CANTON ATOLL LAGOON PHYSIOGRAPHY AND GENERAL OCEANOGRAPHIC OBSERVATIONS

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ABSTRACT

The four major physiographic zones of the Canton Atoll lagoon are defined as the Pass Zone, the Line Reef Zone, the Back Lagoon Zone, and the Altered Zone. Each of these zones has a characteristic physiography, biota, and water quality. The Altered Zone is noteworthy, because it appears to have originated from the degradation of other zones brought about by dredge and fill operations. There does not appear to be any other major artificial damage to the lagoon, aside from direct mechanical destruction by dredging.

The predominant aspects of lagoon circulation are wind drift and tidal flow. Although lagoon tides show a pronounced lag with respect to the ocean tides, there is no measurable amplitude attenuation from the ocean to the back lagoon.

GENERAL OBSERVATIONS

The Canton Atoll lagoon may be divided into four major physiographic zones: the Pass Zone, the Line Reef Zone, the Back Lagoon Zone, and the Altered Zone. Approximate boundaries of the zones are shown in the Frontispiece. These lagoon zones, although shown as distinctly bounded, are broadly transitional from one to another.

Within the Pass Zone, extending to approximately 2 km from the passage between the ocean and lagoon, tidal flushing is obviously the dominant factor in maintaining an environment that is rich in biota and that has nearly oceanic water quality. Patch reefs are the most common physiographic features in this zone, especially immediately east and southeast of the pass. Nearly half of the lagoon floor in this zone was dredged during the construction of seaplane runways and a ship-turning basin. Figure 1 is an air photograph showing much of the Pass Zone and part of the Line Reef Zone.

