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Characteristics of the water-masses of the Philippine, Kermadec and Tonga Trenches

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The *Galathea* Expedition 1950–52, Copenhagen

THE CHIEF purpose of the *Galathea* Expedition 1950–52, The Danish Deep Sea Expedition around the World, was to study the organisms in the deepest parts of the oceans. A considerable number of hydrographic observations, however, were made to learn about the environmental conditions. At least one full series from the surface to the bottom was made in each of the regions where biological work was concentrated. The hydrographic instruments were standard types. During the expedition a total number of 16 reversing thermometers were lost, six of them being simply crushed by pressure at the greater depths in the Philippine Trench.

The greatest care was taken in making observations. Even when only one thermometer was available for each water-bottle, most doubtful temperature readings were repeated. We are therefore fairly confident that our observations, including those presented here, are as exact as any made by specially equipped hydrographic expeditions.

Many technical difficulties resulted from the extreme depth of the Philippine Trench. The effect of high pressure has been mentioned. It was furthermore very difficult to keep the ship exactly above the bottom of the narrow trench, often less than one kilometre wide. We are extremely indebted to Captain S. GREVE, R.D.N. and his officers, for their untiring efforts in fulfilling our requirements. Because of these difficulties we had to repeat the deepest series in the Philippine Trench no less than 10 times, but the efforts were rewarded by 17 observations from depths exceeding 6000 m. The skill and patience of our two assistant hydrographers, Mr. INGOLF CROSSLAND and Mr. ULRIK KLÄNING, is also gratefully acknowledged.

All the observations of the *Galathea* Expedition are to be published in the scientific report of the expedition, but we think it of interest to publish our observations from the Philippine and the Tonga–Kermadec Trenches at once. The first section of the lists of observations (Table I) gives the values observed while the second section (Table II) contains average figures and graphically interpolated figures derived from the total number of reliable observations.

THE PHILIPPINE TRENCH

The temperature from the observations of the *Snellius* Expedition (VAN RIEL, HAMAKER and VAN EYCK, 1950) and the Swedish Deep-Sea Expedition (BRUNEAU, JERLOV and KOCZY, 1953) in the deep water of the trench, are plotted in Fig. 1. The agreement between these and those of the *Galathea* is obvious. The characteristics of the deep water of the trench appears to be very uniform. A minimum of 1·59° C occurs between 3500 and 4000 m. Below this, the temperature increase is very close to that to be expected from adiabatic heating alone. The salinity and amount of oxygen on the other hand are nearly constant for this same interval (Tables I and II).

Thus, it appears that any renewal of the deep water masses of the trench must be derived from that of the West Pacific Basin at the sill depth of the trench (i.e. 3·5–4

