OBSERVATIONS ON TERRESTRIAL SURFACES AND SUBSURFACE WATER AS RELATED TO ISLAND MORPHOLOGY AT CANTON ATOLL

by

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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 ‰ typified channel-bed ponds, while lower salinities (less than 8 ‰) typified potholes and water-filled burrows on the surrounding flats. Highest salinities (greater than 24 ‰ and up to 152 ‰) 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.

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*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)

Table 24. (Contd)

Station	Description	Date	Time	Salinity (°/oo)* A	B
24	Hole dug into center of large salt pan (saltern)	12/5	1530	152	
25	*Cardisoma* burrow on flat just beyond edge of salt pan	12/5	1530	11	
26	Tidal channel on tidal flat	12/5	1130	43	
27	Tidal channel at SE head of tidal flat	12/5	1140	41-43	
		12/5	1500	38.5	
28A	*Cardisoma* burrows at edge of flat	12/5	1515	2	
		12/10	1000	0.5	
28B	Water on low part of flat periodically exposed	12/10	1000	14	
29	Shallow trench (man-made) on flat adjacent to road crossing	12/5	1450	8	
30	Tidal channel in tidal flat (west)	12/6	1045	42	43.42
31	Tidal flat	12/6	1030	43.5	

*Salinity A measured in the field using a refractometer; Salinity B measured in the lab from a bottled sample on a conductivity meter.

OBSERVATIONS

Small, exposed bodies of water on Canton Island are restricted largely to the east and southeast portions of the island. This distribution appears to be a consequence of the factors which initially built the island above the reef base, although construction of fortifications during World War II sufficiently disrupted the ground surface along the northwest and northeast portions of the island so that the original topography there is obscured. The absence of surface water on other parts of the island does not, of course, rule out the occurrence of fresh or brackish groundwater there.

The sampling sites established during this study are shown in Fig. 45 and 46. These stations are described briefly in Table 24. Although an appreciable range of salinities was encountered (from 0 to 152 °/oo), a pattern in the distribution of surface waters does emerge. This pattern is related to the physiography of the flats on which most surface water occurs. Low ground between the seaward beach berm (normally the highest part of the island) and the lagoon beach occurs in the form of extensive flats (lightly stippled areas in Fig. 46). The detailed origin of these flats is unclear, but they are most

