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Diatom Micropaleontology and Deep-Sea Stratigraphy of the North Pacific*

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Abstract: The present status of diatom studies of the North Pacific deep-sea cores is outlined with the view toward the future applications of diatom micropaleontology in the fields of deep-sea stratigraphy, paleobiogeography and paleooceanography. The fact that the distribution of modern diatom thanatocoenoses in pelagic sediments of the North Pacific reflects the areal distribution of the upper watermasses and currents governed by the present climatological and circulatory regime of the Pacific warrants the value of diatom remains as a mean to deduce the past events (oceanological, biological and geological) that took place in the North Pacific.

Quaternary subdivisions so far been proposed for deep-sea sequences of the western North Pacific are analysed. The need for a time control that is independant of the past biogeographic boundaries is stressed in order to relate the sedimentary records from separate oceanic localities, and in this connection is mentioned the recent developments in paleomagnetic stratigraphy and microfossil biostratigraphy to construct a time-stratigraphic framework workable for Tertiary and Quaternary deep-sea sequences.

The diatom criteria so far been applied to detect the Pliocene-Pleistocene boundary in deep-sea sequences require revision. Those diatom species which appear to be extinct or originated in the younger Tertiary and Quaternary are mentioned for future confirmation.

From the view of micropaleontology, the North Pacific is unique in that it almost entirely lacks carbonaceous pelagic sediments containing Foraminifera and Coccolithophorids, except in the Equatorial zone. The feature, generally attributed to the greater depths of the North Pacific Basin lying largely below the calcium carbonate compensation depth, shows a sharp contrast when compared to the South Pacific where an extensive development of carbonaceous pelagic sediments is known in the mid latitudes extending continuously from the Equatorial zone. Instead, in the North Pacific, siliceous pelagic sediments containing siliceous microfossils (diatoms, Silicoflagellata and Radiolaria) occupy a large area.

The deep-sea sediments containing more than 5 percent of amorphous biogenaceous silica occupy the area north of approximately 30°N, Lat. in the western and central North Pacific and north of approximately 50°N, Lat. in the eastern North Pacific (LISITZIN, 1966, Fig. 6). To these siliceous sediments in the North Pacific diatoms are known to be a chief contributor of biogenous silica, except for a zone of Radiolaria ooze north of the Equator around 10°N, Lat. (RIEDEL, 1959). The numerical distribution of diatom valves in a unit weight of surface sediments from the Pacific was summarized by JOUSÉ (1968a). The figure (Fig. 1), taken from JOUSÉ (*ibid.*) shows that the concentration of diatom valves reflects principally that of the nutrient salts in the oceanic surface waters (BRADSHOW, 1959).

The greater availability of the siliceous sediments for study at the paucity of good carbonaceous samples have directed the micropaleontological works of the North Pacific cores to

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that of siliceous microfossils, particularly of diatoms, and the North Pacific Ocean has become one of the extensively studied regions in diatom micropaleontology. Diatom biostratigraphy also has better control in the North Pacific with the knowledge on diatoms from Tertiary marine diatomaceous sequences exposed on land along its periphery, from Japan to California through Sakhalin, Kurile and Kamtchatka (see JOUSÉ, 1968c and KANAYA in press for reference).

The purpose of the present paper is to review the present status of diatom studies of the North Pacific deep-sea sediments, with the view toward future developments of studies in the field of deep-sea stratigraphy, paleobiogeography and paleooceanography. More emphasis will be placed on the North Pacific especially of its western part; those from the Equatorial East Pacific as well as of the South Pacific and Antarctic will be cited only when pertinent to the purpose of the present discussion.

