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THE HOA OF HULL ATOLL AND THE PROBLEM OF HOA

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ABSTRACT

This paper describes the channels known as hoa which are characteristic of atoll land rims and of some islands on barrier reefs, where they often dissect previously more continuous reef-top sediment accumulations and conglomerate platforms. They are especially common in the central Pacific, and are particularly well developed in some atolls of the Tuamotu Archipelago and on some of the Society Islands. Published hypotheses accounting for the origin and development of hoa of different kinds are outlined. Contemporary hoa on the north side of Hull Atoll in the Phoenix Islands are described and surveyed, as are older, probably Holocene hoa, here termed 'paleohoa', on the same atoll. Regional and local distributions of hoa and paleohoa and differences in hoa morphology are used to assess theories of hoa formation. Both hoa and paleohoa are attributed to hurricane activity, and the presence of paleohoa may thus give an indication of the distribution of hurricanes in the Holocene.

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INTRODUCTION

~~The Polynesian term hoa was first introduced into the reef literature by Danielsson~~ (1954) and later incorporated into a comprehensive listing of Polynesian topographic terms by Vallaux (1955, 1991). Danielsson (1954, p. 94) defined hoa as a 'shallow channel beginning on the lagoon side [of an atoll rim], separating completely or partially two motu [reef islands].' He added the terms tairua for a 'closed hoa' and poehoga for the 'inner part of a closed hoa.' As defined by Danielsson hoa are one of the most striking and conspicuous geomorphic features of most central Pacific atolls, and as such had been mentioned by many previous investigators. Thus Agassiz (1903, p. 41-43) described and figured many 'cuts', as he termed them, on the north side of Rangiroa Atoll, Tuamotu Archipelago, as well as on other atolls in that group. But it was Newell's (1956) account of Raroia Atoll, also in the Tuamotu, and especially his spectacular aerial photographs, which brought the phenomenon to general attention. Though in recent years hoa have attracted increasing interest, especially in French Polynesia, they remain enigmatic features. It is the purpose of this paper to draw attention to problems of existing interpretations by reference to the hoa of Hull Atoll, Phoenix Islands, in eastern Kiribati, central Pacific.

CHARACTERISTICS OF HOA

The first detailed descriptions of hoa were made by Agassiz during the *Albatross* expedition through the Tuamotu Archipelago in 1899. In a preliminary paper he describes 'the narrow cuts which divide this part [of the northern rim of Rangiroa, between Tiputa and Avarua] into a number of smaller islands. These secondary passes leave exposed the underlying ledge, full of fossil corals. In some cases there is left a clear channel extending across from the lagoon to the northern [seaward] side through which water flows at high or half tide. In other cases the cuts are silted up with coral sand blown in from the lagoon side. In others the cut is shut off by a high sand-bank, or a bank composed of broken fragments of corals, leaving access to the water from the northern shore only; and finally the cuts are also shut off on the northern side by sand and broken coral banks, the extension of the north-shore beach leaving a depression which at first is filled with salt-water and gradually silted up both from the lagoon side and the sea side, and forms the typical north-shore land of the lagoon' (Agassiz 1900, p. 38). More detailed accounts of hoa on Rangiroa and many other atolls are given in his main report (Agassiz 1903).

At Raroia Newell (1956, p. 330) described 'approximately 260 shallow channels across the [atoll] rim which are drained or are awash during low water at the seaward ends and are filled by 2 to 2.5 meters of water near the lagoon ends'; he did not however use the term hoa for these channels. 'In addition to the shallow channels or spillways between islets, there are some 160 deep, angular clefts or notches (incomplete channels) in the lagoon shore similar to the channels except that they do not extend across the island to the seaward side'; these are the tairua of Danielsson, though this term, unlike hoa, has not entered the reef literature.

Newell saw the incomplete channels as a stage in the formation of hoa: they 'clearly are being lengthened headward as storm waters cross the islets towards the lagoon, and they represent various steps in the formation of shallow channels. It is concluded that the shallow channels are all of very recent origin and were formed chiefly by mechanical (hydraulic) erosion of the uplifted rim' (Newell 1956, p. 330).

Stoddart (1969, p. 8) described very similar features at Rangiroa Atoll, also in the Tuamotus: 'The islands are separated by shallow, narrow channels known as hoa. These are clearly erosional, and represent breaks in formerly more extensive islands. In the walls of islands transected by hoa, conglomerate rock is exposed underlying the island clastics and rising above the level of the reef flat. This conglomerate forms a ledge in the walls, and also floors the hoa itself. Channels cut in the conglomerate by water passing from sea to lagoon are extending seaward by headward erosion, often terminating in small waterfalls with plunge pools. . . . The lagoonward mouths of hoa are often almost closed by spits and bars of fresh small coral shingle. On Mahereretiatae a relict hoa was seen in the process of being recolonised by vegetation, after being sealed at both ends by beach ridges.' Stoddart gave schematic diagrams of the features he described.

Likewise at Borabora, Society Islands, Guilcher et al. (1969, p. 8) found examples of different kinds of shallow passages or hoa on the eastern barrier reef. Some of them are permanently open; others are closed during periods of moderate surf by spits built by lagoon waves at their inner ends and become tairua; still others are active only during exceptional storms, hurricanes or tsunamis. Aprons of sand are prograding into Borabora lagoon through the hoa and are beginning to fill it. Hoa, tairua and prograding sand aprons in lagoons are common elsewhere in the Society Islands and in other atolls of the Tuamotus. Further details are given by Guilcher et al. (1969, p. 28, 46-47), and comparisons made between hoa and tairua on Borabora and on Tahaa, Maupiti and Rangiroa.

Newell, Stoddart and Guilcher all viewed hoa as relatively unproblematic features (see also Guilcher, 1988, p. 148-152); none however surveyed them instrumentally.

CHEVALIER'S TYPOLOGY OF HOA

Chevalier et al (1968, p. 48-49) described hoa in some detail at Mururoa Atoll, Tuamotus, in similar terms. Chevalier in this paper, in his general survey of French Polynesian reefs (Chevalier, 1973), and especially in a paper devoted solely to hoa (Chevalier, 1972), proposed a general classification of hoa:

Type I: open on the lagoon side, closed on the ocean side, permitting throughput of water only during storms. This he found to be the most common type.

Type II: 'Functional hoa', comprising

(a) those open to the sea at high tide;

(b) those open to the sea at low tide during strong wave action;

(c) those fully open to the sea, notably where the algal ridge is unusually low; he quoted examples from Pukarua and Marutea Sud, Tuamotus.

Type III: hoa where the lagoon end is blocked by sediment deposits and the hoa is open only at the seaward end. This form is common on atolls with high sedimentation rates such as Reao. On Mururoa some hoa become enclosed pools open only during storms.

Type IV: hoa of Type I but completely closed by lagoon sediments. Examples are given from Marutea Sud and Fangataufa where as a result the channel becomes hypersaline.