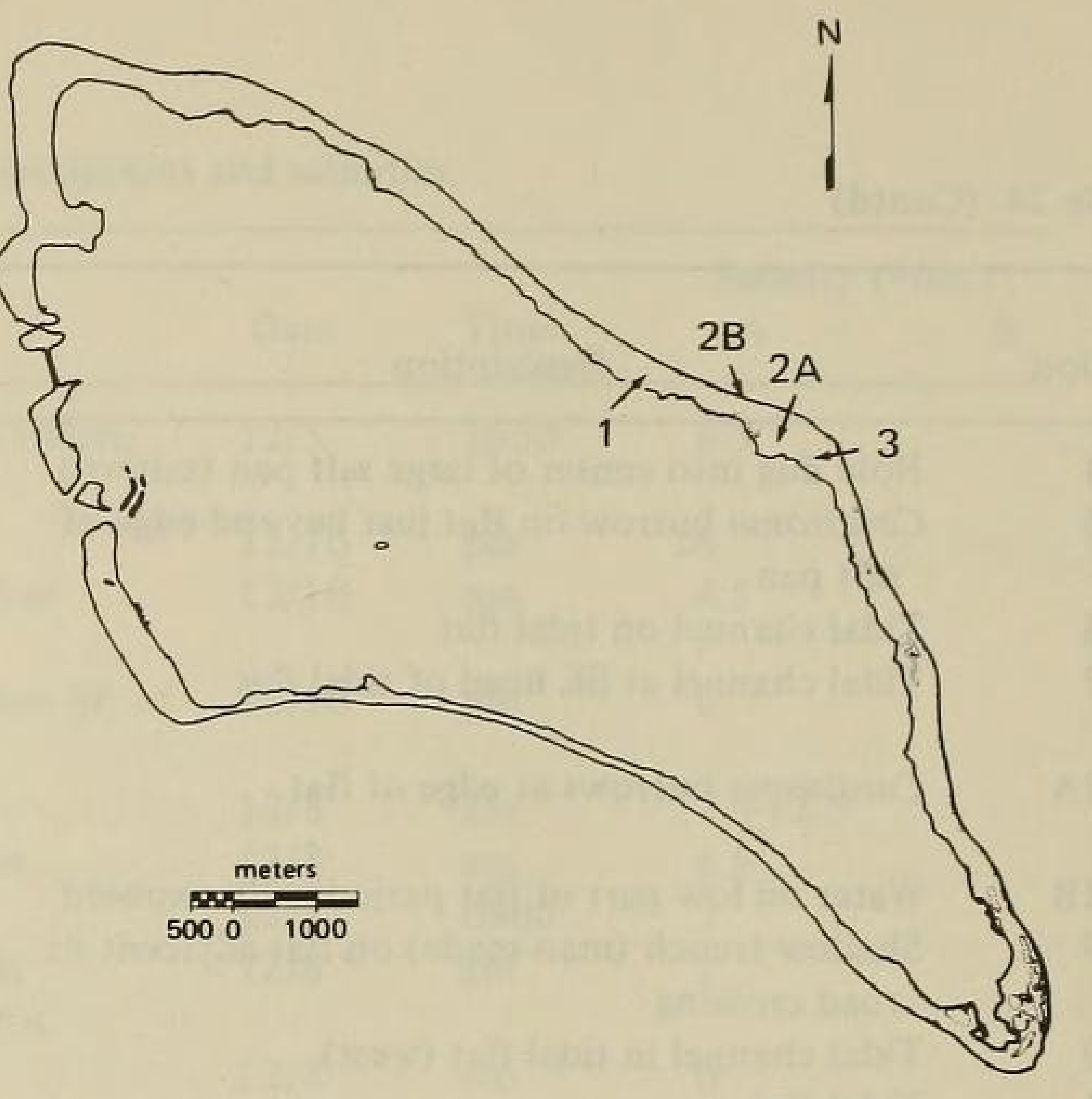

Figure 45. Canton Island, showing water sample sites 1-3.

certainly the work of seawater flowing onto, across, or between ancient islands. The flats are morphologically similar to those described on Fanning Atoll by Guinther (1971) and on Diego Garcia Atoll by Stoddart and Taylor (1971), but the Canton flats differ in not having a regular tidal flow of lagoon water. Evidence for a higher stand of sea level at Canton (either eustatic or tectonic) may be found in the extensive escarpment of detrital limestone surrounding the lagoon and bordering portions of the inland flats. The vertical relief of the limestone exceeds 2 m in some places. A consequence of the subsequent lowering of relative sea level was to strand the intertidally or subtidally formed flats above the present influence of tidal water.

The possibility of present-day seawater incursion onto the flats during the seasonal higher level of the sea at Canton seems unlikely. Our visit coincided with the month of maximum average sea level (December), yet the flats were above any tide level. Nonetheless, particularly large positive deviations in sea level, associated with strong equatorial countercurrent transport (Wyrtki, 1973), might allow occasional tidal flow across the flats. Therefore, formation of these flats at present sea levels cannot be ruled out.

Active tidal flats with well-delimited tidal channels are restricted to one large inlet at the extreme southeast end of the lagoon (stations 26, 27, 30, and 31 in Fig. 46) and to several smaller areas separated from the lagoon by sandbars. The stranded inland flats slope gently toward more or less central dry channels whose courses are eventually lagoonward. These channels apparently connect the inland flats to the lagoon, although the present lagoon beach is not broken where the channels contact the shore. Despite the lack of direct evidence indicating tidal flow, the channel beds of the inland flats are clearly demarcated in most places and appear to be influenced by recent surface flow. Torrential rains during the 1972–1973 period of high rainfall may account for these features.