1. Distribution of diatoms in modern deep-sea sediments

Fig. 1 shows that in a considerable area in the mid latitudes modern sediments from the uppermost layers of the cores practically lack diatom valves, probably due to the low rates of production in the surface water layers and

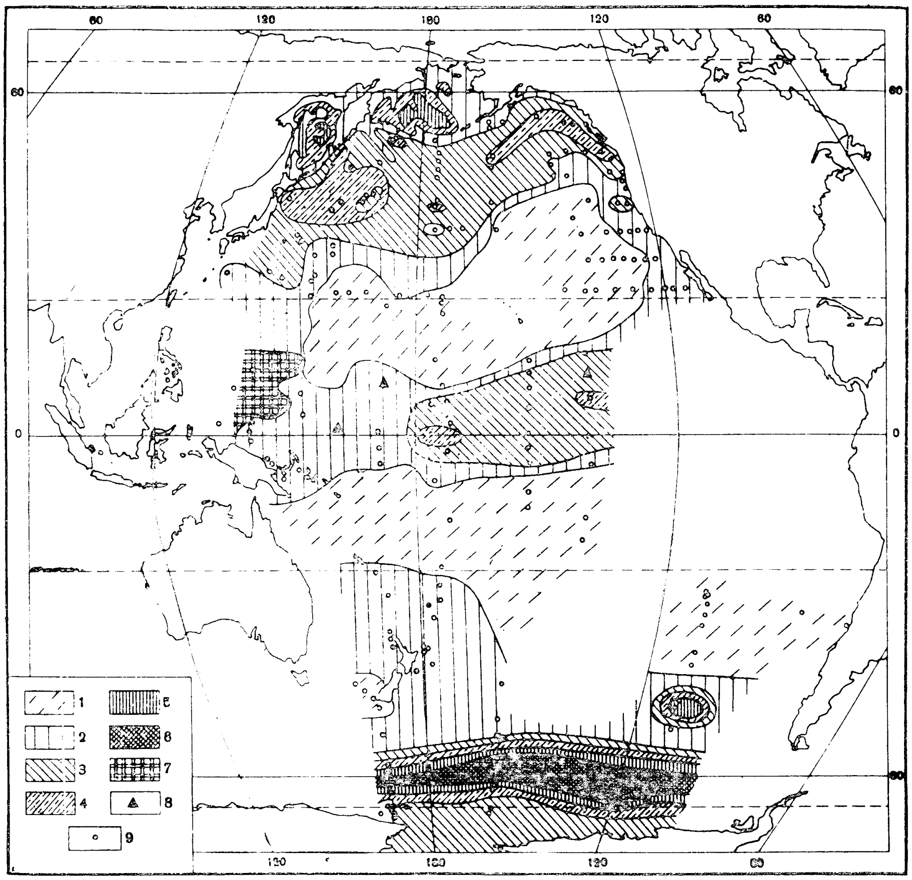

Fig. 1: Quantitative distribution of diatom valves in the uppermost layers of the cores from the Pacific (after JOUSÉ, 1968a, Fig. 1).
1. diatoms lacking; 2. 0.04-5 millions/g; 3. 5-25 millions/g;
4. 25-50 millions/g; 5. 50-100 millions/g; 6. more than 100 millions/g;
7. *Ethmodiscus* ooze; 8. sediments of Tertiary age; 9. stations studied.

to the post-depositional dissolution after reaching the bottom. The sediments in the rest of the region contain substantial amounts of diatom valves for study. JOUSÉ (1962) summarized the works by Russian workers on the distribution of diatom species in the uppermost layers of the deep-sea cores from the Far Eastern Seas, including the Bering Sea, the Sea of Okhotsk, the Sea of Japan and the northwestern part of the North Pacific north of approximately 40°N., Lat. Information presented were, among many things, the identification of all diatoms from a great number of cores to the rank of species, areal patterns of distribution of the more important species, and identification of the phytogeographical habitate of the species (arcto-boreal, north and south boreals, temperate, subtropical, tropical and equatorial) mainly on the basis of their records in surface plankton. The presence of a good correlation in species composition between the modern sediments at the bottom and the planktonic diatom population of the surface water have been emphasized with the allowances for certain groups of diatoms whose valves have dissolved before reaching the deep-sea bottom while sinking through the water column after the death.

By extending the coverage to the Antarctic through the Equatorial Pacific, JOUSÉ *et al.* (in press) distinguished seven diatom complexes (thanatocoenoses) in the modern Pacific deep-sea sediments, of which five are of the North Pacific. They are: arctoboreal, northboreal, subtropical, tropical and equatorial diatom complexes. The species combination characterizing each complex as well as the geographical distribution of the complexes defined were given, incorporating the results of her previous works (1962, 1963) as well as of MUCHINA (1963, 1966).

