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1. Environmental Background of the Habitat of *Nautilus* off the Southeast Coast of Viti Levu, Fiji

by

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The two areas studied by the present project are off the southeast coast of Viti Levu, the largest island in Fiji (Fig. 1). Viti Levu is surrounded by rather shallow seas with many small islands except for its southeastern and southwestern corners facing rapidly deepening waters down to more than 1000 m. In the southwest of Viti Levu, there is no off-shore island, while in the southeast there is rather large island (Kandavu) about 80 km off Viti Levu across a deep channel (Kandavu Passage).

Submarine Topography

Among the two areas studied, the one off Suva has a barrier reef interrupted by a few narrow passage, of which outside shows a steep slope (5°-9°) from the shore line directly to the deep

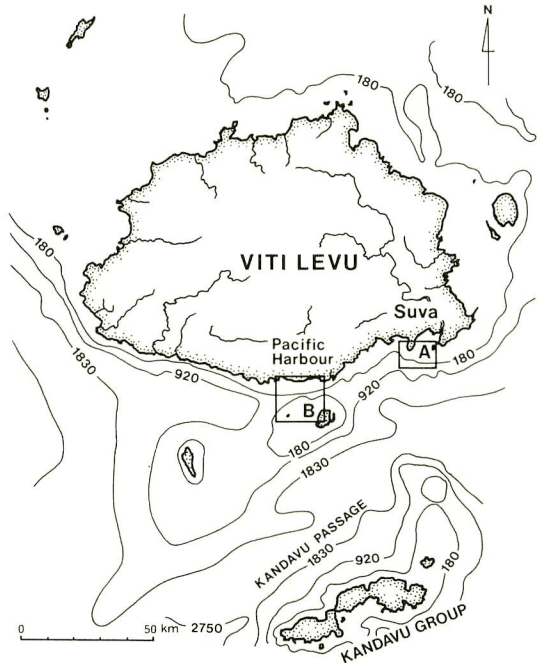

Fig. 1. Index map, with submarine topography, showing locations of the studied areas (A and B). Contours are in meters below sea level.

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bottom more than 1000 m. In this area, the writers engaged in topographic survey as well as oceanographic works on sea water (Fig. 2). Sounding was carried out by the echo-sounder and positioning was by the radar installed on the research ship "Aphareus" owned by IMR*). The lines of surveying were determined to make a few profiles of steep slope perpendicular to the coast-line and a few profiles parallel to the coast-line as well. The former profiles are shown in Fig. 3 and the latter in Fig. 4, and both of them are presented in Fig. 5 as a panel diagram. As shown in Figs. 3 and 5, each of the three profiles among the four perpendicular to the coast-line shows a small-scale step- or valley-like topography at different depths on the way down. These should not be regarded as the topography related to erosion caused by sea-level changes for their discontinuity and difference in depth. The four profiles (Fig. 4) parallel or oblique to the coast-line show irregular topography of various extents. Continuity of valley topography may be assumed between the two profiles parallel with each other (e. g. h'-e' and f'-g', d'-e' and e'-i') (Fig. 5). The extreme irregularity of submarine topography in the direction parallel with the coast-line are judged to have been controlled by the varieties of coral reef formation in different localities, as visually observed by near-shore scuba diving. In relation to the submarine topography, it is interesting that the stations with the best records of *Nautilus* capture (SV-11, SV-12, SV-13, SV-14) are concentrated around the step-like topography (i' in Figs. 3～5) on the profile c-d.

In contrast to the area mentioned above, the studied area off Pacific Harbour is a narrow (about 2 km) passage (Mbengga Passage) between the barrier reefs along the coast of Viti Levu and surrounding Mbengga Island (Fig. 6). Although the writers were not able to carry out the