Type V: dry hoa, comprising

(a) hoa of Type IV but completely blocked by sediment, dried out and vegetated. Chevalier (1972, p. 481) described this type as 'hoa colmaté', figuring an example from Reao.

(b) hoa emersed by a fall in sea-level leaving the floor at 20-40 cm above lagoon high water, examples being cited from Mururoa, Tureia and Maturei-Vavao.

Type VI: hoa open only to the sea, with the lagoon exit closed by conglomerate, as at Reao and Pukapuka (Tuamotus). These were interpreted as similar to Type III hoa but with the lagoon barrier lithifed.

Types III-VI Chevalier grouped as 'non-functional hoa', the others as 'functional'. At Mururoa he described 79 out of a total of 288 hoa, or 27 per cent, as functional (Chevalier et al. 1968, p. 51).

Chevalier's typology systematised and extended previous observations on hoa morphology. But he also drew attention to problems in their distribution, both between and within atolls. Thus he noted the paucity of functional hoa on Reao and Pukapuka and their frequency on Marutea. On Mururoa he found functional hoa concentrated on the southwest to southeast sectors of the atoll rim, with 34 per cent in the southwest compared with 2.4 per cent in the east. Chevalier constructed a rose diagram of the frequency distribution of hoa on the rim in comparison with wind direction and velocity (Chevalier et al. 1968, p. 12, 16): the graphs showed an inverse correlation between wind strength and hoa distribution. It was noted, however, that whereas the dominant winds are easterly the strongest swells are from the south and southwest.

Chevalier noted the probability of a Holocene fall in sea-level of ca. 1.5 m over the last 3000-4000 years. He also proposed that hoa had their origin in transverse fissures on the reef rim formed before the fall in sea-level. Finally, he suggested that lithification processes in reef-top sediments were more effective on the seaward side, and that this was the reason that hoa began eroding in the less consolidated sediments of the lagoon side, cutting back along the lines of fissures. He did not discuss the spacing or apparent clustering of such fissures, nor did he mention the rôle of catastrophic events such as hurricanes or tsunamis in hoa genesis.

Chevalier concluded his analysis by suggesting an evolutionary sequence in hoa development, given in outline in Chevalier et al. (1968, p. 53) and in more complex form in Chevalier (1972, p. 487) (Figure 1). Chevalier's work focussed attention on the

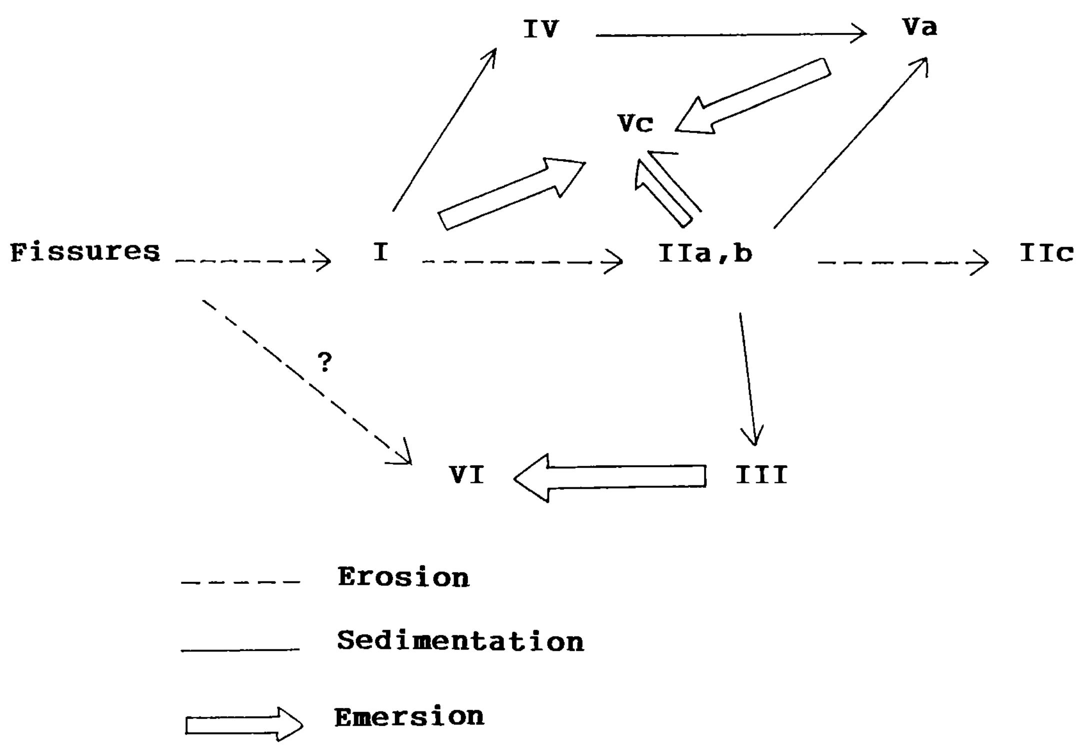

Figure 1. Evolutionary sequence in the development of hoa proposed by Chevalier (1972, p. 487).

diversity of hoa, but it also made clear that many problems remained in explaining their morphology, local and regional distribution, and history.

LATER WORK IN FRENCH POLYNESIA

Subsequent work in French Polynesia has provided additional information on hoa, especially in the context of Holocene sea-level history.

The 150 hoa of Rangiroa Atoll are classified by Ricard et al. (1985) into permanently functioning hoa; partly obstructed hoa, including those 'partly isolated from the ocean by coral boulders but open to lagoon influences' and those 'largely open to oceanic influences, but more or less isolated from the lagoon by a sandy strip'; and entirely obstructed hoa. At Takapoto Atoll Salvat and Ricard (1985) use the terms 'opened hoa' and 'unworking hoa'. At Borabora (Pirazzoli et al. 1985) there are both functional and non-functional hoa. The latter are subdivided into filled-in hoa, invaded by storm debris; emerged hoa, resulting from relative sea-level change; and 'obturated hoa', closed on the seaward side by coral conglomerate and sometimes on the lagoon side by spits of sediment.

In spite of terminological differences these classifications can all be clearly related to Chevalier's typology of hoa.

The Tuamotu atolls show great variability in frequency of hoa. Taiaro and Anaa have rather few (Salvat et al. 1977, Pirazzoli et al. 1988), and with one exception those at Taiaro are non-functional. Conversely hoa are frequent at Temoe and Reao (Pirazzoli 1987, Pirazzoli et al. 1987). In both cases they are highly concentrated on the west and southwest sides of the atolls, with few or none on the north and east sides. On the other hand at Tikehau the hoa are open in the east but closed in the northwest (Harmelin-Vivien et al. 1985).