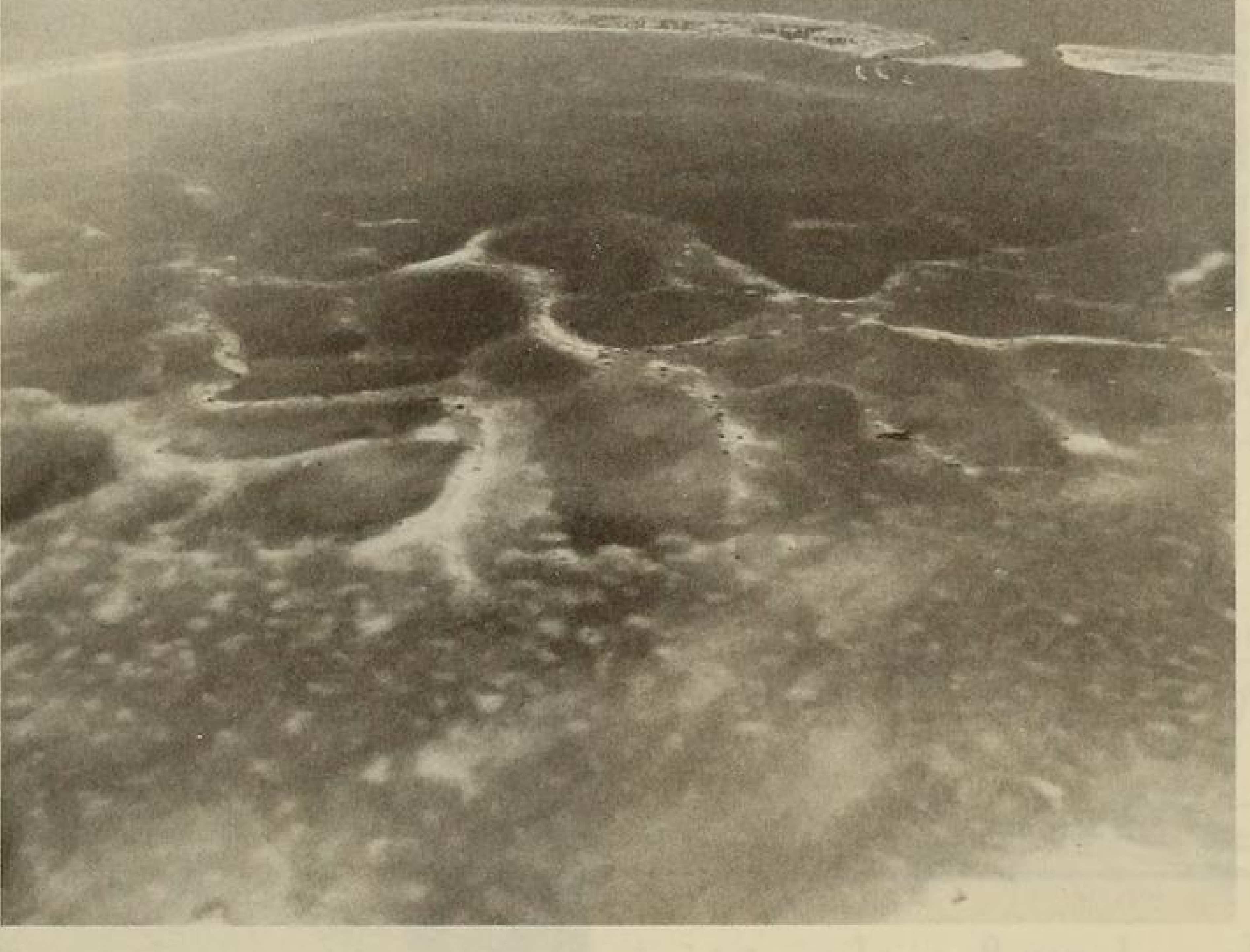

Figure 1. Oblique air photograph showing a portion of the northeastern lagoon fringing intertidal flats (foreground), linear reefs, and the apparently open-water area of the Pass Zone (background).

In the central lagoon, within a 2 to 8 km distance from the pass, line reefs extending in an approximately north–south direction or interconnected into a cellular network (Fig. 2) are the predominant features. Along the intertidal flats fringing the lagoon in the Line Reef Zone, some reef patches protrude through the sand-covered slope. The crests of these structures are kept free of sediment by relatively high-velocity tidal currents.

The Back Lagoon Zone is the zone most distant from the influence of the lagoon pass (Fig. 3). In this zone, line reefs are lacking, patch reefs are sparse, and most of the hard substratum (including much of the live coral) is covered with a thin layer of fine sediment. Tidal currents are barely discernible.