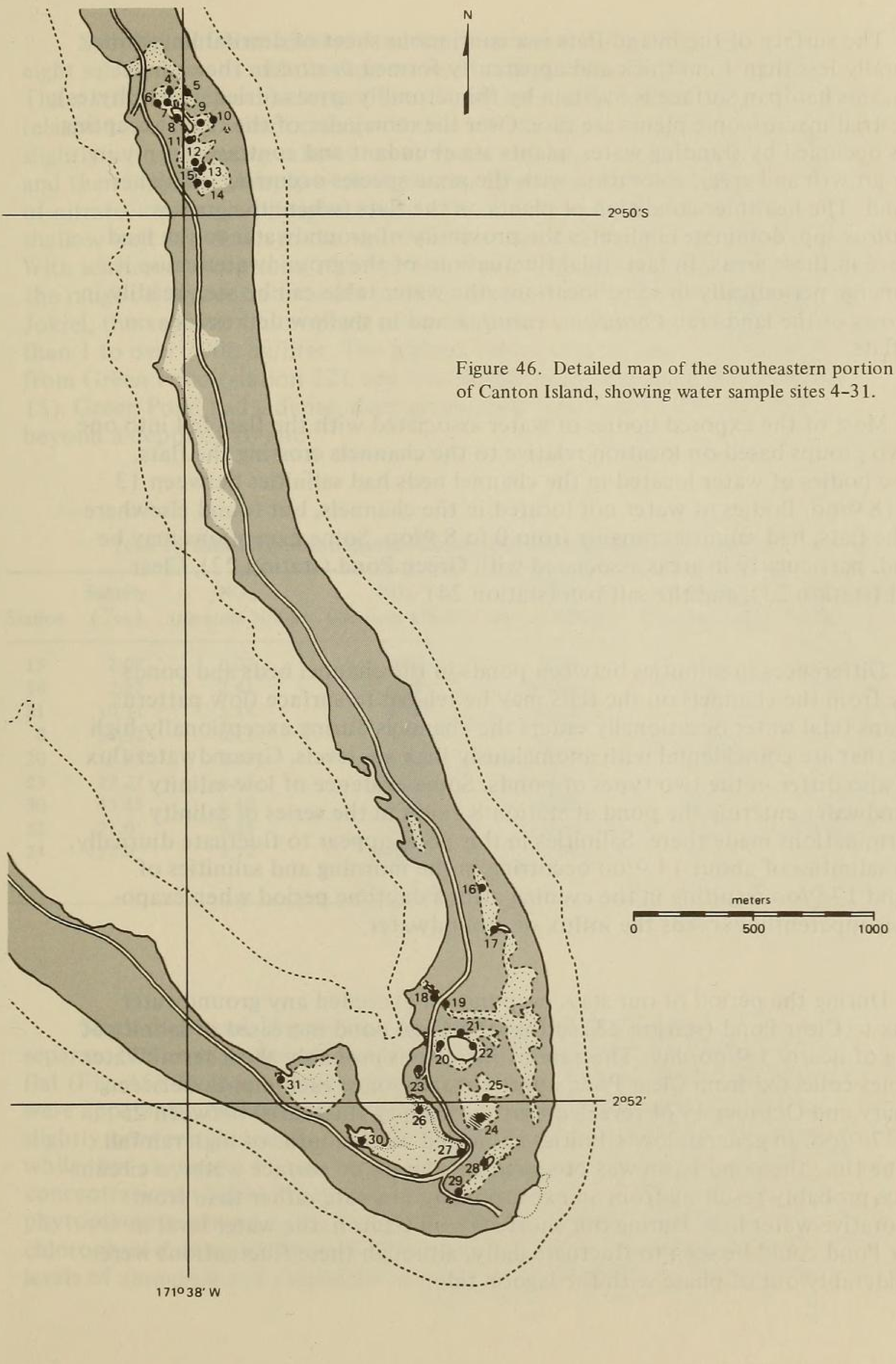

Figure 46. Detailed map of the southeastern portion of Canton Island, showing water sample sites 4–31.

The surface of the inland flats is a continuous sheet of detrital limestone, generally less than 1 cm thick and apparently formed *in situ*. In the channel beds, this hardpan surface is overlain by thin crumbly crusts (dried cyanophytes); terrestrial macroscopic plants are rare. Over the remainder of the flats, excepting areas occupied by standing water, plants are abundant and contrast sharply in their growth and green coloration with the same species occurring on higher ground. The healthier condition of plants on the flats (where the grasses *Lepturus* spp. dominate) indicates the proximity of groundwater to the land surface in these areas. In fact, tidal fluctuations of the groundwater cause it to emerge periodically in some locations; the water table can be seen readily in burrows of the land crab *Cardisoma carnifex* and in shallow depressions on the flats.

Most of the exposed bodies of water associated with the flats fall into one of two groups based on location relative to the channels crossing the flats. Those bodies of water located in the channel beds had salinities between 13 and 18 °/oo. Bodies of water not located in the channels, but found elsewhere on the flats, had salinities ranging from 0 to 8 °/oo. Some exceptions may be found, particularly in areas associated with Green Pond (station 22), Clear Pond (station 23), and the salt pan (station 24).

Differences in salinities between ponds in the channel beds and ponds away from the channels on the flats may be related to surface flow patterns. Perhaps tidal water occasionally enters the channels during exceptionally high tides that are coincidental with anomalously high sea levels. Groundwater flux may also differ in the two types of ponds. Some evidence of low-salinity groundwater entering the pond at station 8 exists in the series of salinity determinations made there. Salinities in this pond appear to fluctuate diurnally, with salinities of about 14 °/oo occurring in the morning and salinities of around 17 °/oo resulting in the evening after a daytime period when evaporation apparently exceeds the influx of groundwater.

During the period of our stay, evaporation exceeded any groundwater influx to Clear Pond (station 23) so that this large pond increased in salinity at a rate of nearly 1 °/oo/day. This rate of increase is probably short-term. Water samples collected from Clear Pond approximately once each month between January and October 1974 revealed that the salinity fluctuated between 25 and 37 °/oo. In general, low salinities coincided with months of high rainfall. At one time the pond basin was observed to contain no surface water, a circumstance probably resulting from an exceptionally low tide rather than from evaporative water loss. During our short stay on Canton, the water level in Clear Pond could be seen to fluctuate daily, although these fluctuations were considerably out of phase with the lagoon tide.