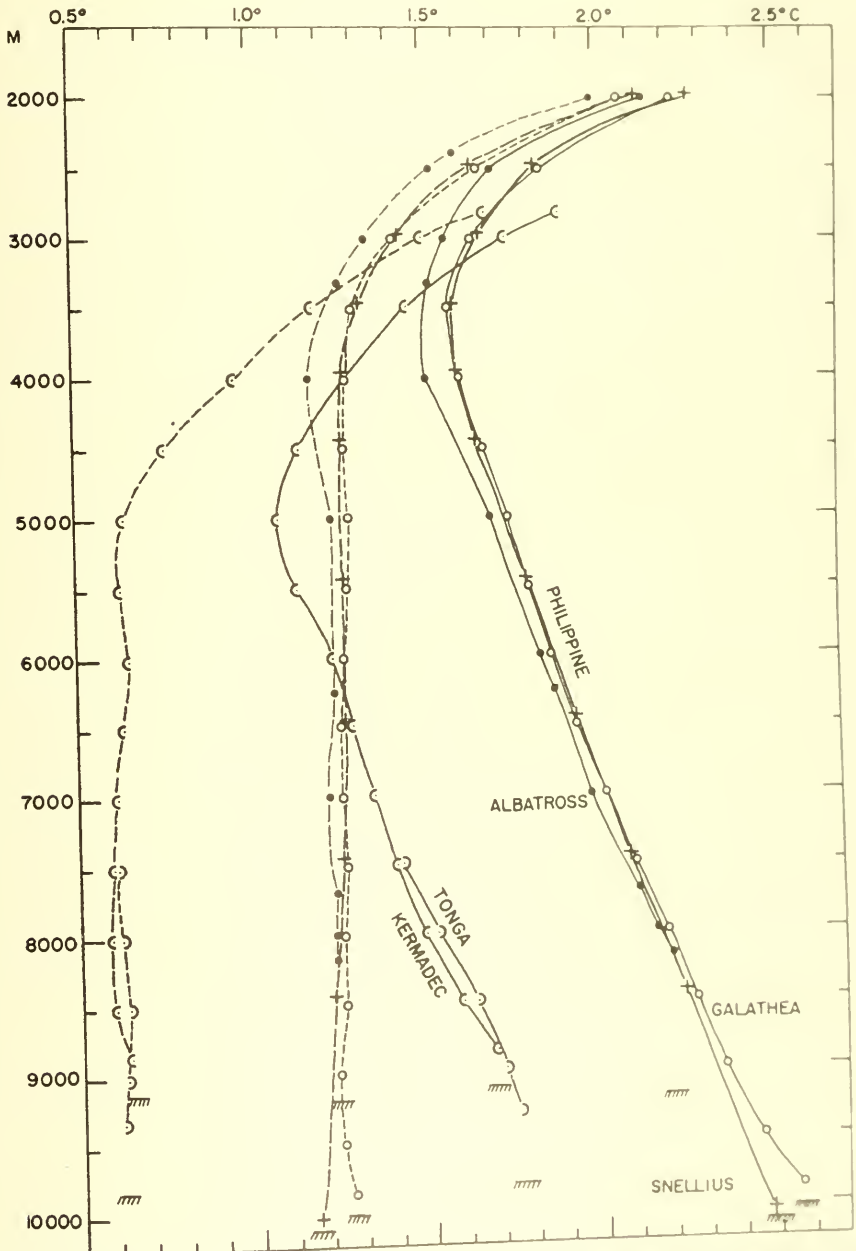

Fig. 1. Temperatures of the Philippine, Tonga, and Kermadec Trenches. Full drawn line indicates temperatures *in situ*, broken line potential temperatures. The signature below each curve denotes the depth at the position of the observations.

km) (Fig. 4). This agrees well with the general concept that the Pacific Deep Water is derived from the region south of Australia with roots in the Indian Ocean, and furthermore that there is a slow movement from south to north in the West Pacific.

The velocity of this current is probably so slow that a renewal of the bottom water in the Philippine Trench would require very many years. We know little about the abundance of the organisms in the trenches (BRUUN 1951, 1953 A, B; ZOBELL, 1952; ZENKEVITCH, BIRSCHTEIN and BELJAEV, 1954; ZENKEVITCH, 1955); but in any case they require a certain amount of oxygen. The content of oxygen is relatively high. Therefore, as an additional possibility, acting in the renewal of the trench