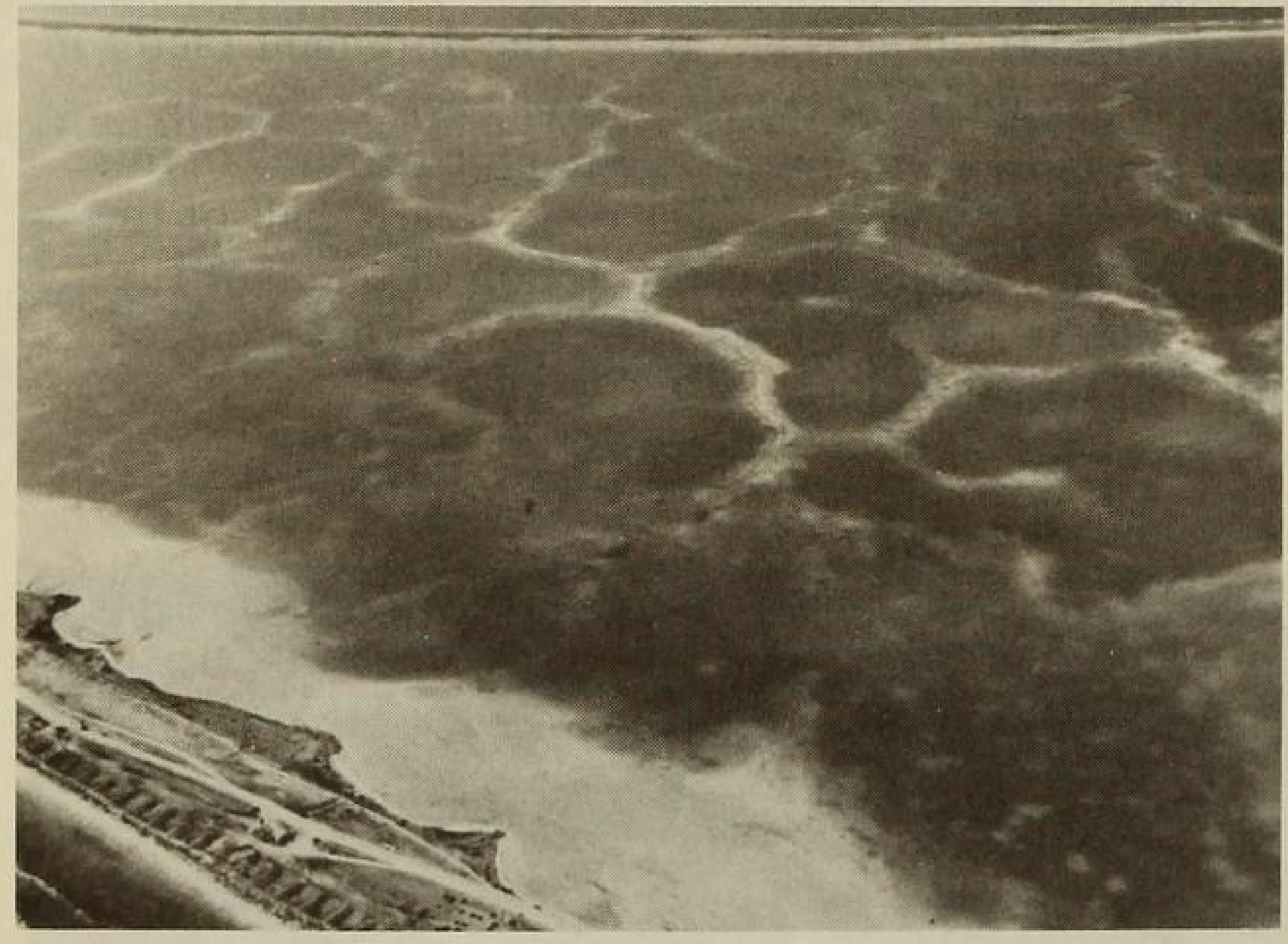

Figure 2. Oblique air photograph from the northeast, across the lagoon in the Line Reef Zone.

Figure 3. Oblique air photograph from the southeast, showing the Back Lagoon Zone and the edge of the Line Reef Zone.

Some reefs in the Canton Atoll lagoon show definite signs of degradation which have apparently occured recently (within the last 100 years). These changes are most obvious in the Altered Zone, located in the northwestern corner of the lagoon. Patch reefs are common in this zone, and some line reef structures occur in the southeastern portion of the area. Yet live coral is sparse on the reef and is limited to a small number of hardy species; practically all hard and soft substrata are being covered with fine sediment. At present this corner of the lagoon has poor water circulation, relatively high salinity, low nutrients, and very high turbidity. An explanation for the condition of this zone can apparently be found in human modification of the atoll physiography.

A general description of the atoll prior to 1938 has been compiled from a number of sources (field notes of and personal discussion with E. H. Bryan, Jr.; aerial photographs; and a 1938 survey of the atoll by Henslee Towill).

Before human disturbance, the Canton Atoll lagoon was connected to the open ocean by four entrances along the western side of the atoll (Fig. 4, left).