Various factors have been suggested to account for the features and origins of the Tuamotu and Society Islands hoa. In particular Pirazzoli and Montaggioni (1988) have summarised a great deal of evidence from corals, conglomerate platforms, beachrock and intertidal notches that mean sea-level stood 0.8-1.0 m above its present level in the period 5000-1250 B.P., and that it did not fall below 0.7 m above present between 4500 and 1250 B.P. Emerged reef flat material in the floors of hoa has been described from Taiaro (+0.6 m, with dates of 1140±80 and 1110±80: Salvat et al. 1977) and Reao (+0.5 m, 4250±100: Pirazzoli et al. 1987). Pirazzoli (1987) has also described 'obturated hoa' blocked on the seaward side by continuous conglomerate platform with a date of 3170±60 B.P., attributed to a Holocene high sea-level stand, at Temoe. Other relevant dates are quoted by Pirazzoli and Montaggioni (1988) for Rangiroa, Takapoto, Pukarua, Mururoa, Borabora, Raiatea-Tahaa, and other localities with hoa.

Although Chevalier did not consider high-magnitude events such as hurricanes as causative agents in the formation of hoa, they have been specifically considered (together with other high-energy events such as tsunamis) by Bourrouilh-Le Jan and Talandier (1985) in the explanation of megablocks on the reef flat and the alternation of motu and hoa at Rangiroa. The megablocks they consider to be fragments of reef flat previously delineated by fractures and dislodged and transported during such events. Hoa they suggest are activated in sectors of reef rim not subject to previous fracturing. They discuss particularly the major hurricanes of January 1903, March 1905 and February 1906, and the six El Niño-related storms between December 1982 and April 1983. Both sets of storms affected Rangiroa and the northwestern Tuamotu atolls (Tikehau, Mataiva). The 1983 storms were particularly badly felt at Mataiva, where some defunct hoa were reactivated. These they call storm hoa ('hoa d'ouragan') (Bourrouilh-Le Jan and Talandier 1985, p. 316). While they give no detailed analysis of the hoa on any particular atoll, they suggest that their distribution and frequency results from the interaction of hurricane waves, their magnitude and angle of incidence, and reef topography and orientation.

Other workers have suggested that sediment transportation during hurricanes has been responsible for the transformation of functional into non-functional hoa. Thus at Taiaro, where the hoa are non-functional, Salvat et al. (1977) draw attention to the formation of storm embankments more than 2 meters high between 1878 and 1906, and Pirazzoli et al. (1987) suggest that the non-functional hoa on the northern rim of Reao were closed by the hurricane of 1903.

Chevalier's suggestion about the importance of diagenesis of reef-top sediments in controlling motu accretion and hoa erosion has been discussed in general terms by Bourrouilh-Le Jan et al. (1985), with specific reference to Rangiroa, Tikehau and Mataiva Atolls.

Lenhardt (1991) has studied the hydrodynamics of hoa at Tikehau, but in the context of their function as normal flow conduits rather than in terms of their formation during extreme events.

QUESTIONS ABOUT HOA

This review readily generates a number of questions about hoa, some of which are not often addressed in the literature. These include the following:

- why are hoa apparently regionally concentrated, especially in the central Pacific? [this is part of the larger question: why do some atolls have a considerable part of their reef rim occupied by land and others do not?].

- why are hoa locally concentrated in particular parts of atolls?

- why do the reef sectors on which hoa are most numerous vary between atolls?

- why do some atolls (for example Diego Garcia, Canton, Gardner) apparently have no hoa?

- why do some atolls (such as Raroia, Temoe, Reao, Rangiroa) have abundant hoa?

- why do some atolls have areas with abundant hoa and others apparently devoid of hoa?

• why on the same atoll can one find both active hoa (both functional and non-functional) and fossil hoa (paleohoa), often in close juxtaposition?

Answers to these and similar questions must include consideration of:

• erosive processes resulting from wave activity generated by trade winds, swell of more distant origins, and episodic storms.

• current sedimentary processes on both seaward and lagoon shores of motu.

• possible fall in sea-level from a Holocene high stand over the past few thousand years (a regional effect).

• possible tectonic deformation consequent on lithospheric flexure.

• the restricted spatial extent of even the most extreme catastrophic storm events.

These issues form the background to our consideration of the hoa of Hull (Orona) Atoll, Phoenix Islands, Central Pacific.

HULL HOA

Hull (or Orona) Atoll, in 172°11'W, 4°31'S, is the central atoll of the southern tier of the Phoenix Islands in the Central Equatorial Pacific. It was discovered by the U.S. Exploring Expedition in August 1840 (Wilkes, 1845, III, p. 369-370). Between 1938 and 1963 it was occupied by settlers from the Gilbert Islands, but has since been uninhabited except for a small U.S. military presence in the early 1970s. The atoll is located 185 km south of Canton Atoll and 98 km due west of Sydney Island; Gardner Atoll lies 245 km further west (Figure 2). It is 10.8 km long, 4.2-5 km wide, and has a total area of 40.5 sq km (Figure 3); of this islands occupy 6.7 sq km, peripheral reef and channels 7.8 sq km, and lagoon 26.0 sq km. There is no pass into the lagoon, and no bathymetric survey has been made of it; it is said to have depths of 15-18 m (Bryan, 1942, p. 63). The seaward reef flats are 80-200 m wide, being narrowest on the east and west sides and widest on the north and south.

The atoll has a mean annual rainfall (1952-1963) of 1171 mm (maximum 2599.2 mm, minimum 245.6 mm). Spring tidal range is approximately 80 cm.

The land rim varies in width from less than 50 m at the eastern point, where it consists of gravel ridges, to a maximum of 650 m on the west side; the average is 250-300 m. The total shoreline periphery on the seaward side, including hoa, is approximately 26.5 km. Of this 5 km (19 per cent) on the northwest side comprises islands with hoa. The definition of the hoa is somewhat problematic but there are some 20 intersecting the conglomerate platform as well as lesser channels between islands on the platform. In addition there are four hoa in the otherwise continuous southern rim, and none on the northeast and southwest sides. There is, however, a sector of ca 1500 m near the south point of former hoa (paleohoa), to be described.