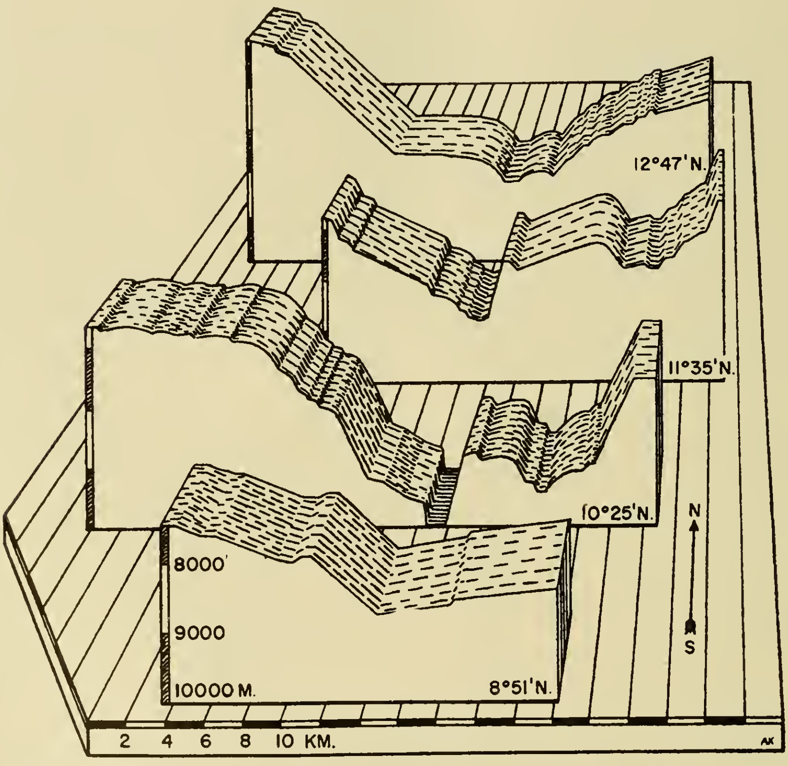

Fig. 2. Four sections of the Philippine Trench. Base line of all sections at 10000 m; distance between any two sections is a little more than 100 km (From KIILERICH, 1953).

water, turbidity currents are suggested. The deepest part of the trench (ca. 10000 m) is nowhere more than 90 km distant from the narrow coastal shelf of the Philippines (Fig. 2). Here turbidity currents can easily get started; typhoons will disturb the bottom of the shelf and add to the velocity of the strong tidal currents in the narrow straits of the islands. Eruptions of submarine volcanoes or the frequent earthquakes, which have their epicentres on the western slope (REPETTI, 1931; 199) should also be considered as the cause of bottom sediment slides. The many stones with rounded edges found by *Galathea* must have been carried down in some such way. (Fig. 3); this is also in agreement with SHEPARD (1951).

Fig. 3. Stones and gravel brought up by a sledge-trawl from the bottom of the Philippine Trench, 10190 m (From BRUUN, 1953 B)

Such currents of higher density because of suspended particles must bring relatively warm water down, which, after the settlement of the particles, must give rise to thermal convection.

THE TONGA-KERMADEC TRENCHES

The water of the greater depths of the Tonga-Kermadec Trenches differs in several ways from that of the Philippine Trench. This is to be expected from the geographical