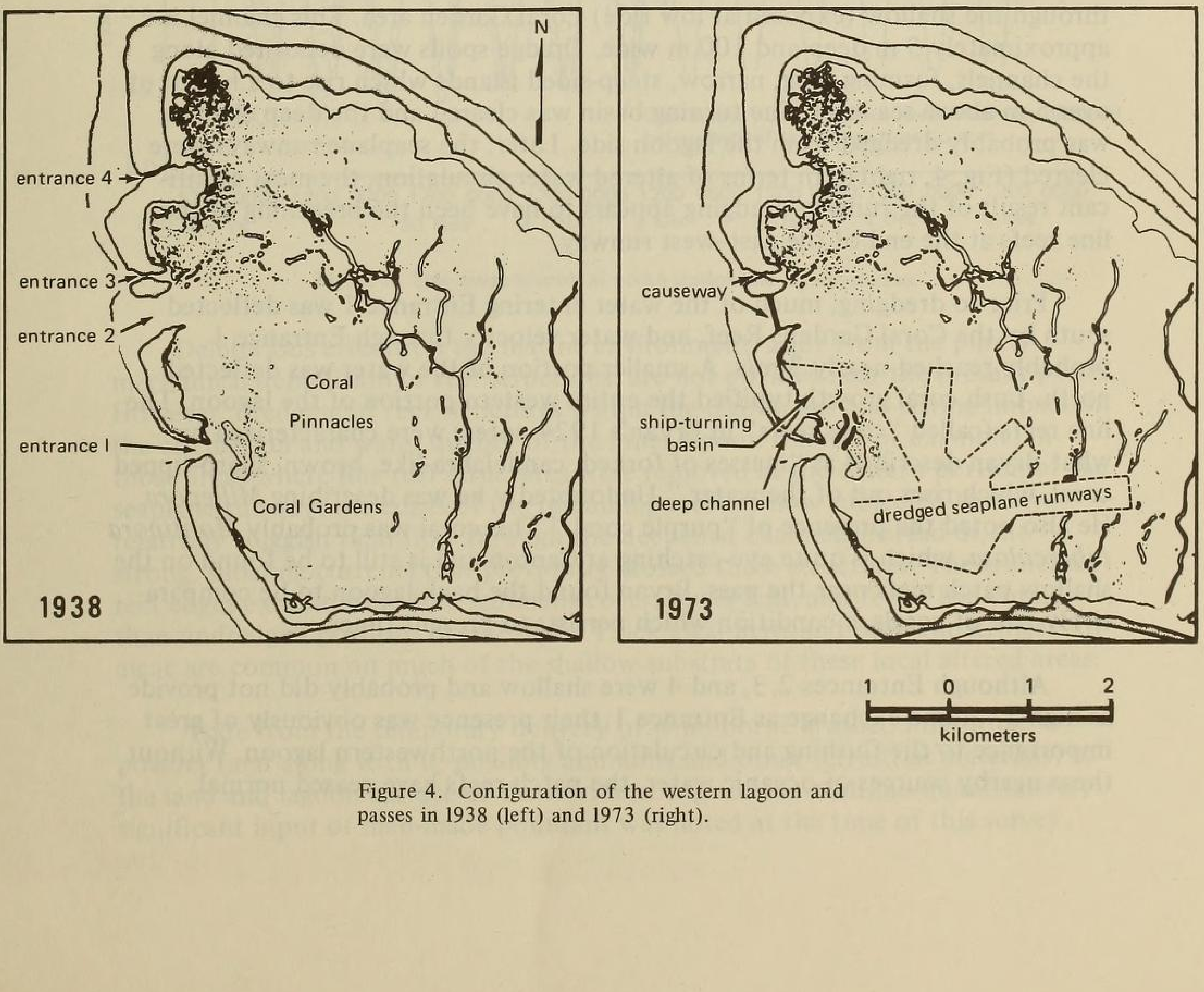

Figure 4. Configuration of the western lagoon and passes in 1938 (left) and 1973 (right).

During the early years of World War II, three of the entrances were closed by causeways, and an additional 8-meter-deep ship channel was cut through the atoll rim, leaving an isolated remnant of land now known as Spam Island, two rows of dredge spoils near the pass, and a small dredged island in mid-lagoon. Entrance 1 still exists; it was deepened in 1943 when the ship channel was dredged (Degener and Gillaspy, 1955). Spam Island, the remaining (double) pass and the dredge spoils can be seen in Fig. 1 and 4 (right).

At the present time, Entrance 1 at its narrowest and shallowest point is approximately 150 m wide and 5 m deep. In his original field notes, E. H. Bryan, Jr. (notes of Whitney South Sea Expedition of the American Museum of Natural History, March 1924; on file at Bishop Museum, Honolulu) described Entrance 1 as "60-150 yards wide, deep, blocked on inside by coral heads." Entrance 2 was "about 200 yards wide, shallow, full of rocks and coral can be easily waded)." He found Entrance 3 to be "15-40 yards wide in places knee deep, but with deeper pools." Entrance 4 was "20-50 yards wide, very long and winding, making two turns, deep in spots (up to 10-12 feet), other places shallow (knee deep)." Water seldom flowed through this pass.

The dredge probably was brought through Entrance 1, cutting the channel through the shallow (exposed at low tide) Coral Garden area. This channel is approximately 5 m deep and 100 m wide. Dredge spoils were deposited along the channels, forming long, narrow, steep-sided islands which rise to a height of over 5 m above sea level. The turning basin was cleared and the deep channel was probably dredged from the lagoon side. Later, the seaplane runways were cleared (Fig. 4, right). In terms of altered water circulation, the most significant result of the runway dredging appears to have been the breaching of the line reefs at the end of the east–west runway.

Prior to dredging, much of the water entering Entrance 1 was deflected south by the Coral Gardens Reef, and water velocity through Entrance 1 probably reached nearly 3 m/s. A smaller portion of the water was deflected north. Lush coral growth typified the entire western portion of the lagoon. The line reefs (called "cross reefs" in Bryan's 1924 notes) were characterized by what Bryan described as "masses of forked, candelabra-like, brown, sharp-tipped coral, which rises out of the water." Undoubtedly he was describing *Millepora*. He also noted the presence of "purple coral." This coral was probably *Montipora tuberculosa*, which is quite eye-catching at Canton and is still to be found on the shallow patch reefs near the pass. Bryan found the back lagoon to be comparatively free of corals, a condition which persists to present times.

Although Entrances 2, 3, and 4 were shallow and probably did not provide as high a volume exchange as Entrance 1, their presence was obviously of great importance to the flushing and circulation of the northwestern lagoon. Without these nearby sources of oceanic water, the patch reefs have ceased normal growth; the general environment of the Altered Zone is more nearly like that of the back lagoon. Closing the northern passes apparently did not reduce the total volume of tidal exchange of the lagoon, as evidenced by the tide-gauge data, which show no attenuation of tidal amplitude from the ocean to the back lagoon (Fig. 5). However, this change did greatly affect the circulation velocities and patterns of the western lagoon. Most of the lagoon environment located beyond the Pass Zone and Altered Zone areas was probably not appreciably affected by the pass modifications. The distance of most of the lagoon to the nearest pass remained unaltered because of the lagoon and pass geometry.