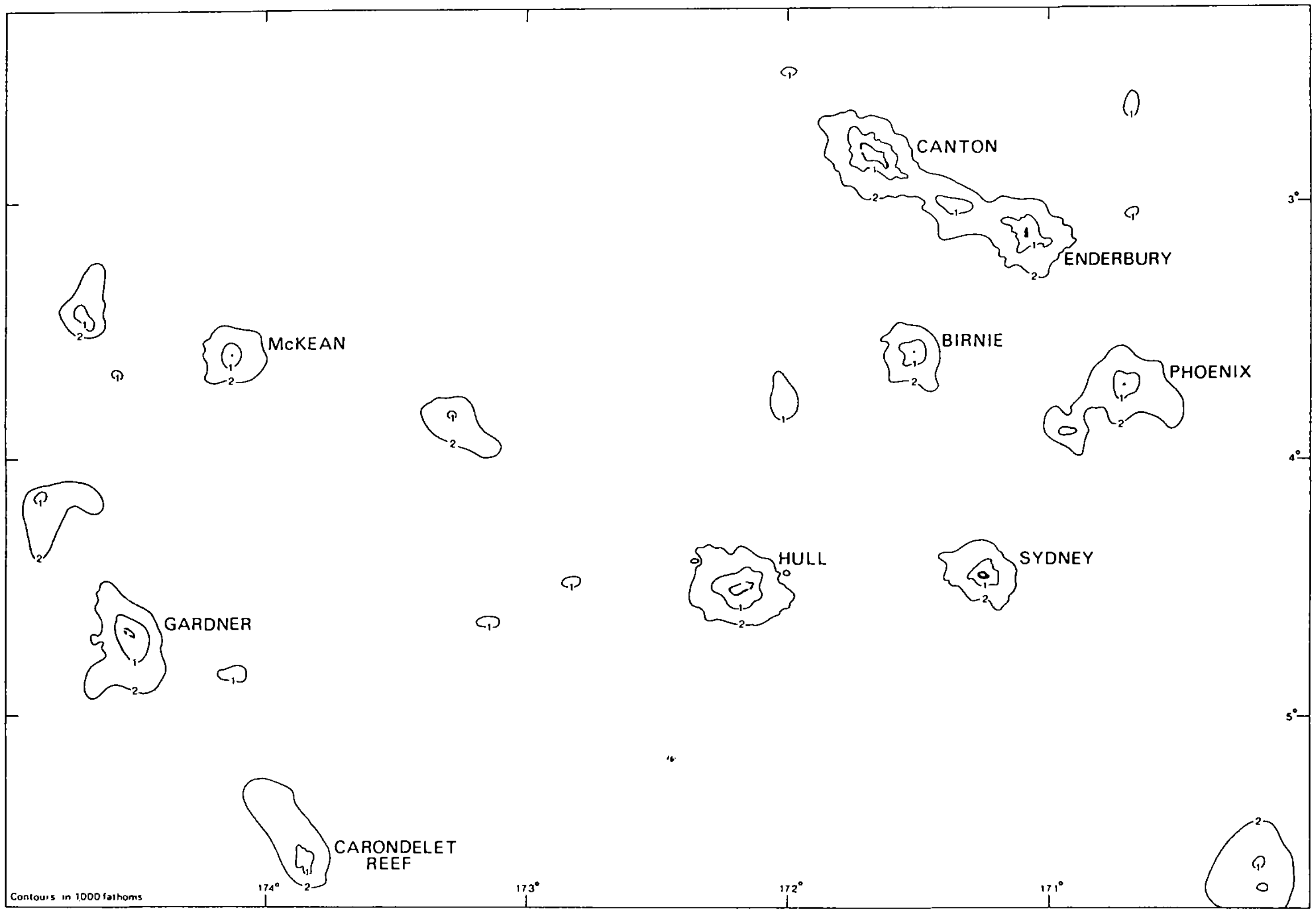

Figure 2. The Phoenix Islands, central Pacific.

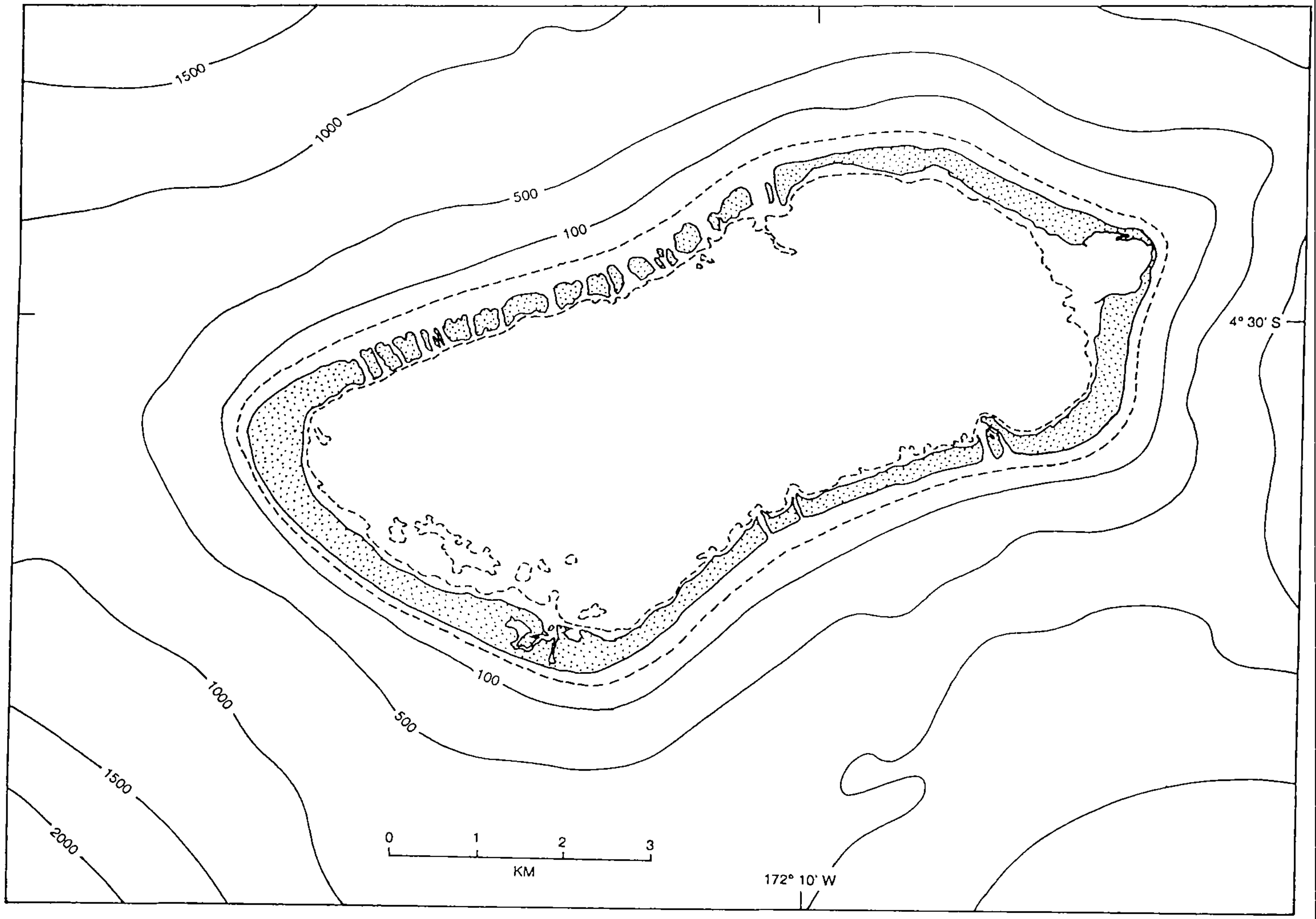

Figure 3. Hull Atoll. Bathymetric contours in meters.