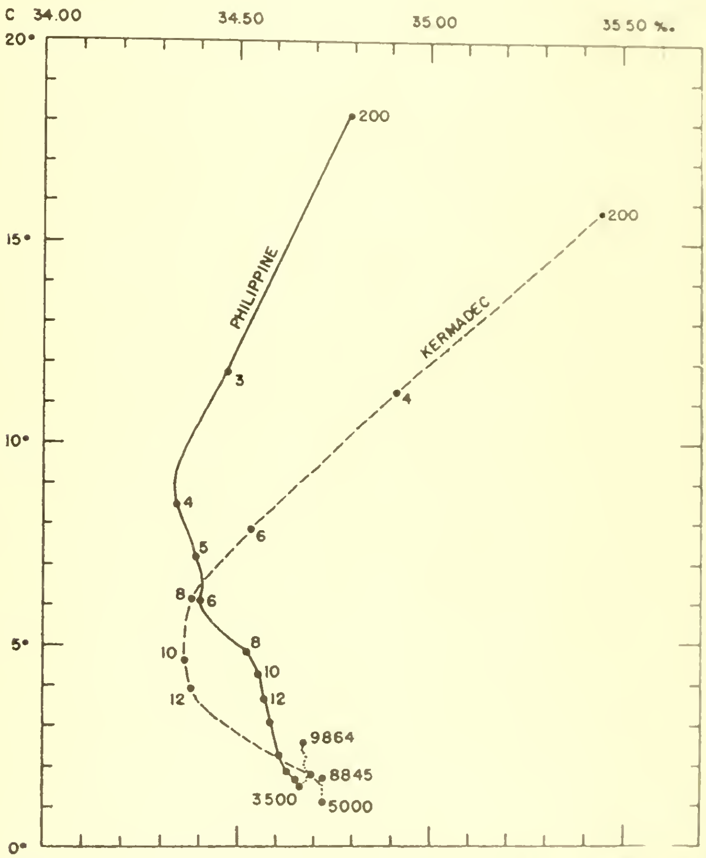

Fig. 4. T–S diagram of the water masses of the Philippine and Kermadec Trenches. Except for the uppermost and lowermost observations the figures along the curves denote hundreds of m.

position, which is much closer to the sources of the bottom water of the Pacific. This is shown by the minimum temperature, 1·07° C, at about 5000 m (see Figs. 1 and 4). Here also the increase in temperature towards the bottom closely follows what would be expected from adiabatic heating.

Galathea Station nr. 686 was taken in the Tonga Trench, 8 degrees of latitude north of the full series of observations of St. 677 in the Kermadec Trench. Lack of time prevented us from making more than three observations, but they are sufficient to prove that the deep water is essentially the same. This corroborates well the results from the echo-soundings, that the connection between these trenches is below the level of the surrounding basin. Lengthwise of the connection we found no depth shallower than 6000 m. Therefore it might even be reasonable to speak of one trench only, the Tonga-Kermadec Trench. The potential temperatures calculated are as constant as could be expected from the quality of thermometers, just as in the Philippine Trench. We want, however, to draw attention to the slight increase close to the bottom. It is only 0·04° C, but it has been recorded on four occasions with two different thermometers. This is the opposite of what was found by the *Snellius* Expedition (VAN RIEL, *et al.*, 1950, 29–30); it will be most important to have this disagreement further studied. As it is, it does not justify further comment.

Table I

Values of temperature, salinity, density and oxygen at various depths as actually observed by the Galathea

St. 412. Philippine Trench. 11° 13′ N. 126° 21′ E. 12–13/7 1951

Depth 8981–8956 *m*

m	*C°*	*S°/₀₀*	σ_t	O_2 *ml/L*
0	29·60	34·20	21·46	—
24	·15	·15	·41	4·38
47	·00	·28	·54	·41
71	28·70	·43	·76	·36
94	·38	·58	·97	·50
142	23·42	35·00	23·83	3·94
189	18·78	34·83	24·98	·55
283	12·44	·49	26·13	2·71
378	8·94	·33	·65	·10
472	7·55	·39	·92	1·62
567	6·40	·39	27·07	·67
756	5·00	·51	·34	·80
945	4·45	·55	·43	2·17
1133	3·77	·56	·50	·06
1417	·26	·58	·57	·20
1890	2·33	·60	·67	·39
2362	1·93	·62	·71	·66
2835	·72	·64	·74	·96
3307	·59	·66	·76	3·38
3779	·59	—	—	—
4252	·63	·67	·77	·08
4724	·71	·68	·77	·32
5669	·81	·68	·76	2·92
6755	·95	·66	·74	·26
7700	—	·66	—	3·13
8076	2·22	·68	·73	·22
8503	—	·66	—	·06

St. 430. Philippine Trench. 10° 20′ N. 126° 37′ E. 3–4/8 1951

Depth 10110 *m*

m	*C°*	*S°/₀₀*	σ_t	O_2 *ml/L*
945	4·82 (*a*)	34·51	27·36	1·16
1606	2·99	·58	·59	·62
2079	·16	·61	·69	·92
7640	·12	—	—	—

St. 431. Philippine Trench. 10° 21′ N. 126° 38′ E. 4–5/8 1951

Depth 10110 *m*

m	*C*	*S*	σ_t	O_2 *ml l*
7558	2·01 (*a*)	34·69	27·75	3·04
8503	·27	·69	·73	·11
9165	·35	·67	·72	2·88
9636	·50	·67	·71	3·27