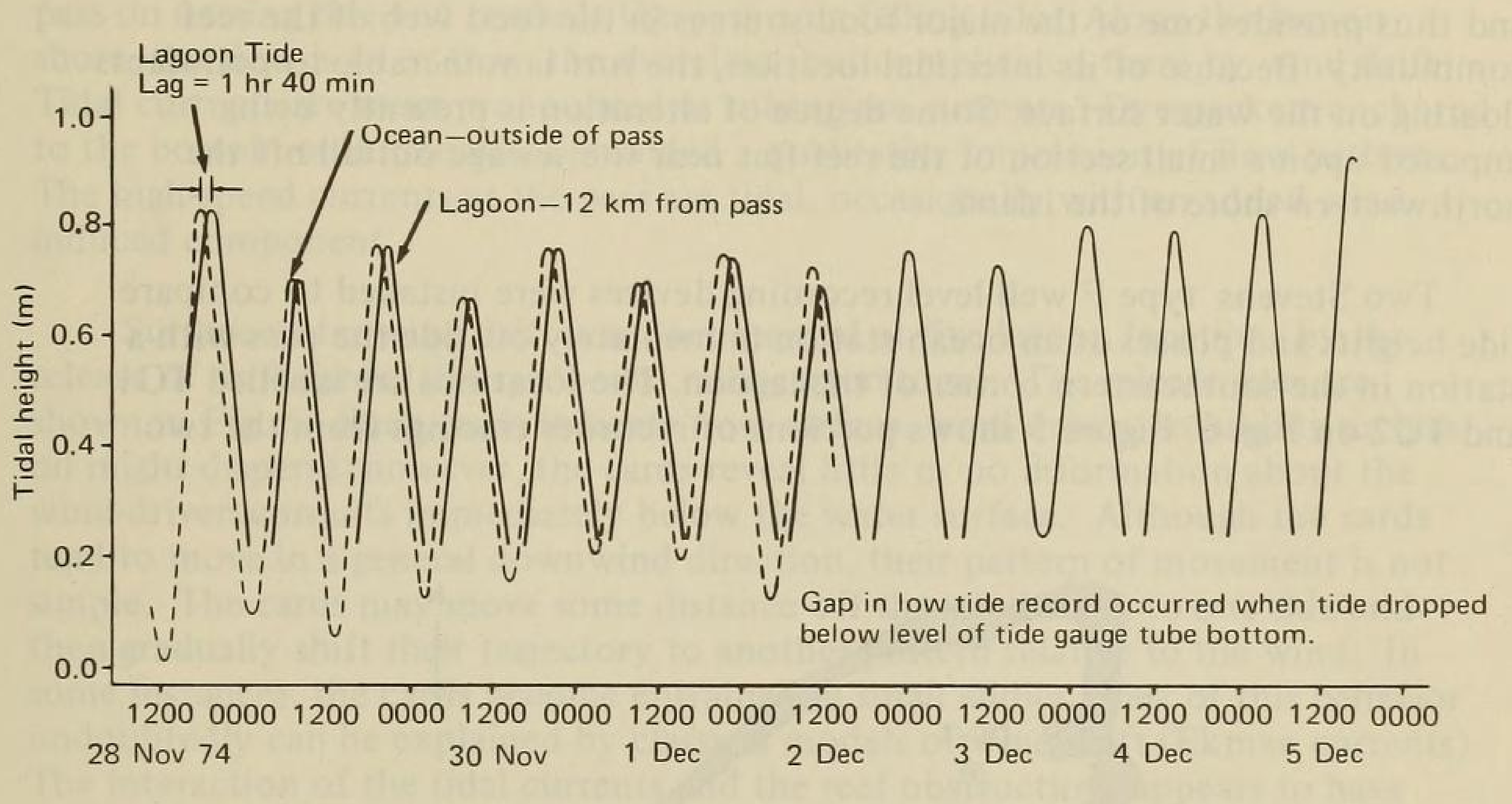

Figure 5. Tide gauge records at ocean station and lagoon station.

