 11. Surveyed sections across islands on the eastern atoll rim.

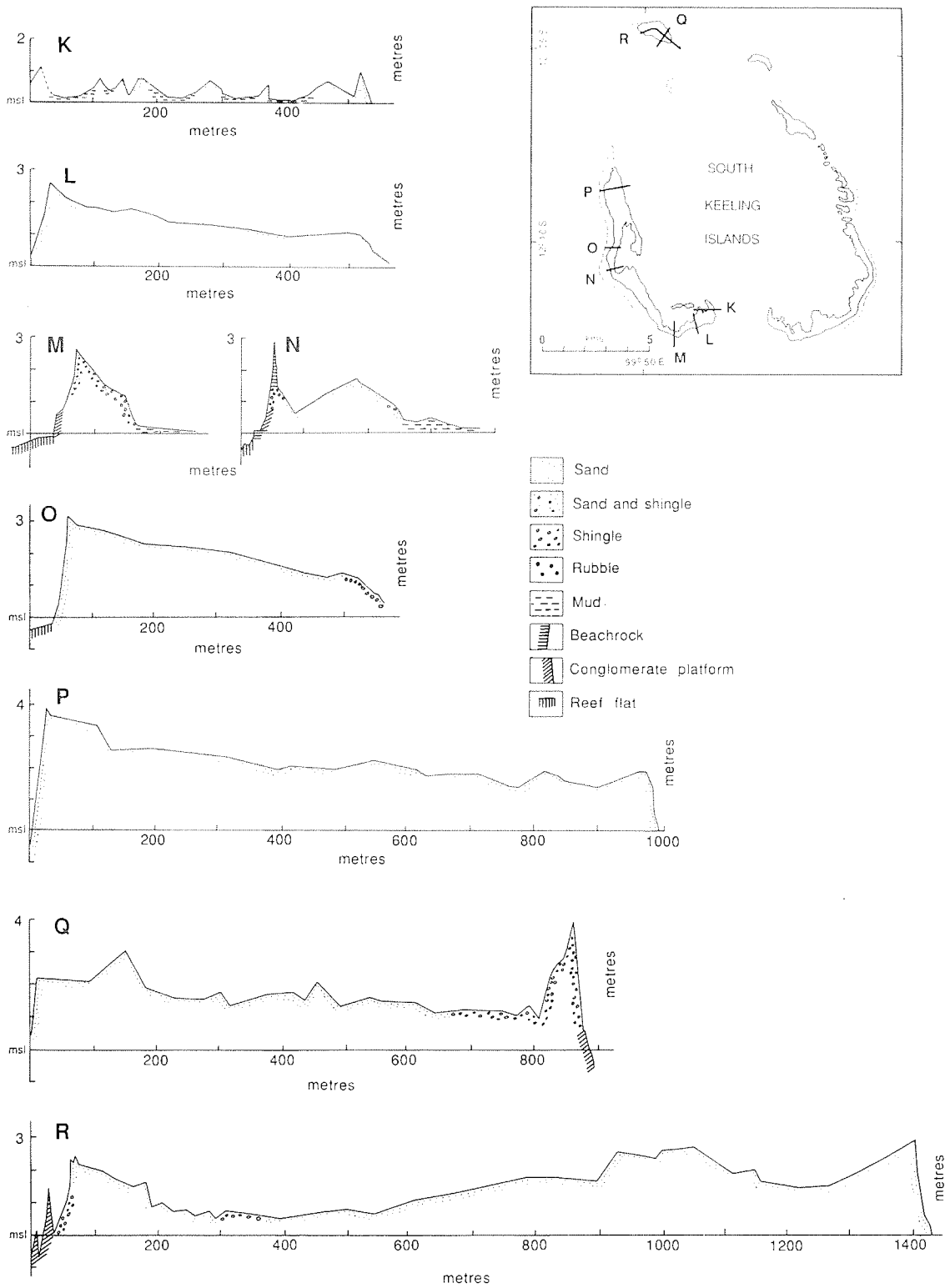


Figure 12. Surveyed sections across West and Horsburgh Islands.