St. 433. Philippine Trench. 9° 51′ N. 126° 51′ E. 5–6/8 1951

Depth 10003 *m*

m	*C*	*S*	σ_t	O_2 *ml l*
3779	1·57	34·67	27·77	3·27
4252	·57 (*a*)	·69	·78	·15
4724	·70	·67	·77	·11
5669	·80	·69	·77	·12
6614	·95	·69	·76	·36
7511	·97 (*a*)	·68	·75	·20
8456	2·18	·66	·72	·16
9498	·28 (*a*)	·66	·71	2·93
9589	·47	·69	·72	3·31

(*a*) Thermometer not absolutely reliable.

St. 440. Philippine Trench. 10° 25′ N. 126° 40′ E. 14/8 1951

Depth 10016 *m*

m	*C°*	*S*	σ_t	O_2 *ml L*
3068	1·61	34·65	27·75	2·92
5900	·83	·67	·75	3·01
7788	2·13	·68	·74	2·90
9770	·56	·67	·70	3·19
9864	·55	·67	·70	·11

St. 677. Kermadec Trench. 28° 38′ S. 175° 53′ W. 4–5/3 1952

Depth 9127–9192 *m*

m	*C°*	*S* ‰	σ_t	O_2 *ml L*
0	24·02	35·64	24·14	—
47	*C* 22·	·58	·68	5·15
94	17·92	·55	25·74	·02
182	16·08	·46	26·10	4·55
376	11·77	34·97	·63	·35
564	8·25	·58	·93	·61
766	6·42	·39	27·03	·97
956	5·13	·37	·18	·50
1145	4·07	·37	·30	·16
2822	1·89	·68	·74	3·37
3762	·34	·72	·83	4·44
4232	·19	·72	·83	·52
4723	·09	·72	·84	·58
5194	·07	·72	·84	·48
5665	·16	·70	·83	·56
6496	·27	·72	·82	·62
7905	·46	·70	·81	·60
8845	·68	·72	·81	·56

St. 686. Tonga Trench. 20° 53′ S. 173° 51′ W. 11/3 1952

Depth 9818 m				
m	*C°*	*S°/oo*	σ_t	O_2 *ml/L*
7428	1·40	34·71	27·81	4·52
8373	·60	·71	·80	·46
9318	·74	·71	·79	·48

Table II

Average values of temperature, salinity, density and oxygen at standard depths as derived from interpolation on graphs and based on the total number of reliable observations

Philippine Trench. Interpolation referred to standard depths; based on all *Galathea* observations

m	*C°*	*S°/oo*	σ_t	O_2 *ml/L*	*potential temp.*
0	29·40	34·20	21·46	—	
25	·14	·15	·40	4·4	
50	28·97	·30	·57	·4	
75	·65	·46	·79	·4	
100	·10	·63	22·11	·5	
150	22·65	·99	24·04	3·9	
200	18·15	·79	25·09	·5	
300	11·75	·47	26·24	2·7	
400	8·50	·34	·74	·0	
500	7·12	·39	·98	1·6	
600	6·05	·40	27·12	·7	
800	4·86	·52	·36	·9	
1000	·22	·55	·46	2·1	
1200	3·62	·57	·53	·1	
1500	·05	·59	·59	·2	
2000	2·22	·61	·68	·4	2·07
2500	1·84	·63	·72	·6	1·66
3000	·64	·65	·75	·9	·41
3500	·57	·67	·77	3·3	·29
4000	·60	·67	·77	·2	·27
4500	·66	·68	·77	·1	·26
5000	·73	·68	·77	·1	·27
5500	·79	·69	·76	·0	·26
6000	·85	·69	·76	·0	·25
6500	·92	·68	·75	·0	·24
7000	2·00	·68	·75	2·3	·24
7500	·09	·67	·74	3·0	·25
8000	·18	·68	·73	·0	·24
8500	·26	·68	·73	1·1	·24
9000	·34	·67	·72	·0	·22
9500	·45	·67	·71	2·9	·23
9864	·56	·67	·70	3·1	·26