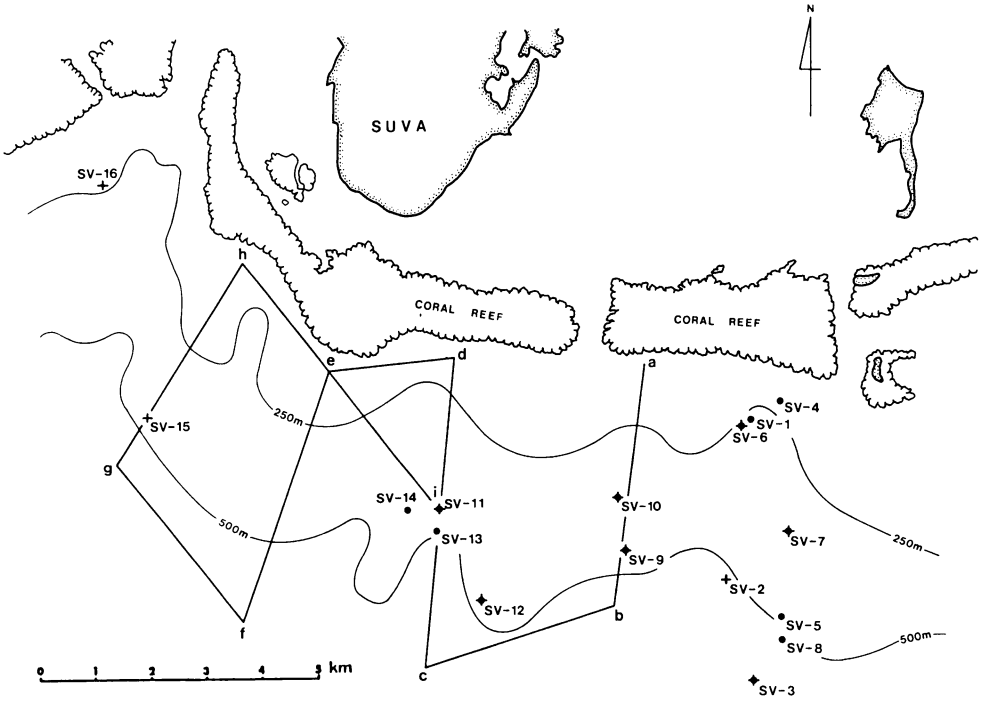

Fig. 2. Map of the area off Suva (A in Fig. 1), showing lines of echosounding, stations for oceanographic observation (+) and for sampling of bottom sediments (●).

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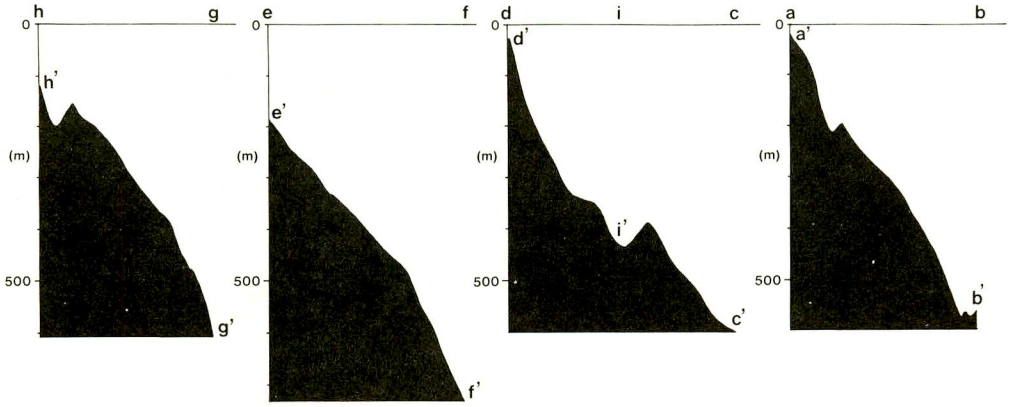

Fig. 3. Bathymetric cross sections of the area off Suva (A in Fig. 1) along the lines perpendicular to the coast-line. Lines of cross sections are shown in Fig. 2.

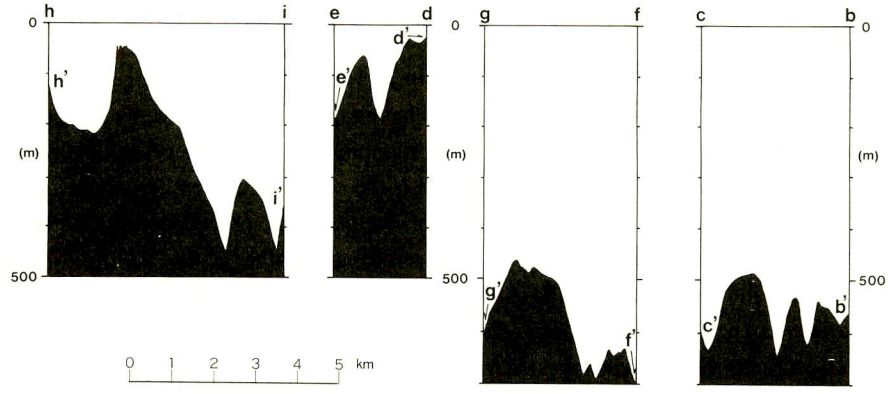

Fig. 4. Bathymetric cross sections of the area off Suva (A in Fig. 1) along the lines parallel to the coast-line. Lines of cross sections are shown in Fig. 2.

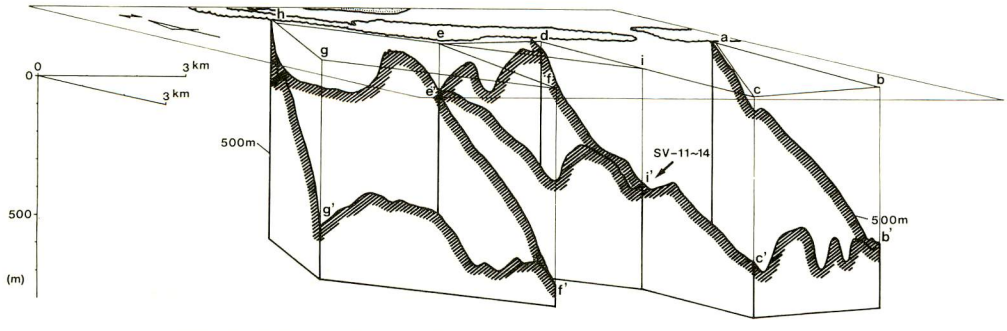

Fig. 5. Panel diagram showing submarine topographic features of the area off Suva Fig. 1).