The classification and areal distribution of modern diatom thanatocoenoses of the North Pacific were also given by KANAYA and KOIZUMI (1966). On the basis of occurrences from 118 deep-sea cores, the species were grouped statistically. In terms of the groups (recurrent groups) thus identified, explicit definition of each assemblages was possible. Seven assemblages were discriminated in the North Pacific. They are: Subarctic, Northwest Marginal, Subarctic-Central Mixed, Northeast Transitional (North) Northeast Transitional (South), Central and Equatorial assemblages.

The distribution patterns of modern diatom assemblages (thanatocoenoses) presented in two papers, KANAYA and KOIZUMI (1966) and JOUSÉ *et al.* (in press, the same figure was given in JOUSÉ, 1968a) show difference in details due mainly to the difference in approaches to identify the discrete species group. Nevertheless, two papers clearly bear out a theme: the distribution of modern diatom thanatocoenoses in pelagic sediments of the North Pacific show patterns that is best explained by the areal distribution of the upper watermasses governed by the climatological and circulatory regimes of the Pacific. Where two watermasesses mix as along the subarctic boundary in the Northwest Pacific, the mixed assemblage results in the composition of the bottom sediments; even where the current flows continuously, like off the West Coast of North America, the boundaries of the different assemblages remain distinct in the bottom sediments, reflecting the changes in water characteristics as it flows south. It appears logical to conclude that a diatom valve will reach the abyssal bottom after traveling much shorter horizontal distances than one would expect considering the assumed hydrolic diameter of a single empty diatom valve sinking. Their actual paths to reach the bottom is an enigma. RIEDEL (1963) suggested their relatively rapid sinking as aggregates; JOUSÉ (1957) held the view that the movement of water layers in different directions in deeper layers cancel out the lateral transport of the diatom valves after they pass through the column of surface water.

2. Quaternary biostratigraphy of the North Pacific

With the information on the areal distribution of diatom species in modern sediments that have accumulated, the efforts have turned toward interpreting the geological events that left records in the deeper layers of the deep-sea cores.

The species composition as well as the geographical distribution of the assemblages in modern sediments reflects the present day surface water circulation and distribution of the upper watermasses in the North Pacific. The large majority of the species used as criteria for defining the modern assemblages have been found extant throughout the deeper layers of the cores so far taken from the western North Pacific. The knowledge of modern thanatocoenoses, therefore, provides criteria useful to interprete the ancient conditions that prevailed during the accumulation of the deeper layers of the cores in oceanic localities.

Both A.P. JOUSÉ and T. KANAYA have arrived at the view, after examining the geographical patterns of the distribution of individual species as well as of assemblages, that the temperature of the surface water is the parameter which, among others, should have the most effective role in determining the species make up of the assemblages in deep-sea bottoms. With this view, JOUSÉ (1961, 1962, 1963) proceeded in identifying the sequential fluctuation in the species composition of diatom thanatocoenoses in the successive layers of the cores in terms of the temperature variation. The fluctuation in concentration of diatom valves in a unit weight of sediments was also used by JOUSÉ as a guide: the greater concentration indicates the betterment of the condition for diatom production that took place during the interglacial or warmer intervals in high latitudes in the North Pacific, according to JOUSÉ. Her works have resulted in subdividing the sequence of deep-sea cores from the North Pacific into stratigraphic horizons which, starting from the top (Horizon 1, Holocene) represent alternatingly the interglacial and glacial intervals in descending order, odd number horizons being interglacial, and the even numbers glacial.

Table 1 lists those Russian cores from the

Table 1. List of USSR cores for which more important diatom information has been reported. The Roman numerals indicate that of the "Horizons" adopted in the works by the scientists of the Institute of Oceanology, Moscow, to represent major subdivisions of the Quaternary sequence. Starting with Horizon I (Holocene) they represent alternatingly interglacial and glacial intervals in a descending order.