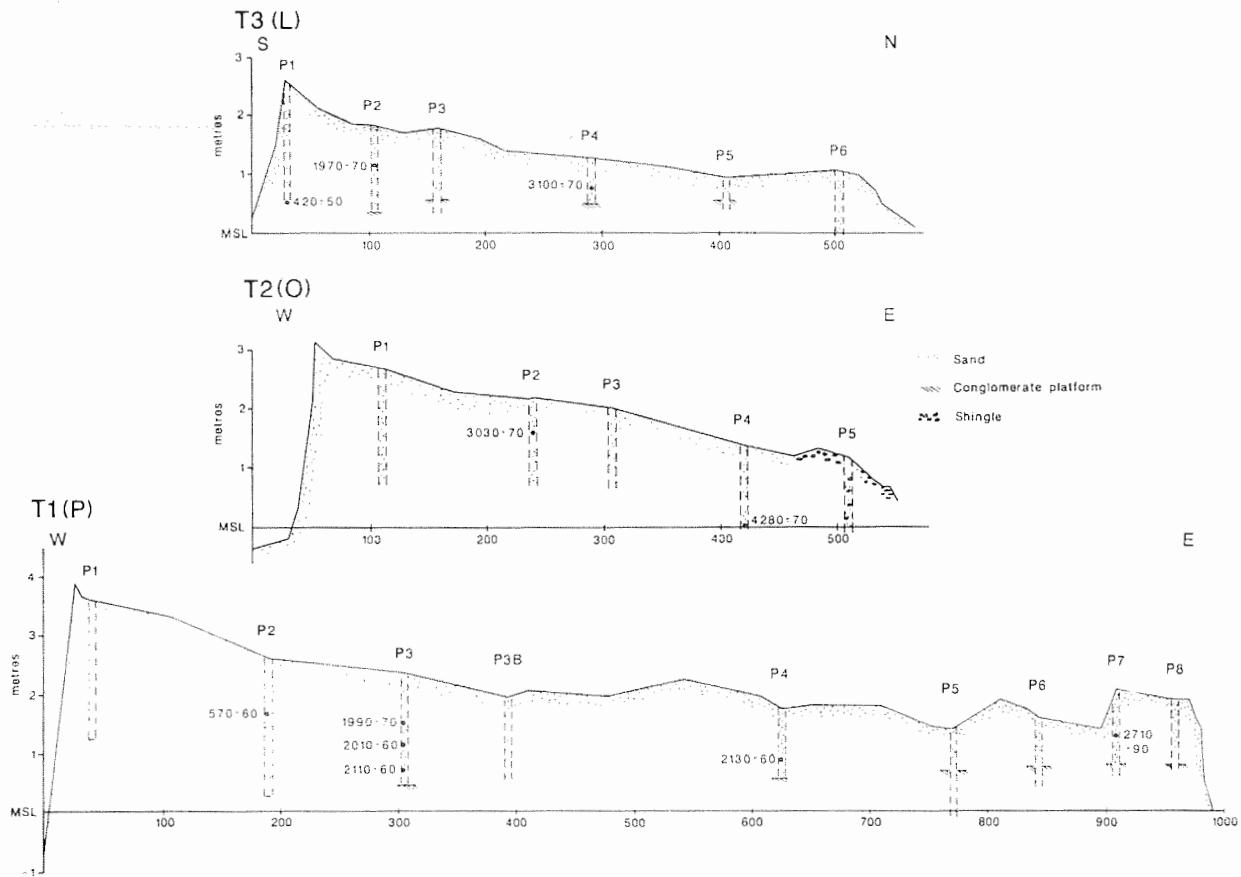


Figure 13. Cross-section and pits from three transects on West Island (see Fig. 12 for locations), showing radiocarbon dates (see Table 2).



Figure 14. Aerial photograph of Direction Island, 1987 (reproduced by permission of the General Manager, Australian Surveying and Land Information Group, Department of Administrative Services, Canberra).



Figure 15. Aerial photograph of Pulu Ampang and neighbouring islands, 1987 (reproduced by permission of the General Manager, Australian Surveying and Land Information Group, Department of Administrative Services, Canberra).



Figure 16. Aerial photograph of Pulu Pandan and neighbouring islands, 1987 (reproduced by permission of the General Manager, Australian Surveying and Land Information Group, Department of Administrative Services, Canberra).



Figure 17. Aerial photograph of eastern end of West Island, 1987. Radiocarbon dates on coral shingle indicate the progressive buildout of the spits (reproduced by permission of the General Manager, Australian Surveying and Land Information Group, Department of Administrative Services, Canberra).