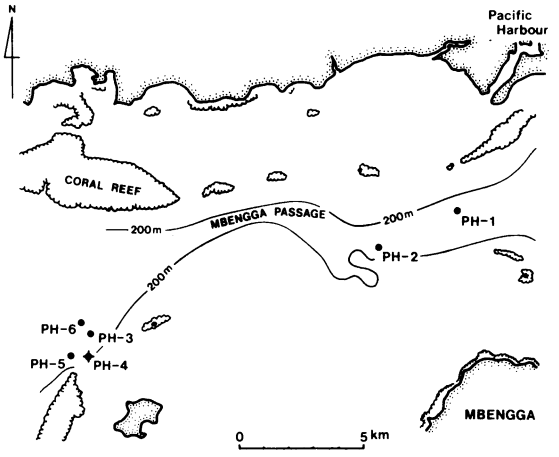

Fig. 6. Map of the area off Pacific Harbour (B in Fig. 1), showing stations for oceanographic observation (+) and sampling of bottom sediments (●).

detailed profiling of the submarine topography in this area, the following general features are known from the chart. The slopes of barrier reefs facing the passage are steeply descending to the bottom of passage (about 220 m). The bottom topography of the passage is almost flat and about 260 m in depth. Such a topographic feature suggests the occurrence of rather strong tidal or long shore currents in the present area. The trappings of *Nautilus* were practiced at the stations located close to the barrier reef around Mbengga Island resulting in rather good catch of *Nautilus*.

As pointed out by HAMADA (1977), the occurrence of shallow shelf sea acts as a kind of zoogeographic barrier for the geographic distribution of *Nautilus pompilius*. Through the writers' field works on the three different types of *Nautilus* habitat, namely, the almost closed strait in the Philippines (HAYASAKA *et al.*, 1982; HAYASAKA *ed.*, 1983), the open sea and the short passage in Fiji (the present study), the writers recognized a peculiar topographic feature being common to each other. That is, the habitat of rich population of *Nautilus* is, without exception, on the steep slope or on the bottom just below the steep slope. This means the geographic approximation of deep and shallow bottoms and may provide some clue for understanding the life cycle of *Nautilus*.

Bottom Sediments

The property of bottom sediments seems to be one of the important factors controlling the distribution of *Nautilus* directly or indirectly. The grain size analysis of the bottom sediments collected from the studied areas was carried out to know the relation between the distribution of *Nautilus* and the substratum for their life.

To collect 23 samples of bottom sediments, two small dredges were used connected to both ends of a set of five to seven traps. In Table 1, the samples collected by the dredges heaved up together with the first and the last traps are indicated by the letters F and L, respectively, annexed to the station numbers.

Table 1. Grain size measurements of bottom sediments from the areas off Suva (SV) and off Pacific Harbour (PH).

Station	Depth (m)	Gravel	Sand	Silt	Clay	Md ϕ	So ϕ	Sk ϕ
SV- 1F	275	0.0	5.6	82.3	12.3	6.28	1.0	0.34
SV- 1L	275	0.0	7.5	78.9	13.7	6.41	1.2	0.19
SV- 3F	640	0.0	12.5	82.2	5.3	5.93	1.2	0.26
SV- 4F	180	0.0	7.5	86.5	5.9	6.15	1.0	0.24
SV- 5L	460	0.0	9.5	83.4	7.1	5.89	1.0	0.38
SV- 6L	240	0.0	5.9	83.4	10.7	6.34	1.1	0.19
SV- 7F	365	0.0	4.3	88.4	7.3	5.74	1.1	0.52
SV- 7L	365	0.0	2.2	89.5	8.3	6.33	1.0	0.21
SV- 8F	550	0.0	5.1	88.8	6.1	5.72	1.0	0.47
SV- 9F	460	0.0	29.3	65.6	5.3	5.18	2.2	-0.21
SV-10F	330	0.0	7.0	87.0	6.0	5.58	0.9	0.58
SV-10L	330	0.0	3.1	90.5	6.4	5.97	1.2	0.39
SV-11F	420	0.0	3.2	86.0	10.9	6.39	1.2	0.12
SV-11L	420	0.0	35.9	62.6	1.4	5.43	2.1	-0.33
SV-12F	460	0.0	11.0	85.1	4.0	6.2	0.9	0.13
SV-13F	420	0.0	13.0	80.4	6.4	5.93	1.3	0.22
SV-14F	385	0.0	5.5	89.9	4.6	6.41	0.9	0.07
PH-1L	330	0.0	42.4	55.2	2.4	5.21	2.4	-0.40
PH-2L	255	0.0	40.7	55.8	3.4	5.19	2.6	-0.53
PH-3F	460	0.0	2.3	85.1	12.7	6.32	1.1	0.25
PH-4F	385	0.0	21.9	74.5	3.6	5.57	1.7	-0.27
PH-5F	420	0.0	13.3	81.5	5.2	5.89	1.0	0.29
PH-6L	465	0.0	2.2	89.6	8.1	5.86	1.2	0.43

All samples were preserved in buffered formalin (5 %) and a small part near the surface of each sample was stained with Rose Bengal for discrimination of living foraminifera. All the samples brought back to Japan were analyzed by the Emery settling-tube method and by making use of the automatic grain size analyzer (Nichiei-denki Co.) to determine the relative proportions of gravel, sand, silt and clay (Fig. 7). Based on these data, the textural relations among sediments are indicated on the SHEPARD's triangle (Fig. 8). Median diameter (Md), sorting coefficient (So) and skewness (Sk) were obtained graphically from the cumulative curve (INMAN, 1952).