Deleterious effects on the marine environment, aside from the purely mechanical demolition of reef structures, are not obvious near the present passes. However, dredging of reef structures within the lagoon has had lasting impact on the circulation and water quality of the inner lagoon zones. For example, in those areas where line reef structures were removed at the eastern portion of the seaplane runway, the edges of the remaining reef are now subjected to only relatively sluggish tidal flow through the deepened channels instead of the strong, shoaling currents that previously crossed these structures. The truncated reef edges exhibit more fine sediment cover, fewer fish, and fewer live corals than undredged portions of line reefs. Thick algal mats and buoyant stringers of algae are common on much of the shallow substrata of these local altered areas.

Aside from the temporary delivery of wind-borne crushed limestone powder (and along with it, possibly ammonia and other terrestrial materials) to the land and lagoon surface of the northern edge of the atoll, no quantitatively significant input of man-made pollutant was noted at the time of this survey.

The intertidal and nearshore areas of the oceanic fringing reef are generally in good health and appear to be unaffected by water exiting the lagoon. Most of the water exiting the lagoon is of approximately oceanic composition because of relatively limited horizontal mixing in the inner lagoon. This plume of water from the lagoon is quickly diluted and dispersed by ocean currents.

Although the intertidal fringing reef flats may appear barren, these areas are important to the atoll biota because of the inconspicuous algal turf that covers most of the surface. Many cryptic organisms (for example, Foraminifera and mollusks) abound in this turf. The turf is grazed by herbivorous organisms and thus provides one of the major food sources in the food web of the reef community. Because of its intertidal location, the turf is vulnerable to pollutants floating on the water surface. Some degree of alteration is presently being imposed upon a small section of the reef flat near the sewage outfall off the northwestern shore of the island.

Two Stevens type F well-level recording devices were installed to compare tide heights and phases at an ocean station immediately outside the pass with a station in the southeastern corner of the lagoon. The locations are labelled TG1 and TG2 on Fig. 6. Figure 5 shows portions of recorder tracings from the two