Core number	Latitude	Longitude	Depth of water (m)	Length of cores (cm)	The age interpretation of the lowermost core level
USSR 3155	40°31′8N	166°12′3E	5414	525	VI (JOUSÉ, 1968b)
USSR 3163	43°49′0N	156°37′9E	5441	1170	VII (JOUSÉ, 1961); VIII (ROM. *et al.*, 1966)
USSR 3252	46°00′2N	160°21′4E	5397	380	IV (JOUSÉ, 1961); III (JOUSÉ, 1968b)
USSR 3274	51°04′0N	162°13′3E	5417	255	IV (JOUSÉ, 1962)
USSR 3325	52°03′0N	166°44′8E	4061	188	II (JOUSÉ, 1961); IV (JOUSÉ, 1962); II-3 (ROM. *et al.*, 1966)
USSR 3342	54°42′0N	164°30′9E	4588	245	II (JOUSÉ, 1961); IV (JOUSÉ, 1962); II-3 (ROM. *et al.*, 1966)
USSR 3359	51°21′4N	172°14′0E	4880	276	IV (JOUSÉ, 1962); II-3 (ROM. *et al.*, 1966)
USSR 3361	49°28′0N	169°04′2E	5511	470	IV (JOUSÉ, 1961)
USSR 3378	50°53′2N	162°24′7E	5461	340	II (JOUSÉ, 1961); IV (JOUSÉ, 1962); II-3 (ROM. *et al.*, 1966)
USSR 3797	2°01′5N	172°32′5W	5328	320	IV (JOUSÉ, 1963; MUCHINA, 1966)
USSR 3802	3°17′ S	172°52′ W	5300	266	IV (MUCHINA, 1963, 1966)
USSR 4066	47°18′9N	175°57′0W	5735	320	IV (JOUSÉ, 1961, 1963)
USSR 4084	34°59′8N	172°56′5W	5971	325	IV (JOUSÉ, 1968b, 1963)
USSR 4104	41°07′5N	159°53′9W	5427	340	VI (JOUSÉ, 1963)
USSR 4112	47°32′0N	160°03′0W	5158	297	VI (JOUSÉ, 1963)
USSR 5113	5°01′ S	154°15′ W		290	IV (MUCHINA, 1966)
USSR 5117	0°03′7N	154°14′7W	4724	700	Pleistocene (JOUSÉ, 1968b)
USSR 5124	7°55′3N	153°41′5W	5571	890	Pliocene (MUCHINA, 1966; JOUSÉ, 1968b, c)
USSR 5133	5°58′5N	176°04′4E	5396	780	Pliocene (JOUSÉ, 1968c)

western and central North Pacific, together with a few from south of the Equator, for which diatom evidences were sufficiently given, either in the forms of descriptions or by tables and lists, showing the frequencies of the species through the core sequences. The scheme of deep-sea Quaternary stratigraphy of the western part of the North Pacific developed by JOUSÉ and her collaborators were drawn mostly upon the diatom records of these cores, some of which have been mentioned repeatedly in their papers. In the table the Horizon identified for the lowermost part of each core is indicated in Roman numeral accompanied by the reference. Works by ROMANKEVICH *et al.* (1966) dealt with some of these cores when they made the absolute age determination of 28 deep-sea cores from the western Pacific. Their designation of the lowermost portion of the core in terms of the Horizon are also indicated, because their work resulted in the necessity for change in Horizon designation in some cores from that originally made by JOUSÉ mainly by diatoms. ROMANKEVICH *et al.* (*ibid.*) includes extensive studies made on granulometric composition, contents of amorphous silica, calcium carbonate and organic carbon as well as of diatoms and Foraminifera. The apportionment of the core sequences into units of layers and Horizons were said to have been done on the basis of the changes in gross characters of these attributes investigated; the knowledge on the diatom flora by JOUSÉ played a role to identify colder and warmer intervals together with the interpretation based upon the composition of the sediments. Absolute ages for the lapse of Horizons were then calculated by the varieties of radiochemical methods, and the results were discussed taking the time-scale presented by ROSHOLT *et al.* (1961) for Atlantic cores as reference, together with the age interpretation of the Pleistocene Stages of Europe and North America suggested by ROSHOLT *et al.*