As the result of mechanical analysis, the following points were made clear.

(1) The median diameters of bottom sediments collected from all the stations deeper than 180 m fall within a narrow range from 5.18 to 6.41 (Mean : 5.19, Standard deviation : 0.40). This suggests that both areas deeper than 180 m off Suva and off Pacific Harbour are under the condition of silt deposition irrespective of water depth and topography.

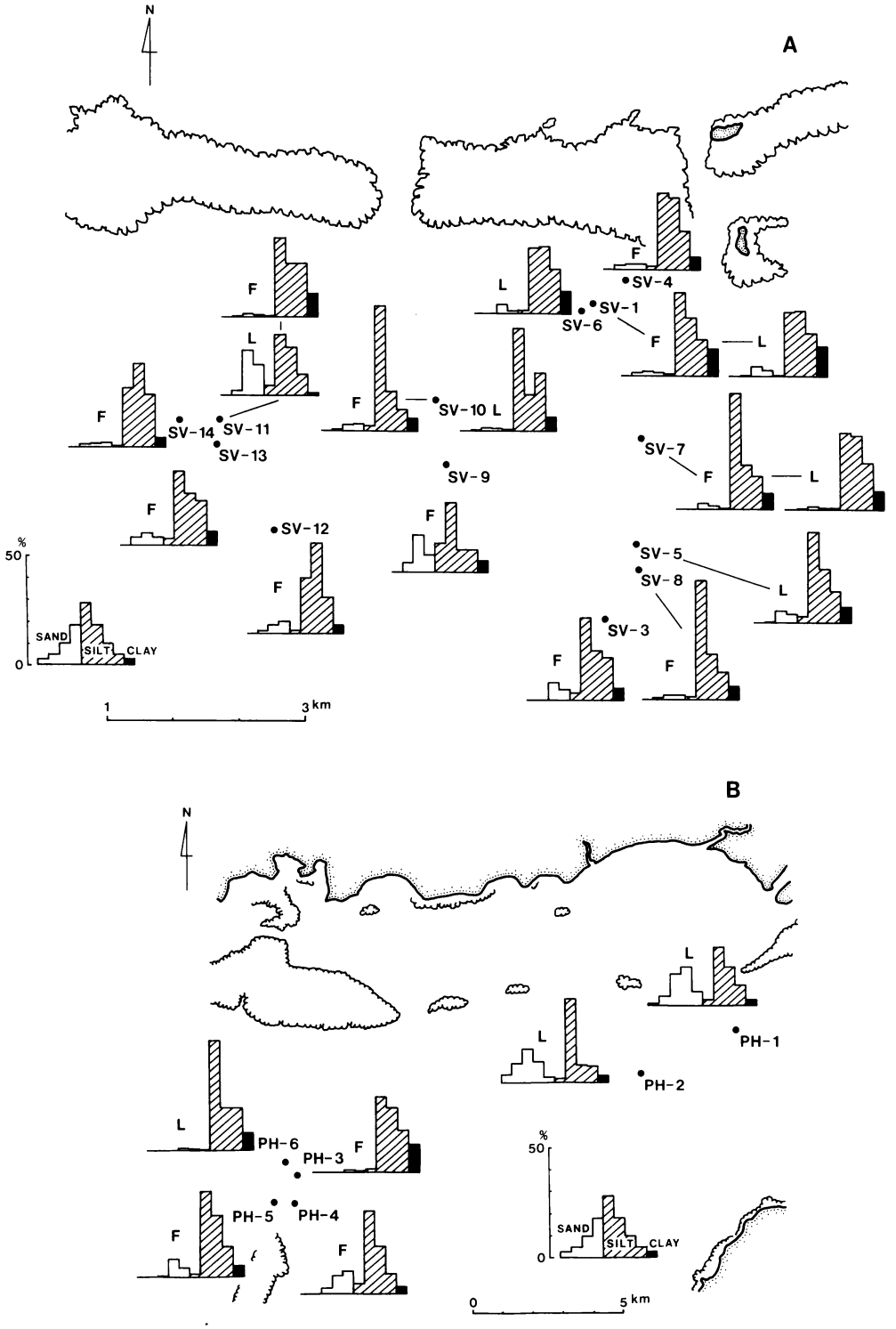

Fig. 7. Grain size ratios of bottom sediments at each station in the areas off Suva (A) and off Pacific Harbour (B).