Normal Rim

Profile 4 (Figure 4) was surveyed at the easternmost point of the atoll, near the former settlement, using a Kern automatic level. The land rim at this point is ca 600 m wide, and the profile extends inland for 280 m from the seaward shore. Extensive cemented conglomerate forms steep bastions rising to 3.4 m at the seaward beach, which is backed by a broad sand and rubble seaward ridge rising to over 3.0 m.

Aerial observation shows that much of the continuous land rim consists of parallel, presumably storm-deposited, shingle and rubble ridges (Figure 6). Lagoon beaches are low and sandy.

Hoa

The hoa on the north side of Hull are channels intersecting the broad conglomerate platform underlying the reef-rim motu. They are normally widest toward the lagoon end and narrow and sometimes bifurcate seawards (Figures 7, 10, 13 and 14). They rarely penetrate through the seaward reef rim, but terminate in a pronounced cliff of conglomerate over which water pours at high tide and during storms. The conglomerate platform usually outcrops along both sides of each hoa (Figures 11 and 12). The lagoon mouths are often partially closed by sandspits (Figures 7 and 8), and the lagoon ends of larger hoa are marked by lobate deltas and aprons of sand transported through the hoa and building out into the lagoon (Figures 9 and 10). The sectors of conglomerate platform defined by the hoa carry individual vegetated islands or motu; frequently there is more than one such vegetated island to a sector of conglomerate platform (Figures 7, 8, 9 and 10). The channels between the vegetated islands may be carpeted with sediment and thinly vegetated, and are less frequently occupied by water than the hoa.

The hoa and motu vary considerably in size. Most of the hoa are not more than 50-100 meters in maximum width, and most of the motu vary from less than 100 up to about 600 meters in maximum east-west dimension. Profile 1 in Figure 5 gives a section through one of the northern hoa. The seaward reef-flat surface rises to 1.1 m, with ponded living microatolls on the outer reef flat at 0.15 m. Sand dunes on the seaward side of the motu reach over 3 m. The conglomerate surface on which the motu stands declines from 1.1 to 0.4 m in a distance of 370 m from the seaward edge of the conglomerate to the lagoon.

Paleohoa

The term 'paleohoa' is here used to describe features now no longer active but which clearly originated in the same way as modern hoa in the southwest sector of the atoll rim (Figure 15). Profile 2 (Figure 5) crosses the island rim near the southwest point, where the seaward perched beach ridge reaches a height of 4.0 m. The floor of the paleohoa, which is completely dry, stands at approximately 1.5 m for its entire extent; it is scattered with undercut storm boulders, especially on its seaward side, and these must date from the time when the channels were active (Figures 17 and 18). The seaward end of the former

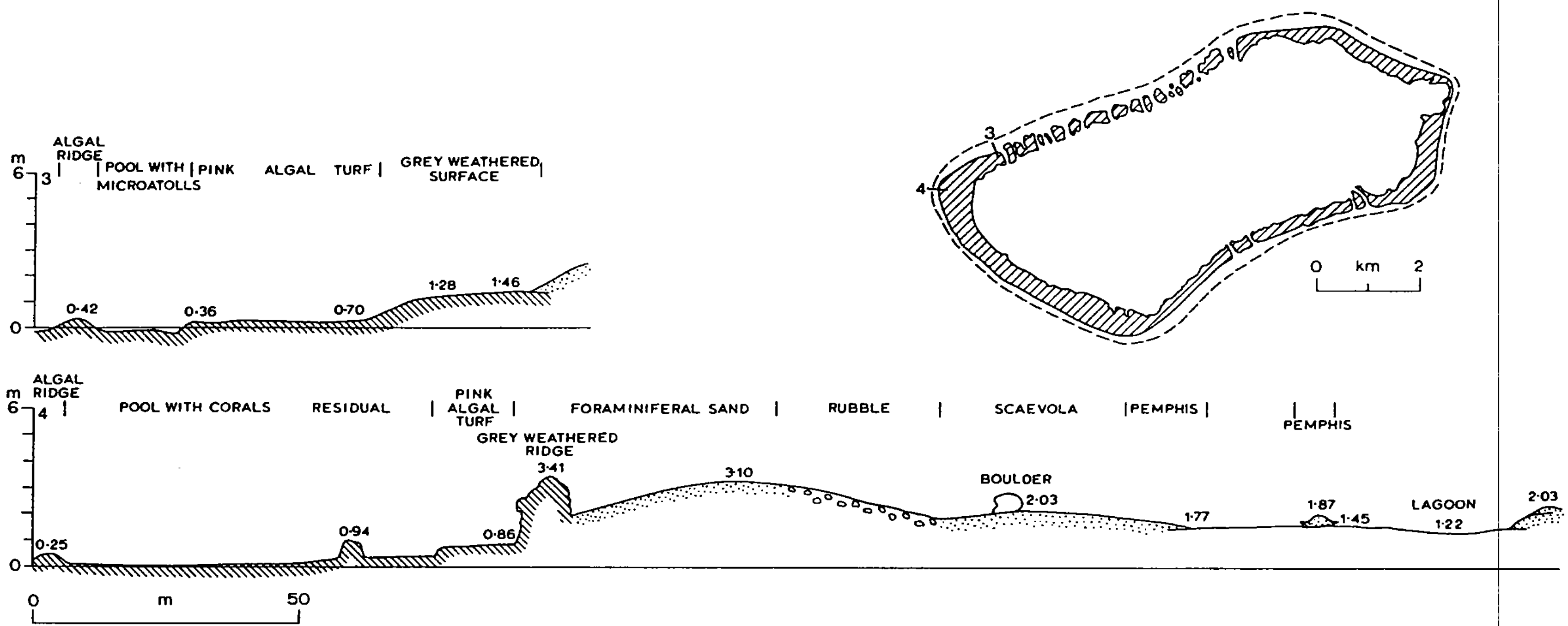

Figure 4. Topographic profiles 3 and 4 surveyed at the northwest corner of Hull Atoll. Datum is approximately mean low water (MLW).