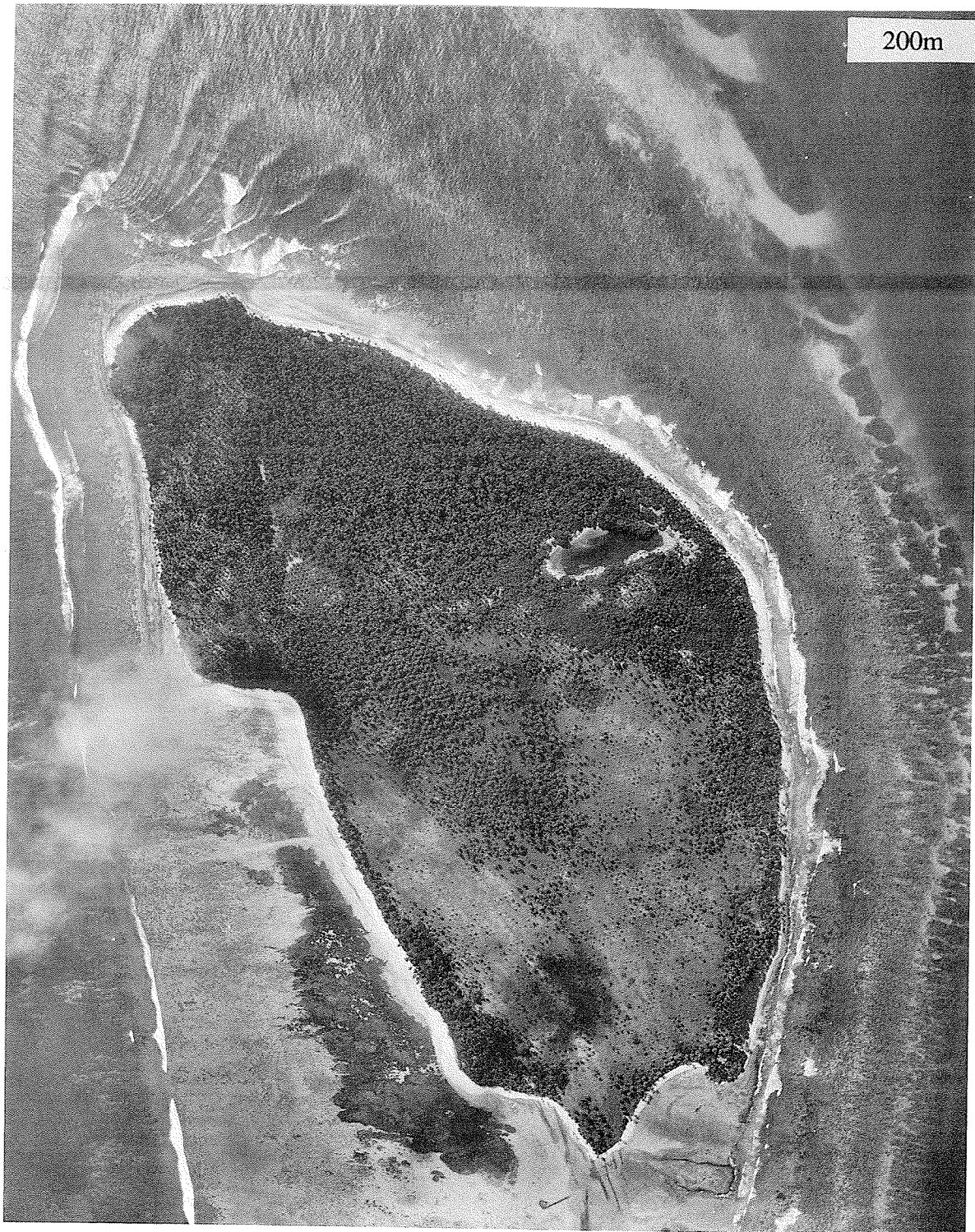


Figure 18. Aerial photograph of Horsburgh Island, 1987 (reproduced by permission of the General Manager, Australian Surveying and Land Information Group, Department of Administrative Services, Canberra).