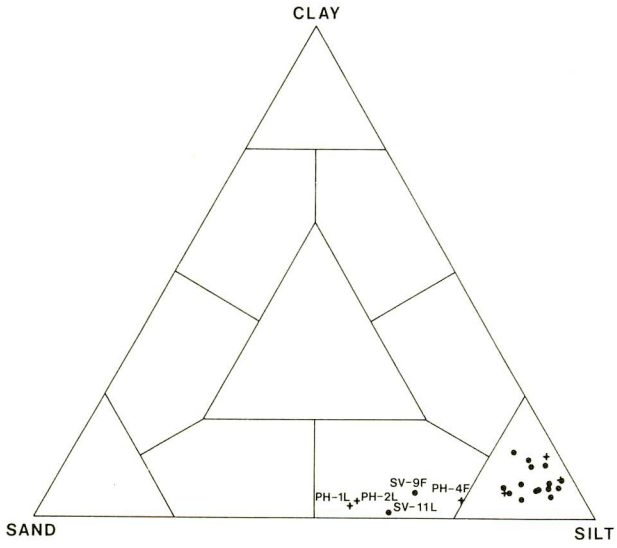

Fig. 8. Textural relations between the samples of sediments indicated on the SHEPARD's triangle. (● : stations off Suva, + : stations off Pacific Harbour)

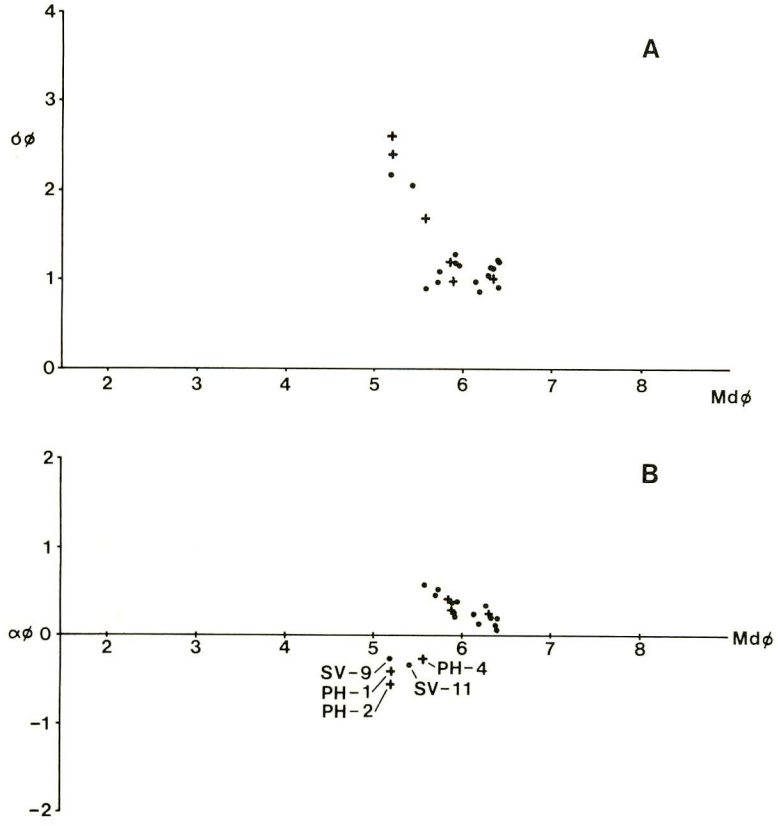

Fig. 9. Relations of grain size to sorting (A) and to skewness (B) of the bottom sediments. (● : stations off Suva, + : stations off Pacific Harbour)

Table 2. Carbonates contents dissolved with a solution of hydrochloric acid from 13 samples of bottom sediments off Suva (SV) and 6 samples off Pacific Harbour (PH).

Station No.	Depth (m)	Carbonates Content (wt %)
SV- 1	275	10.36
SV- 3	640	7.38
SV- 4	180	20.09
SV- 5	460	2.56
SV- 6	240	20.54
SV- 7	365	5.42
SV- 8	550	17.22
SV- 9	460	14.57
SV-10	330	8.60
SV-11	420	16.54
SV-12	460	12.73
SV-13	420	14.74
SV-14	385	32.50
PH- 1	330	19.42
PH- 2	255	1.69
PH- 3	460	4.72
PH- 4	385	35.49
PH- 5	420	7.06
PH- 6	465	15.57

(2) The samples of bottom sediments treated in the present article are divided into two groups, namely, (a) the group of samples collect from the two stations off Suva (SV-9F and SV-11L) and from the three stations off Pacific Harbour (PH-1L, PH-2L and PH-4F) all of which represent sandy silt, and (b) the group of samples collected from all of the other stations, of which textures fall within the category of silt. The five samples of the first group (sandy silt) are rather ill-sorted (So = 1.7-2.6) and show bimodal grain size distribution with the peaks around 6 ϕ and 3 ϕ and negative skewnesses (Fig. 9). Judging from the fact that median diameters of these samples have little difference from those of the other samples in spite of negative skewnesses, the peak around 3 ϕ recognized in the grain size distribution of these bottom sediments seems to imply that the sediments were supplied to the site of deposition not by the ordinary bottom current but by some accidental power of transportation, e. g. submarine sliding originated from the shallower bottom. This may be endorsed by the fact that the tests of benthonic foraminifera inhabiting shallower bottom are abundantly comprised in these sediments.