The oldest Quaternary Horizon indentified by JOUSÉ is Horizon VII at USSR 3163 (1961), which according ROMANCHEVICH *et al.* (1966) is Horizon VIII. JOUSÉ has been in the opinion (1968b) that, judging from the floral composition of the diatoms, USSR 3163 is still too short to represent the entire Quaternary by its total length of approximately 12 m. ROMANKEVICH *et al.* (*op. cit.*) on the other hand correlated Horizon VIII provisionally with the Günz Glacial Stage by extraporation on the basis of the rate of accumulation calculated for the upper part of that core.

A statistic, *Td* (diatom temperature), was proposed by KANAYA and KOIZUMI (1966) to deduce the surface water temperature during the accumulation of the lower levels of the core sequences. *Td* of a sample as defined as $Td = Xw/(Xw+Xc) \times 100$, where Xw is the frequencies of warm water forms and Xc is that of cold water forms in a random count of 200 specimens for a bottom sample, shows broadly a positive correlation with the surface water temperature of oceanic water of that geographical site in the North Pacific. Diatom temperature curve derived for a North Pacific core V20-130 (36°57.8′N, 152°36′E; depth 6,547 m, length 1,039 cm) by calculating the *Td* value for each of the 86 core levels has shown fluctuation through the core sequence; four temperature maxima (including the uppermost part representing present condition) and four temperature minima were identified through its upper 650 cm of the sequence. The type of assemblage identified at the core levels showing *Td* maxima and minima are the expected, judging from the correlation between the surface water temperatures and type of modern assemblages (thanatocoenoses) at North Pacific localities. In the lower part of the core (below 650 cm level), the diatom temperature curve also fluctuates; the type of assemblage, however, was not necessarily the one anticipated from the *Td* values.

KANAYA and KOIZUMI (*op. cit.*) took this discrepancy as indicating that, although the species composition were more or less the same, the frequency relationship among the species were different from the modern ones during the accumulation of the lower part of the core (below 650 cm). Commencing from about the 650 cm level, the structure has changed to become similar to the modern ones that continued to the present time. It was maintained that a change in structure of the diatom assemblage, from the older one to the younger one, is thus detected in a seemingly continuous sequence that was interpreted as of the Quaternary in age, due to the lack of obvious Pliocene species, except for sporadic occurrences of secondary origin. *Coscinodiscus weilesii* Gran and Angust that was extant in the lower part of the core is lacking in the upper part, paralleling the change in the assemblage structure. The correlation of temperature maxima and minima detected in the core with that of the continental Pleistocene Stages was not made in that study (*ibid.*) as premature, and the need for a reliable time control was pointed out in correlating the peaks of temperature fluctuations in the deep-sea cores with the continental Pleistocene Stages.

Superimposed on these fluctuation reflecting that of the surface-waters temperatures the evolutionally changes of the diatom flora are found in the cores. Extinctions of species and appearances of new species, forma, and ecological races have been observed (JOUSÉ, 1968a). According to JOUSÉ (*ibid.*), *Rhizosolenia curvirostris* Jousé and *Actinocyclus oculatus* Jousé become extinct by the end of "middle Pleistocene" in temperate latitudes. In the subtropical latitudes, *Coscinodiscus weilesii* Gran and Angust does not cross the upper boundary of the "middle Pleistocene." In the equatorial latitudes, *Rhizosolenia praebergonii* Muchina, *Thalassiosira convexa* Muchina are characteristics for "early" and "middle" Pleistocene. Some of the important species of modern thanatocoenoses were interpreted by JOUSÉ (*ibid.*) to have descended from the older counterparts that were extant in "early Pleistocene" in the same biogeographic zone: *Rhizosolenia bergonii* Perag. is the descendant of *Rhizosolenia praebergonii* Muchina; *Rhizosolenia alta* f. *curvirostris* Jousé is of *Rhizosolenia curvirostris* Jousé; *Actinocyclus ochotensis* Jousé is of *Actinocyclus oculatus* Jousé; *Nitzschia marina* Grun. is of *Nitzschia praemarina* Jousé (MS); *Coscinodiscus nodulifer* A. Schmidt is of *Coscinodiscus nodulifer* f. *cyclopus* Jousé.