Salinity, nutrient content, and the suspended chlorophyll content of eight selected ponds and one lagoon inlet station are presented in Table 25. The stations have been arranged in order of increasing salinity. The only pattern relative to salinity which emerges is that the silicate concentration decreases slightly with increasing salinity up to approximately normal seawater salinities, and then increases sharply with increasing hypersalinity. The highest levels of nitrate, ammonia, phosphate, and silicate were found at station 24, a shallow well dug down to the water table at the bottom of a natural salt pan. With scattered exceptions, nutrient levels in all the ponds sampled were within the range of concentrations observed in the Canton Atoll lagoon (Smith and Jokiel, this report). Chlorophyll *a* concentrations varied over a range from less than 1 to over 3000 μg/liter. The highest values were in two samples obtained from Green Pond (station 22), and one sample from the crater pond (station 15). Green Pond had a dense, deep green color which obscured visibility beyond a depth of 10 cm.

Table 25. Salinity, nutrients, and chlorophyll *a* levels of selected ponds at Canton.

Station	Salinity (‰)	NO_3 (μg-atom N/liter	NH_4 (μg-atom N/liter)	PO_4 (μg-atom P/liter)	SiO_3 (μg-atom Si/liter)	Chlorophyll *a* (μg/liter)
15	2.02	0.02	0.62	0.30	12.6	239.0
14	2.22	2.41	0.09	0.03	3.2	0.58
21	10.31	5.14	4.70	0.62	2.75	–
8	17.52	0.11	1.33	0.87	2.3	2.89
20	18.95	0.31	1.23	2.21	2.2	4.82
23	29.27	6.65	0.83	0.11	2.1	3.65
30	43.42	0.10	0.51	0.18	2.3	0.98
22	71.0	0.25	0.97	0.45	10.4	3270,2740
24	152.0	2.52	360.0	22.88	23.6	–

Stations 14 and 15 present a particularly curious situation. These two separate bodies of water are located within 5 m of each other on the flat (Fig. 45). Each is a small crater about 1 m across and 0.5 m deep; both were apparently formed by ordnance explosions. Salinity differed only slightly between the ponds in December, but water at station 14 was clear, while that at station 15 was bright green. A comparison of chlorophyll *a* concentrations (Table 25) reveals the magnitude of the difference in phytoplankton abundances. The pond at station 14, with the lowest chlorophyll *a* concentration of all samples taken, showed relatively low levels of ammonia and phosphate, but moderately high concentrations of nitrate. The nutrient concentrations at station 15 were reversed, with moderate levels of both ammonia and phosphate and low levels of nitrate. Silicate concentration was very high at station 15 and consequently did not fit the salinity-to-silicate relationship apparent in the other samples.

The general distribution of chemical nutrients in the aquifer cannot be determined from the data collected. Samples for the analyses reported were taken from open bodies of water in all but one case (station 24), and biological activity in the ponds certainly alters the dissolved nutrient concentrations in the adjacent groundwater as this water enters the ponds. Seepage into Green Pond from the base of a limestone escarpment (station 21) provides some indication of chemical nutrient levels in groundwater having a salinity of 10 $^{o}/oo$. Of the dissolved substances measured, only the concentration of silicate is increased by evaporation in the receiving body. However, even in the case of silicate, additional mechanisms must be considered to explain a four-fold increase in silicate with a seven-fold increase in salinity.

The wide variation in nutrient and chlorophyll *a* concentrations from pond to pond suggests that the ponds are ecologically dissimilar. To some extent this dissimilarity would follow from the wide range of salinities encountered. On the other hand, ponds with similar salinities differed appreciably in properties closely tied to biological processes. In at least one comparison (stations 14 and 15) differences in the chemistry of input waters are unlikely, and random introductions of specific phytoplankters or herbivores may serve to explain differences in phytoplankton standing crop as measured by chlorophyll concentration. However, standing bodies of water appearing to be chemically similar at the time of this survey may have recently been dissimilar; random colonizations would then be significant in determining biological community composition. Insufficient time may have elapsed for all potential colonizers to have reached all habitable environments.

REFERENCES

Cox, D. C. 1951. The hydrology of Arno Atoll, Marshall Islands. Atoll Research Bulletin. 8, 29 pp.

Guinther, E. B. 1971. Ecologic observations on an estuarine environment at Fanning Atoll. Pac. Sci. **25**:249–259.

Stoddart, D. R., and J. D. Taylor. 1971. Geography and ecology of Diego Garcia Atoll, Chagos Archipelago. Atoll Research Bulletin. **149**, 237 pp.

Wyrtki, K. 1973. Teleconnections in the equatorial Pacific Ocean. Science. **180**: 66–68.