(3) Carbonates dissolved from the 19 bottom samples with a solution of hydrochloric acid are shown in Table 2. Dissolved carbonate values show considerable variation from place to place between 1.69 and 35.49 % (Mean ; 14.06, Standard deviation ; 8.92) irrespective of water depth. This is judged to be caused by the differential rate of deposition of calcareous organic skeletons such as foraminifera controlled by the relief of bottom topography.

Sea Water Characteristics

To obtain the basic informations on the sea water characteristics, the oceanographic observation was carried out during the period of field works late in August and early in September, 1983 at the ten stations off Suva and one station off Pacific Harbour, Viti Levu, Fiji as shown in Figs. 2 and 3. At each station, water samples were collected by a bucket from the surface and by two Nansen bottles from the depths of 10, 20, 30, 50, 75, 100, 200, 300, 400, 500 and 600 meters. Sea water temperature, salinity and dissolved oxygen (DO) were measured on each water sample on the boat. Sampling of plankton by the Marukawa plankton-net (30 cm in diameter, 0.092 mm × 0.092 mm mesh) from the water between 30 m and 0 m in depth were also carried out at each station.

As seen in the table of oceanographic data (Table 3), changes in water temperature with depth is rather gradual without any conspicuous change (thermocline) at every station. Generally, the sea water temperature is constant (about 25°C) from the surface to about 100 m in depth, and rather rapidly lowers from 100 m to 400 m in depth (about 12°C). The temperature of waters deeper than 400 m seems to change gradually and at the depth of 600 m it is about 7.40°C. With regard to the vertical distribution of water temperature at the Stn. SV-3 (Fig. 10), the following interpretation may be possible. Namely, the uppermost layer from the surface (25.3°C) to 100 m depth (24.4°C) is regarded to be the surface-mixed warm water. And rather rapid change in temperature between 100 and 400 m in depth may be regarded as an indistinct thermocline.

The pattern of the salinity distribution in the studied area is represented by the record of the Stn. SV-3 (Fig. 11). The sea water salinity in this area is rather constant from the surface (about 34.30 ‰) to about 100 m depth (34.38 ‰) and gradually decreases from 100 m to deeper layer. The surface-mixed isohaline water of the uppermost layer (0-100 m) corresponds to the surface-mixed warm water in the temperature distribution mentioned above.

Dissolved oxygen (DO) is nearly constant and slightly decreases with depth (Fig. 10). Its maximum value was usually observed at the depths between the surface and 30 m. This may indicate the existence of a maximum layer of phytoplankton producing plenty of oxygen around this layer.

In the profile of water temperature from the coast offshore (Fig. 12) compiled from the data at the four Stations, SV-6, SV-7, SV-5 and SV-3 with the aid of the data in chart, the water temperature in the depths between 240 m and 550 m from where *Nautilus* specimens were collected is judged to be 20°~8°C.

References

HAMADA, T., 1977 : Distribution and some ecological barriers on the habitat condition of

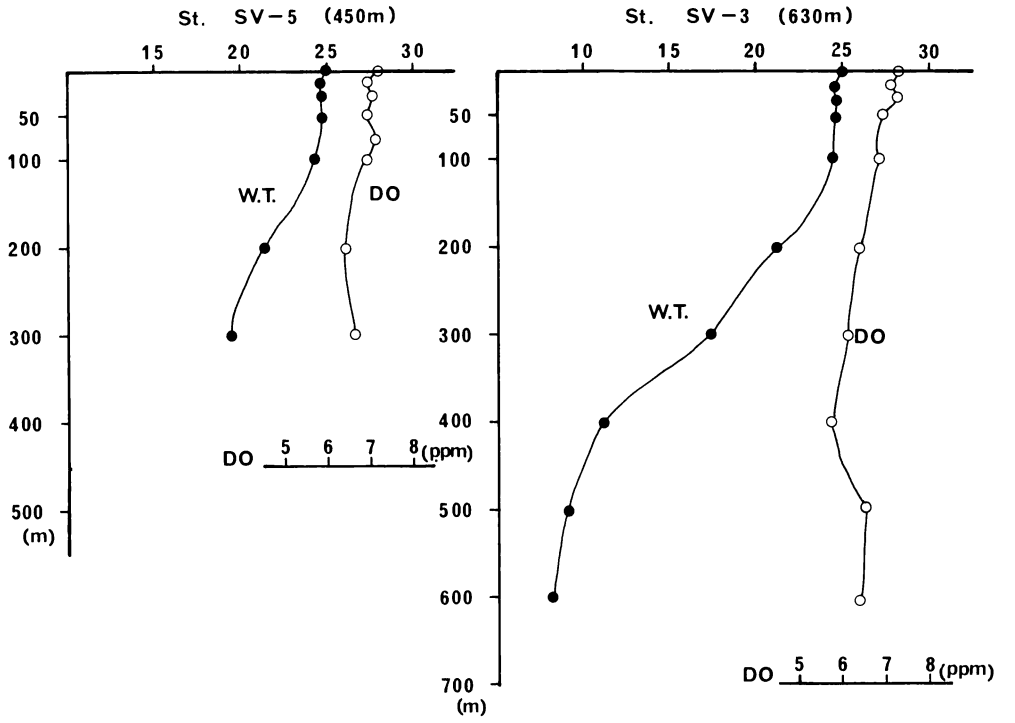

Fig. 10. Vertical distribution of water temperature and dissolved oxygen at the Stations SV-3 and SV-5.