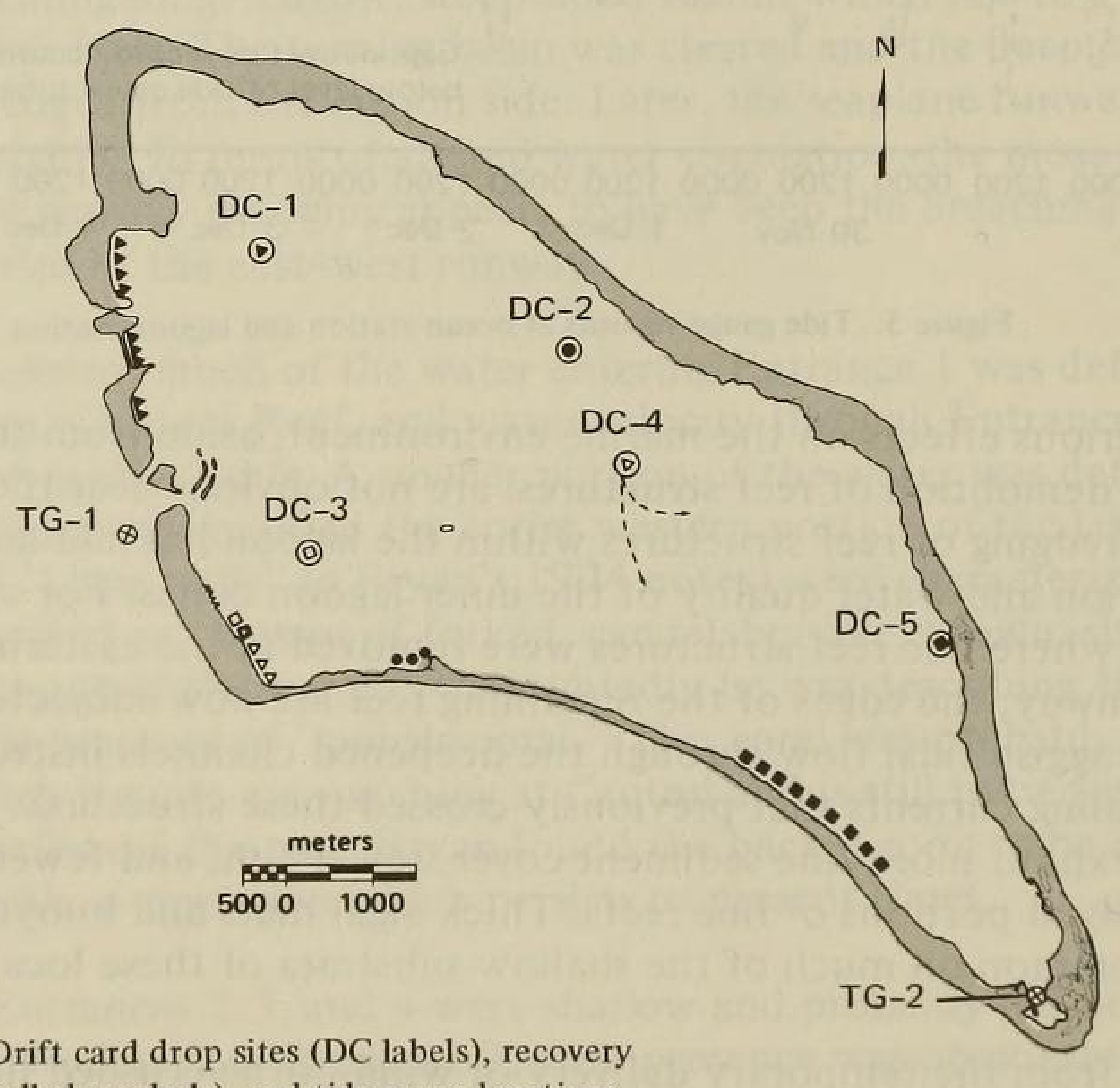

Figure 6. Drift card drop sites (DC labels), recovery sites (unlabelled symbols), and tide gauge locations (TG). Dashed arrows from DC-4 represent dye tracks from bottom-placed dye packet.

stations. There is a 100-minute time lag between the ocean and tidal extremes and those of the lagoon, but no measurable attenuation of tidal amplitude. Some detail may be lost in this tidal record, both because the lagoon gauge became exposed on some low tides and because there was a great deal of high-frequency noise in the ocean record. Nevertheless, the records fail to show the dramatic (about 50%) attenuation which Gallagher *et al.* (1971) observed at Fanning Atoll.

Relatively high-speed tidal currents occur and could be sensed by divers at most locations in the lagoon. Direction of flow is predominantly away from the pass on a rising tide and towards the pass on a falling tide. Along the lagoon shore, the flow is to or from the shoreline (but complicated there by wind drift). Tidal currents are most pronounced as subsurface currents. Dye packets anchored to the bottom or in midwater provided a qualitative impression of flow patterns. The high-speed currents at the pass are tidal, occasionally with an added wind-induced component.

Surface-water wind drift was documented at five lagoon locations by the release of drift cards (flat cardboard milk-carton tops). The release sites are shown in Fig. 6. Such cards indicate how surface, wind-driven pollutants such as oil might disperse; however, the cards reveal little or no information about the wind-driven currents immediately below the water surface. Although the cards tend to move in a general downwind direction, their pattern of movement is not simple. The cards may move some distance off the wind track to one side and then gradually shift their trajectory to another pattern relative to the wind. In some instances, the cards become entrained in small eddies. Part of this behavior undoubtedly can be explained by classical models of wind drift (Ekman currents). The interaction of the tidal currents and the reef obstructions appears to have more important influences on wind-drift patterns. For example, cards released on the upwind side of a reef, but downstream of the reef with respect to tidal flow, were seen to remain "trapped" on the upwind side of the reef even though the top of the reef was submerged by several decimeters. Apparently the tidal currents actually break the surface under these circumstances, with force on the sea surface equal to that of the wind drag.

The net direction of surface drift is ultimately downwind. As shown in Fig. 6, drift cards from all locations except DC-1 were found several days after their release along the lagoon beaches south of the pass. Cards from that single exception (DC-1) were found along the western lagoon shore north of the pass. During the survey period, the wind direction ranged from NE to E.

Incidentally, the drift cards only confirm the pattern suggested by other evidence. Specific recovery sites were sandy beaches heavily littered by flotsam and jetsam. Points or areas clear of recent sand accumulation or debris tended not to collect drift cards.

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Gallagher, B. S., K. M. Shimada, F. I. Gonzalez, Jr., and E. D. Stroup. 1971. Tides and currents in Fanning Atoll lagoon. Pac. Sci. 25: 191–205.

ABSTRACT

Reconnaissance sampling of isolated bodies of water on Canton Island* revealed a pattern in salinities related to the physiography of the channels and flats of the island. Moderate salinities between 13 and 18 o/oo typified channel-bed ponds, while lower salinities (less than 8 o/oo) typified potholes and water-filled burrows on the surrounding flats. Highest salinities (greater than 24 o/oo and up to 152 o/oo) were encountered in two larger ponds, in lagoon tidal channels, and in a saltern. A wide variation in concentration of nutrients and chlorophyll *a* suggests ecological dissimilarities stemming either from salinity differences where such differences are great or from variations in biological community development owing to vagaries in colonization or previous environmental histories or both.

*The term "Canton Island" refers to the largest land mass of Canton Atoll.