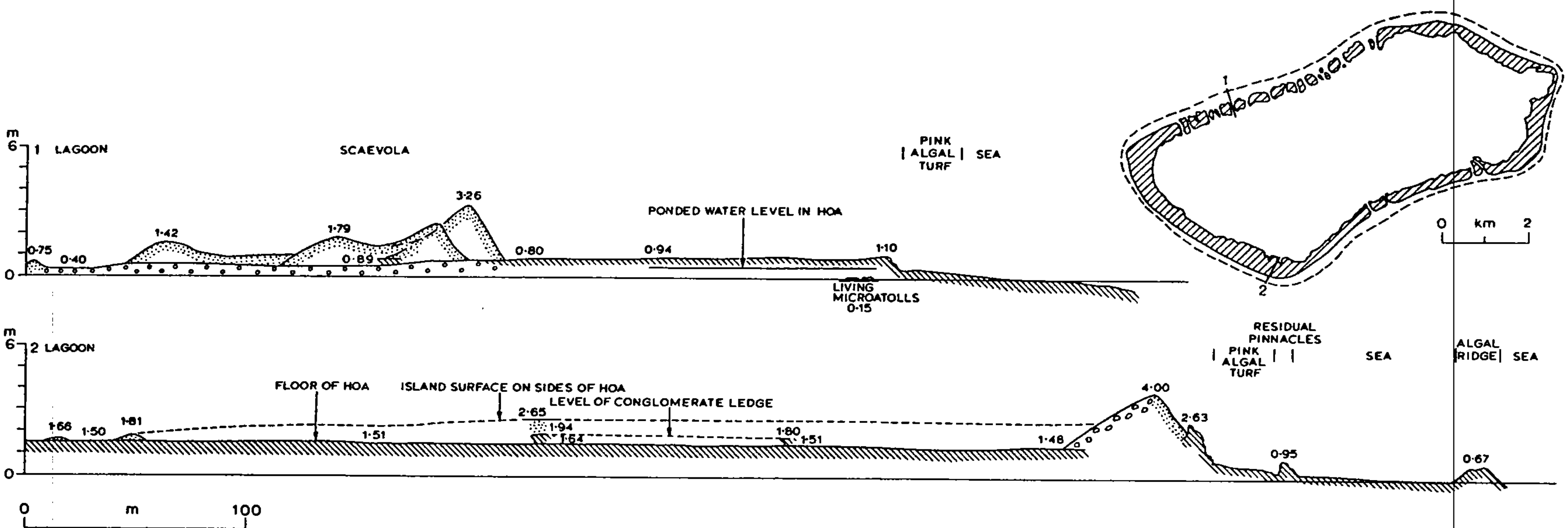

Figure 5. Topographic profiles 1 (through an active northern hoa) and 2 (through a southwestern paleohoa) at Hull Atoll. Datum is approximately MLW.

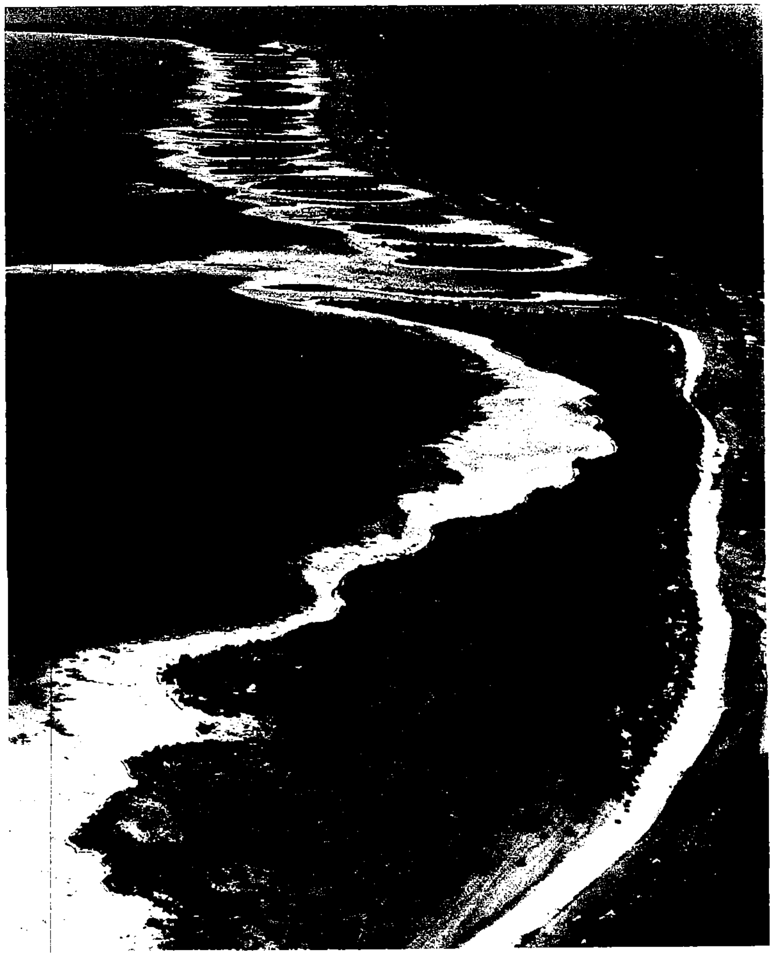

Figure 6 . View along the northern rim of Hull, looking southwest from the northernmost point of the atoll: normal rim in the foreground and active hoa beyond.

Figure 7 . Conglomerate platform dissected by active hoa and with small motu, northern rim of Hull; also shows well-developed groove and spur.

Figure 8. View toward the east of active hoa and motu on the northern rim at Hull.

Figure 9. Larger active hoa with through passage to the seaward side and well-developed sediment lobe on the lagoon side, northern rim of Hull.

Figure 10. Motu with adjacent functional and non-functional hoa, northern rim at Hull. This sector of conglomerate platform appears on hydrographic charts as a single island.

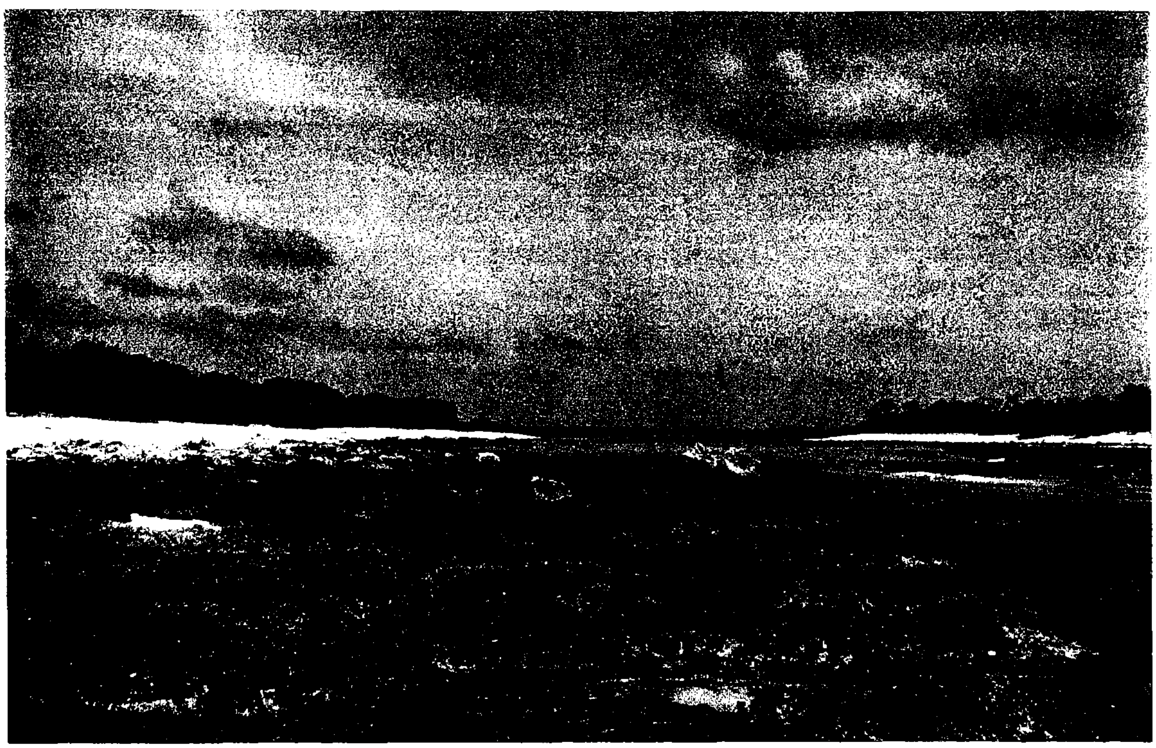

Figure 11. Conglomerate platform on the sides of a hoa, looking toward the lagoon, northern rim of Hull.