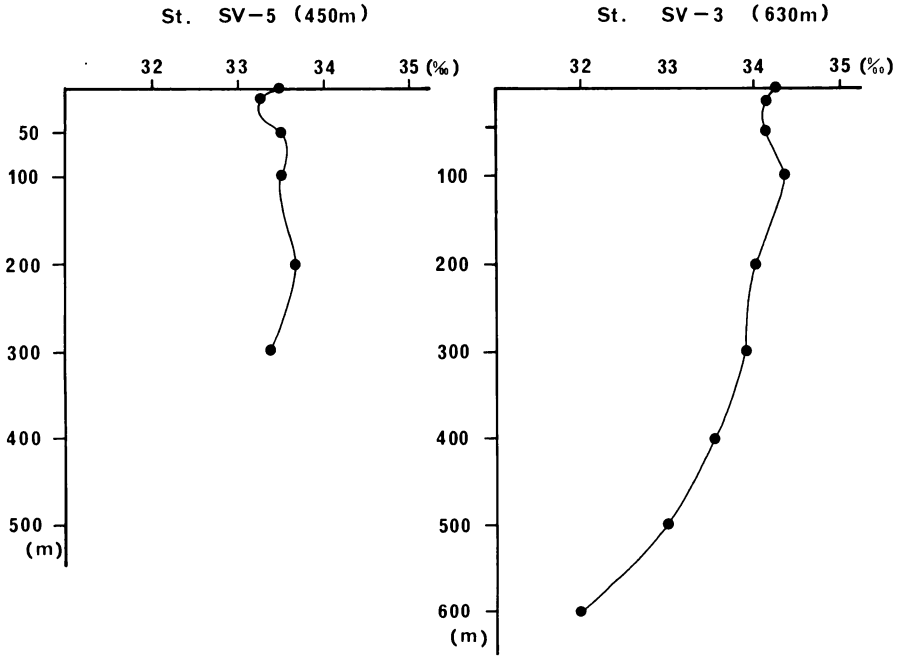

Fig. 11. Vertical distribution of water salinity at the Stations SV-3 and SV-5.

Table 3. Oceanographic data in the areas off Suva (SV) and off Pacific Harbour (PH).

St. SV-3
Date Sep. 16, 1983 Lat. 18°14'19"S
Time 9 : 40-13 : 00 Long. 178°30'05"E
Ship Nautilus Depth 640 m

Depth (m)	Temp. (°C)	Salinity (‰)	DO (ppm)
0	25.30	34.29	7.3
10	24.96	34.31	7.3
20	24.90	34.21	7.2
30	24.92	34.24	7.1
50	24.87	34.18	7.1
75	24.85	34.26	7.0
100	24.40	34.38	6.9
200	21.79	34.02	6.4
300	17.50	33.87	6.2
400	12.23	33.60	5.7
500	8.65	33.01	6.7
600	7.41	32.03	6.5

St. SV-6
Date Sep. 14, 1983 Lat. 18°11'46"S
Time 10 : 33-11 : 30 Long. 178°29'54"E
Ship Nautilus Depth 240 m

Depth (m)	Temp. (°C)	Salinity (‰)	DO (ppm)
0	25.04	33.51	6.9
10	24.90	33.82	7.1
20	24.82	33.93	6.9
30	24.78	33.87	7.0
50	24.59	33.96	7.0
75	24.54	33.98	6.9
100	24.50	33.86	6.9
200	22.99	34.05	6.5

St. SV-9
Date Sep. 13, 1983 Lat. 18°13'00"S
Time 13 : 00-14 : 22 Long. 178°28'42"E
Ship Nautilus Depth 460 m

Depth (m)	Temp. (°C)	Salinity (‰)	DO (ppm)
0	25.21	33.78	7.3
10	24.91	34.04	7.3
20	24.91	34.08	7.4
30	24.74	33.83	7.4
50	24.59	33.83	7.3
75	24.61	34.22	6.9
100	24.56	34.02	7.1
200	21.97	34.12	6.8
300	18.40	33.87	6.8

St. SV-11
Date Sep. 13, 1983 Lat. 18°12'40"S
Time 10 : 30-12 : 30 Long. 178°26'40"E
Ship Nautilus Depth 420 m

Depth (m)	Temp. (°C)	Salinity (‰)	DO (ppm)
0	25.07	33.72	7.4
10	24.81	34.12	7.4
20	24.80	33.90	7.4
30	24.81	34.12	6.9
50	24.71	33.80	6.8
75	24.54	33.89	6.9
100	22.09	33.95	6.9
200	22.07	34.01	6.4
300	17.60	33.47	6.2