INTRODUCTION

Because atoll soils are typically highly permeable, standing bodies of water are rare features of the atoll terrestrial environment. Large islets with substantial inputs of freshwater in the form of precipitation will develop groundwater bodies of the Ghyben-Herzberg type (Cox, 1951). The extent of fresh or brackish water in aquifers of this type depends on complex relationships between rainfall, evaporation, islet size, sediment permeability, and tidal range. Atoll islets are low in profile; topographical depressions may expose portions of the water table, resulting in the formation of ponds or, under special circumstances, even streams (Guinther, 1971). The chemical composition of water in such ponds may not always coincide with that of the groundwater in the immediate vicinity, because surface water is subject to different rates from the groundwater in input (rainfall, seepage, tidal inflow), output (evaporation and outflow), and biogeochemical alteration. Nevertheless, exposed bodies of water on atoll islets are ecologically interesting and can also be used to indicate uppermost groundwater conditions. Freshly dug wells serve as the most simple means of sampling groundwater directly.

METHODS

Salinity observations on standing bodies of water at Canton Island were made between 4 and 11 December 1973. In addition, water samples from selected sites were analyzed for NO_3, NH_4, PO_4, Si, and phytopigments. Salinity measurements were of two types. Salinities were determined in the field by measuring the refractive index of small quantities of water with an American Optics hand-held refractometer. At some stations, water samples were collected and the salinity determined in the lab by comparing the sample conductivity with that of a known standard (Smith and Jokiel, this report). This latter method yields more precise (but, at low salinities, not necessarily more accurate) results than does the refractivity method. The results of both types of salinity determinations are presented in Table 24. When both methods were used on the same samples, the values derived by refractivity were about 1.5 $^{o}/oo$ lower than the values derived from conductivity analyses. Although analytically interesting, this difference does not change the basic interpretations of the data.

Table 24. Station descriptions and salinities.

Station	Description	Date	Time	Salinity (°/oo)* A	B
1	Cement-lined sump adjacent to lagoon beach, NASA site (abandoned)	12/5	1630	6.5	
2A	Sump hole at crusher plant (in use)	12/10	pm	26	
2B	Gravel pit behind shingle berm (ocean) at crusher plant	12/10	pm	4.5	
3	Old man-made trench in flat, about 2 km SE of crusher plant	12/10	pm	6	
4	Small ordnance craters on flat	12/8	am	2.5-12.5	
5A	Shallow depression, seaward side of flat	12/8	am	6.5	
		12/11	0900	3	
5B	*Cardisoma* burrow and seepage beneath consolidated shingle rise adjacent to 5A	12/8	am	2	
6	Small ordnance craters on flat	12/8	am	0	
7	Small ordnance craters on flat	12/8	am	4-5	
8	Moderate-sized pond in depression on flat	12/6	1830		17.52
	(natural channel)	12/8	0810	12.5-14	14.68
		12/8	1410	14	
		12/8	1630		16.02
		12/11	1000	13	
9	Small ordnance craters	12/8	pm	0-5	
10	Shallow depression, seaward side of flat	12/8	pm	2	
11	Shallow depression on flat (natural channel)	12/8	pm	13	
12	Small ordnance craters	12/8	pm	0.5-2	
13	Small pond in depression on flat (natural channel)	12/8	pm	14	
14	Large ordnance crater on flat	12/8	pm	0.5	2.04
		12/10	1100		2.22
15	Large ordnance crater on flat	12/8	pm	0	
		12/10	1100		2.02
16	Small potholes and *Cardisoma* burrows on flat	12/5	1615	1-2	
17	Shallow pond in depression on flat (natural channel)	12/10	am	15.5	
18A	Moderate-sized pond behind lagoon beach in natural channel leading to flat	12/5	1600	13.5	
18B	*Cardisoma* burrow adjacent to 18A	12/5	1600	8	
19	Shallow hole dug into dry channel	12/5	1615	3	
20	Shallow depression (man-made?) in flat adjacent to Green Pond	12/6	1240	17	18.95
21	Seepage from beneath beachrock rim beside	12/5	1015	8-12	
	Green Pond	12/6	pm		10.31
22A	Green Pond; largest "pond" on Canton	12/5	1000	71	
22B	Channels in cyanophyte mat extending outward from shore of Green Pond	12/5	1000	82	
22C	*Cardisoma* burrow in dry channel leading NE from Green Pond basin	12/5	1000	108	
23	Clear Pond; second largest "pond" on Canton	12/5	1125	24	
		12/6	1220		26.84
		12/8	0940		27.92
		12/10	1030		29.27

(Contd)