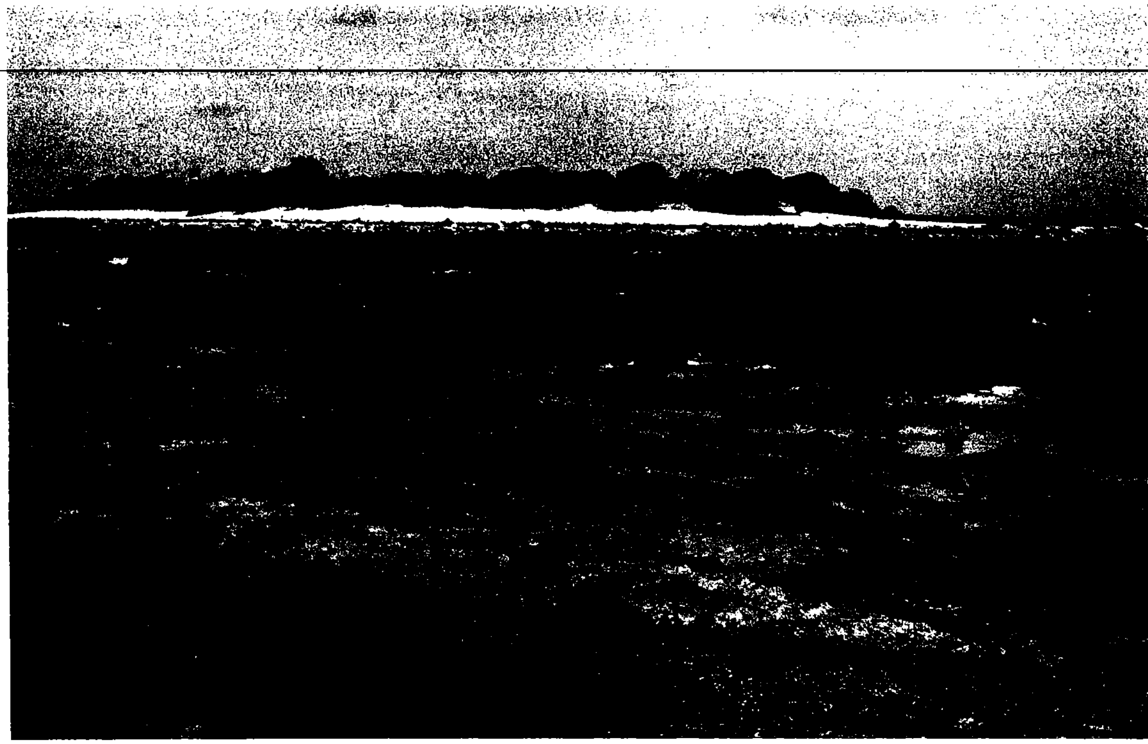

Figure 12. Conglomerate platform on the seaward side of a motu, northern rim of Hull.

Figure 13. Incompletely eroded (non-functional) hoa, blocked by the conglomerate platform.

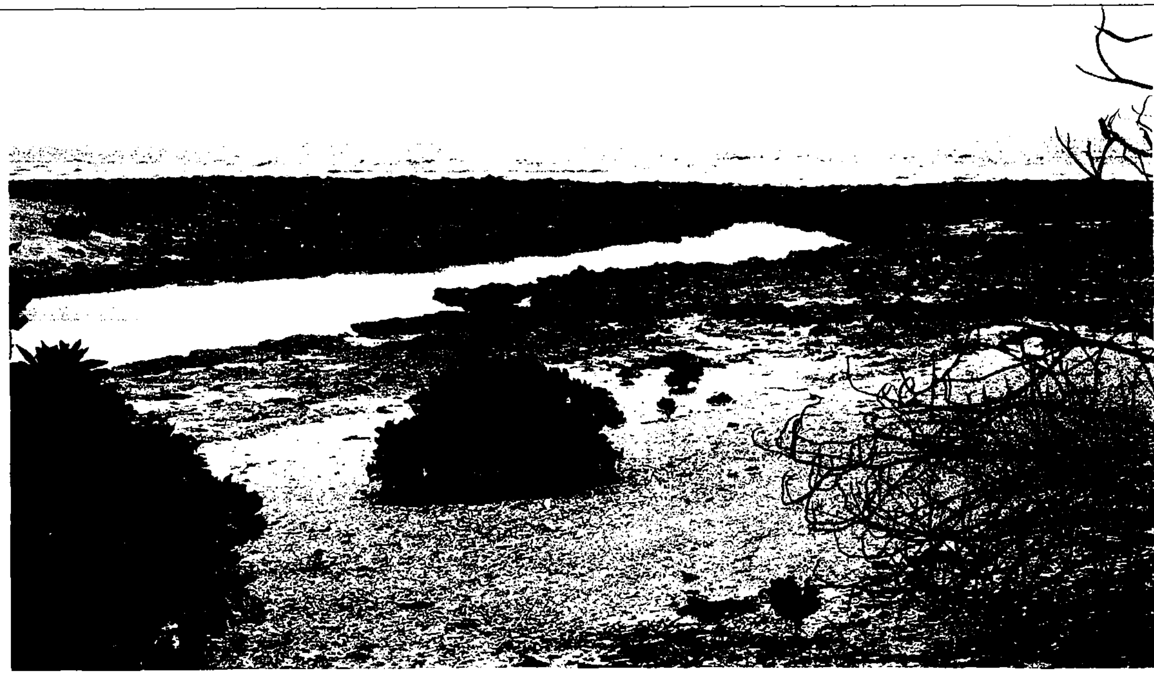

Figure 14. Non-functional hoa which fails to transect the seaward conglomerate platform, northern rim of Hull.

channel is now closed by a steep high ridge of storm rubble (Figures 18 and 19). The top of the conglomerate platform along the channel walls stands at 1.8 to 1.94 m, and the level of the island surface above the platform at 2.65 m. These elevations may be compared with those of the active hoa in Profile 1, and with the crest of the algal ridge at 0.67 m, which may be taken to approximate a datum in the range of Mean Low Water/Mean Sea Level (i.e. a range of perhaps 30 cm).