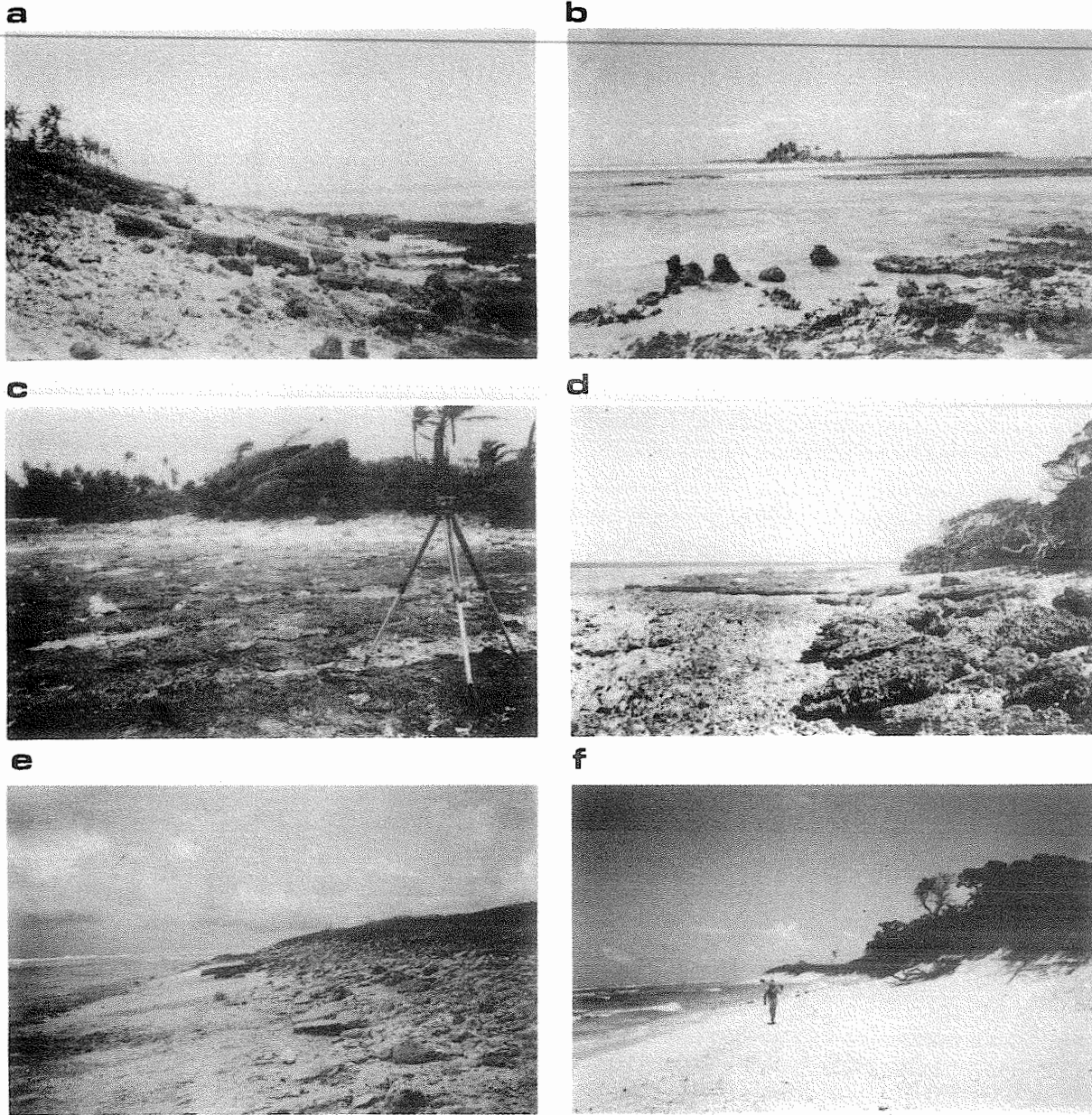


Figure 19. a: Oceanward shore of Direction Island; rubble is from ruins of Cable Station, b: View looking North from Home Island. Conglomerate platform in middle distance is where Button Islets were, Prison Island is in the middle of the photograph and Direction Island in the distance, c: Conglomerate platform on Ampang Island, d: conglomerate platform on Pulu Pandan; it appears to consist of a shingle conglomerate layer overlying typical conglomerate platform, e: Conglomerate ramp, oceanward shore of South Island, f: Sandy and beach dune on the southern side of South Island.