St. SV-5
Date Sep. 13, 1983 Lat. 18°13'39"S
Time 14 : 55-16 : 20 Long. 178°30'24"E
Ship Nautilus Depth 460 m

Depth (m)	Temp. (°C)	Salinity (‰)	DO (ppm)
0	25.26	33.57	7.2
10	24.70	33.73	6.9
20	24.69	33.79	7.0
30	24.69	33.82	7.3
50	24.76	33.84	6.9
75	24.46	33.88	7.2
100	24.40	34.07	7.0
200	21.31	34.08	6.4
300	18.11	33.84	6.7

St. SV-7
Date Sep. 9, 1983 Lat. 18°12'51"S
Time 11 : 30-15 : 00 Long. 178°30'28"E
Ship Aphareus Depth 365 m

Depth (m)	Temp. (°C)	Salinity (‰)	DO (ppm)
0	25.21	33.00	8.4
10	25.00	33.30	8.0
20	24.70	33.30	7.9
30	24.65	33.78	7.0
50	24.70	33.89	7.4
75	24.65	33.73	6.4
100	24.40	33.87	5.9
200	21.30	33.87	6.7
300	18.51	33.65	6.8

St. SV-10
Date Sep. 15, 1983 Lat. 18°12'30"S
Time 10 : 00-11 : 40 Long. 178°28'37"E
Ship Nautilus Depth 330 m

Depth (m)	Temp. (°C)	Salinity (‰)	DO (ppm)
0	24.90	33.72	6.7
10	24.85	33.92	6.3
20	24.83	33.72	6.7
30	24.86	33.73	6.9
50	24.85	33.76	6.9
75	24.75	33.72	6.6
100	24.55	33.65	6.7
200	22.59	33.81	6.3
250	19.80	33.79	5.8

St. SV-12
Date Sep. 16, 1983 Lat. 18°13'34"S
Time 13 : 30-15 : 26 Long. 178°27'12"E
Ship Nautilus Depth 460 m

Depth (m)	Temp. (°C)	Salinity (‰)	DO (ppm)
0	25.42	33.25	7.4
10	24.95	34.18	7.4
20	24.90	34.14	7.5
30	24.90	34.38	7.4
50	24.80	34.30	7.4
75	24.68	34.26	7.3
100	24.67	34.28	7.1
200	21.78	34.29	6.4
300	17.78	33.88	6.5
400	13.60	33.57	6.3

St. SV-15
Date Sep. 12, 1983 Lat. 18°11'42"S
Time 11 : 40-13 : 25 Long. 178°23'39"E
Ship Nautilus Depth 480 m

Depth (m)	Tem. (°C)	Salinity (‰)	DO (ppm)
0	25.03	33.41	6.8
10	25.00	33.19	6.8
20	24.92	33.40	7.4
30	24.90	33.49	7.4
50	24.76	33.61	7.3
75	24.49	33.61	7.3
100	24.50	33.51	7.0
200	21.50	33.69	6.4
250	18.90	33.36	6.2

St. SV-16
Date Sep. 12, 1983 Lat. 18°09'27"S
Time 13 : 55-15 : 00 Long. 178°23'07"E
Ship Nautilus Depth 320 m

Depth (m)	Temp. (°C)	Salinity (‰)	DO (ppm)
0	25.16	32.42	6.7
10	25.01	33.75	7.5
20	24.90	33.72	7.5
30	24.80	33.62	7.7
50	24.69	33.68	7.7
75	24.60	33.57	7.4
100	24.56	33.60	7.5
200	21.64	33.38	6.8
300	16.56	33.19	6.9

St. PH-4
Date Sep. 20, 1983 Lat. 18°20'42"S
Time 10 : 30-11 : 40 Long. 177°58'30"E
Ship Aphareus Depth 385 m

Depth (m)	Temp. (°C)	Salinity (‰)	DO (ppm)
0	25.08	34.10	7.4
20	24.96	34.00	7.3
50	24.75	34.02	7.3
100	24.45	34.11	6.9
200	21.05	34.08	6.6
300	18.18	33.65	6.7

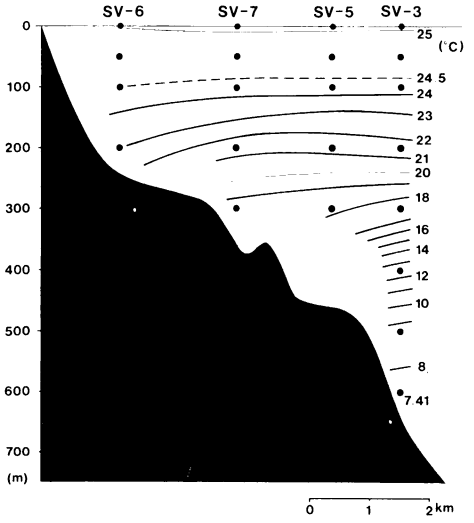

Fig. 12. Distribution of water temperature in the profile perpendicular to the coast-line off Suva.

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