St. 677. Kermadec Trench. Interpolation referred to standard depths. 28° 38′ S. 175 53′ W. 4 5/3 1952

m	C°	S‰	σ_t	O_2 ml/L	potential temp.
0	24·02	35·64	24·14	—	
50	C 22·	·58	·68	5·2	
100	17·80	·54	25·76	·0	
200	15·75	·44	26·16	4·5	
400	11·30	34·91	·68	·4	
600	7·90	·53	·98	·6	
800	6·15	·38	27·10	5·0	
1000	4·65	·36	·25	4·4	
1200	3·95	·38	·34	·1	
3000	1·74	·69	·77	3·5	1·51
3500	·45	·72	·82	4·3	·18
4000	·27	·72	·83	·5	0·95
4500	·13	·72	·84	·5	0·75
5000	·07	·72	·84	·5	0·63
5500	·12	·72	·84	·5	0·62
6000	·22	·72	·83	·6	0·64
6500	·27	·72	·83	·6	0·62
7000	·33	·72	·83	·6	0·60
7500	·40	·72	·82	·6	0·59
8000	·48	·72	·82	·6	0·58
8500	·58	·72	·81	·6	0·59
8845	·68	·72	·81	·6	0·63

St. 686. Tonga Trench. Interpolation referred to standard depths. 20° 53′ S. 173° 51′ W. 11/3 1952

m	C°	S‰	σ_t	O_2 ml/L	potential temp.
7500	1·41	34·71	27·81	4·5	0·60
8000	·51	·71	·80	·5	0·61
8500	·62	·71	·80	·5	0·63
9000	·70	·71	·79	·5	0·62
9318	·74	·71	·79	·5	0·61

REFERENCES

BRUNEAU, L., JERLOV, N. G. and KOCZY, F. F. (1953), Physical and chemical methods. *Repts Swedish Deep-Sea Exped.*, 1947–1948, *Phys. Chem.*, 3 (4), 101–112.

BRUUN, A. FR. (1951), The Philippine Trench and its bottom fauna. *Nature*, 168, 692.

BRUUN, A. FR. (1953 A), Problems of life in the deepest deep sea. *Geogr. Mag.*, 26, 247–262.

BRUUN, A. FR. (1953 B), Dybhavets Dyreliv. In: A. F. Bruun, Sv. Greve, H. Mielche and R. Spärck, *Galatheas Jordomsejling*, 1950–52, 153–192.

KIILERICH, A. (1953), Ekkolod og hydrografiske Undersøgelser. In: A. F. Bruun, Sv. Greve, H. Mielche, R. Spärck, *Galatheas Jordomsejling*, 1950–52, 43–54.

REPETTI, WM. C. (1931), Philippine earthquakes. Marine epicenters. *Publ. Manila Observ.*, 3 (9), 199–2)3.

SHEPARD, F. P. (1951), Transportation of sand into deep water. *Soc. Economic Paleontol. Mineral., Spec. Publ.*, 2, 53–65.

VAN RIEL, P. M., HAMAKER, H. C. and VAN EYCK, L. (1950), Tables, serial and bottom observations, temperature, salinity and density. *Snellius Exped., Oceanogr. Res.*, 1929–1930, 2 (6), 44 pp.

ZENKEVITCH, L. A. (1955), Erforschungen der Tiefseefauna im Nordwestlichen Teil des Stillen Ozeans. *Int. Union Biol. Sci.*, (B), 16, 72–84.

ZENKEVITCH, L. A., BIRSCHTEJN, J. A. and BELJAEV, G. M. (1954), Izutchenie fauni Kurilo-Kamtchatskoj viadinui. (The exploration of the fauna in Kurile-Kamtchatka Deep). *Priroda*, 1954, 61–73.

ZOBELL, C. E. (1952), Bacterial life at the bottom of the Philippine Trench. *Science*, 115, 507–508.