DISCUSSION

We now consider the bearing of the hoa of Hull Atoll on the general questions of hoa previously discussed.

First: the distribution of the hoa. Active hoa of the kind found on Hull are not found elsewhere in the Phoenix Islands. They are notably absent from the other two 'typical' atolls of Canton and Gardner. Second, on Hull, the hoa are confined to a sector of the northern rim.

Figure 15. Sequence of paleohoa near the southwest point of Hull Atoll. The darker areas are vegetated former motu.

Figure 16. Detail of motu and paleohoa shown in the foreground on Figure 15.

Figure 17. Basally-eroded storm blocks on the dry floor of paleohoa at Hull.

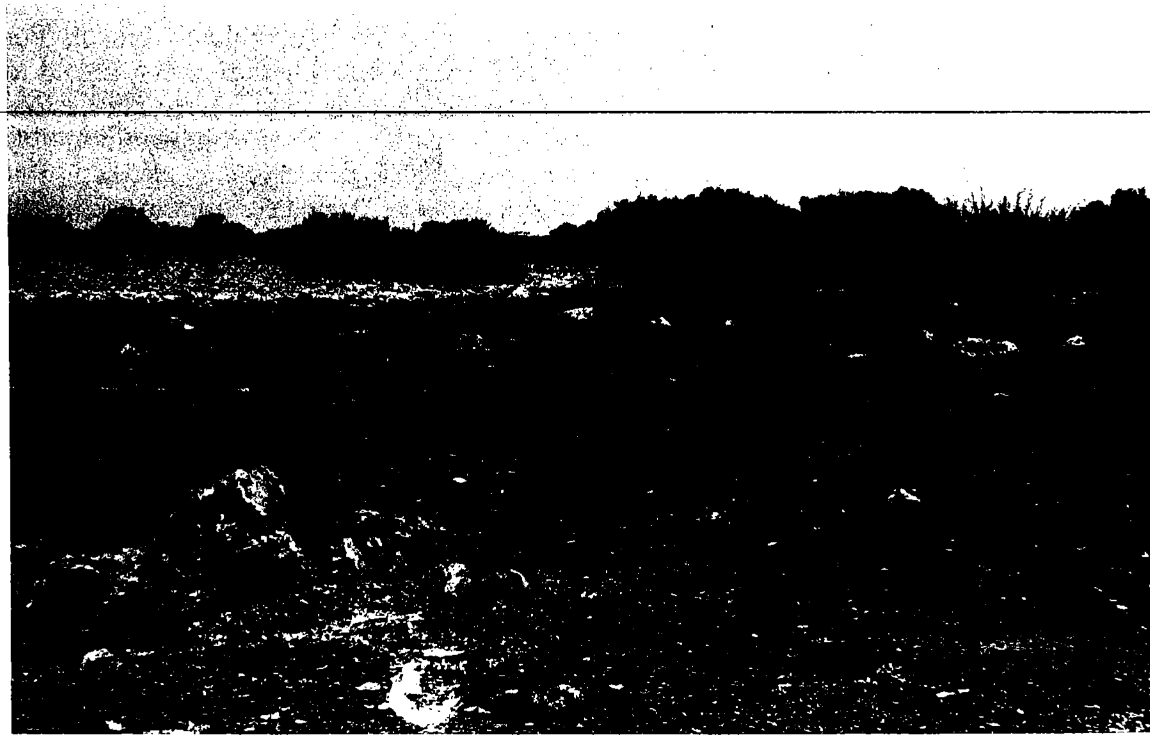

Figure 18. The dry floor of a paleohoa blocked in the background by a vegetated seaward storm ridge, southwest rim of Hull.

Figure 19. Coarse coral rubble forming the storm ridge invading the seward ends of a paleohoa at Hull.

This indicates to us that their primary cause must be local rather than regional. For this reason we do not believe that a Holocene fall in sea-level, whether or not linked to diagenetic changes in reef-top sediments as proposed by Chevalier and Bourrouilh-Le Jan, is either a necessary or a sufficient condition for hoa formation. The most probable agency for eroding the hoa is overtopping storm water associated with hurricanes, the action of which has often been described. A higher Holocene sea-level may have been instrumental in making possible the stranding of extensive spreads of sediment on reef tops as sea-level fell, and which then became available for dissection into smaller motu by the cutting of hoa during overtopping storms. Bourrouilh-Le Jan and Talandier's (1985) suggestion of erosion by tsunami-generated waves seems less likely, both because these are more infrequent than hurricanes and also usually generate waves of negligible magnitude on open-ocean atolls (see Stoddart and Walsh, 1992, p. 13).

The close spatial association of hoa on the north side and paleohoa on the west side of Hull is also significant. The floors of the paleohoa and the upper surfaces of the conglomerate platforms which margin them and which underlie the motu are substantially higher (by the order of a meter) in the case of the paleohoa than in the case of the hoa. Comparable paleohoa have been identified at Canton Atoll (Guinther, 1978) and at Enderbury in the Phoenix Islands, and they thus appear to be a more widespread phenomenon than currently active hoa. While paleohoa could be broadly categorized as non-functional hoa in Chevalier's terms, and while at Hull they are conspicuously blocked on their seaward sides by a contemporary beach ridge of coarse storm sediments, their non-functioning nature stems from their elevation rather than from sediment-blocking: indeed the lodging of the beach ridge on the edge of the conglomerate platform was doubtless aided by its elevation. At Enderbury the paleohoa are associated with lagoonal emergent reefs of Holocene age (Tracey, 1972, 1980), and their floors stand at approximately the same level as those at Hull (Stoddart and Fosberg, unpublished surveys).

We suggest that these paleohoa were formed by the same kind of storm action that is responsible for the formation of contemporary hoa, but at a period when sea-level stood higher in the Holocene. They were subsequently abandoned when sea-level fell to its present level and storm beaches accumulated along the seaward edges of emergent conglomerate platforms and on emergent hoa floors.

We see no evidence that hoa are initiated by reef-flat fracturing, though doubtless their development may be guided by joints. If fissuring or fracturing is involved, the regional and local distribution of hoa raises considerable problems about surficial reef structure.

Hoa are thus characteristic of reef rims with high proportions of land exposed by the Holocene fall in sea-level and affected subsequently by major hurricanes. They are not characteristic of reefs outside the hurricane seas, e.g. Diego Garcia Atoll in the Chagos Archipelago, and indeed also Gardner and Canton Atolls in the Phoenix Islands. Historic hurricanes are in fact rare in the Phoenix group, and the storm which formed the hoa on the north side of Hull must have been an unusual event. Conversely both hurricanes and hoa are common in the Tuamotu.

The presence of paleohoa at Enderbury and Canton as well as Hull suggests that hurricanes may have been more frequent in this sector of the central Pacific in mid-Holocene times. It would be of interest to search for paleohoa on the margins of the modern hurricane belts to see if these features could serve as a general index of Holocene hurricane extension.

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