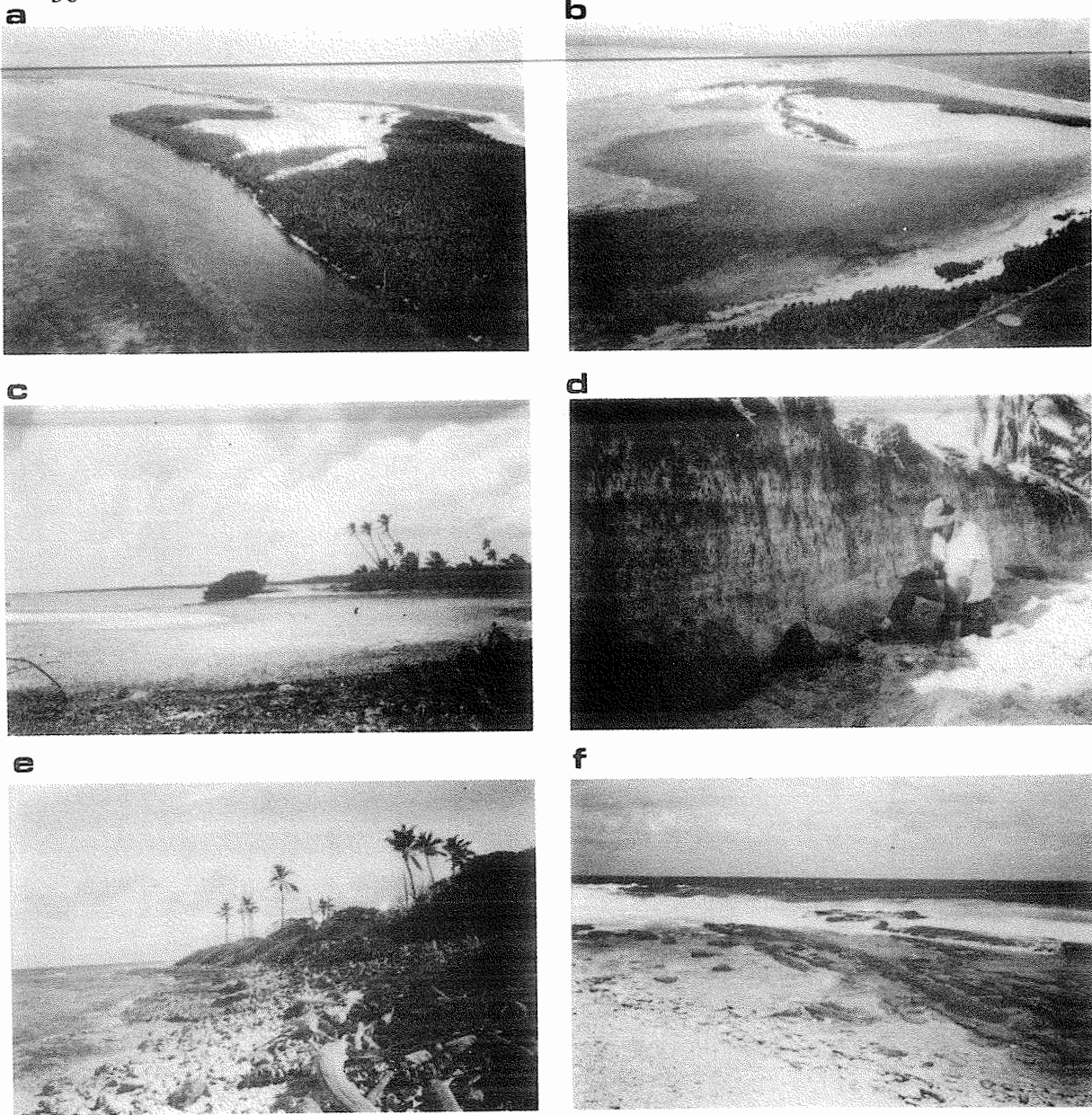


Figure 20.

a: Telok Jambu, West Island viewed from the north, b: Telok Kambing, West Island viewed from the west, c: Sheltered telok on South Island with stand of *Pemphis* on ridge at the mouth of lagoonlet, d: Ocean-dipping bedding revealed in trench on Home Island, e: Rubble-strewn shoreline on Pulu Wak Banka, f: Arcuate ridges, southern North Keeling; these appear to have been termed former reef margins by Guppy, but are reinterpreted as beach conglomerate marking foot of former rubble-strewn beaches.