The premise held by JOUSÉ and her collaborators (JOUSÉ, 1968c; MUCHINA, 1963, 1966) in recognizing the Pliocene in deep-sea cores appears to be the substantial occurrences of Pliocene elements besides that of "precursors" of modern species. In cases for the cores from the mid and high latitudes, the Pliocene flora reported from Saghalin, Kamtachatica and Iturup island (Kurile islands) are available for control (JOUSÉ, 1962). In the case of the cores from tropical latitudes, the bases of their concept of the Pliocene flora seems to rely heavily on the record by KOLBE (1954) from an Albatross core, SW 76 (3°45′N, 149°44′W; depth, 5,153 m; length 1,342 cm), who concluded that "5-6 m zone represents, in core 76, the Plio-Pleistocene boundary" (*ibid.*, p. 18). It is true, as pointed out by KOLBE (*ibid.*), that the classical sample, "the limestone from Nankoori," contains* many species which are restricted to the lower part (below that boundary) of SW 76. The so-called Nankoori sample, however, is quite likely to have come from the Archipelago Series of Nicobar island, judging from the geological information made available by GLAESSNER (1943). According to GLAESSNER (*ibid.*) the Archipelago Series is of the Miocene Age, ranging from the Burdigalian to Tortonian. Correlation extended by diatoms from the sequence of the Experimental Mohole has shown (KANAYA, in press) that the lower part of SW 76 is Miocene in age and underlies also diatomaceous upper part which is likely of Pliocene in age. Some part of the upper Miocene (*sense* RIEDEL and FUNNELL, 1964) appears to be missing in the core in a hiatus indicated by the undulating boundary at the core level 519 cm, described by OLAUSSON (1961).

3. Time control in deep-sea stratigraphy

As pointed out elsewhere (*e.g.*, HAYS and BERGGREN, in press), most microfossil species suitable for deep-sea stratigraphy have limited geographic distribution, hence no single criteria can be applied to tracing the time line in deep-sea records over the entire Pacific. The fluctuation of surface temperature due to the Pleis-

* Based on the observation of slide no. 618, labelled "Polystins Mergel v. Nankoori" in J. Brun's collection, Conservatoire Botanique, Geneve, Oct. 1967.

tocene glaciation may be a global phenomenon, but the correlation, either by paleontological or lithological means, of identified warmer or colder horizons in the deep-sea core sequences from stations of different climatic zones involves a great deal of subjective interpretation. In most studies made of deep-sea cores (*e.g.* ARRHENIUS, 1952) more numbers of temperature minima and maxima have been identified than may be anticipated from the records of the continental glaciation during the Pleistocene. Seeking the parallelism between the temperature histories of land and sea may be justified. However, the age interpretation of the temperature minima and maxima in terms of continental glacial and interglacial stages usually runs into difficulties by the lack of adequate time control in deep-sea sequences. Paleomagnetic stratigraphy that has been extended to deep-sea sequences (OPDYKE *et al.*, 1966; NINKOVICH *et al.*, 1966) provides, combined with the biostratigraphic datum and zones, time controls for the Quaternary and younger Tertiary stratigraphy of deep-sea sediments. At the SCOR symposium, "Micropaleontology of marine bottom sediment," held in Cambridge, England, in September, 1967, J.D. HAYS and W.A. BERGGREN related the recent developments in this field in an excellent paper (HAYS and BERGGREN, in press) dealing with the Pliocene-Pleistocene and Quaternary boundaries in deep-sea succession; historical reviews of the criteria that have been invariably adopted among anthropology, glaciology, invertebrate paleontology and vertebrate paleontology to define the Quaternary Period were given explicitly in the paper (*ibid.*). Some of the implications of their conclusions to the deep-sea stratigraphy of the western North Pacific will be briefly outlined, but firstly, some basic facts and reasoning that are presented in that paper.

1) By the line of study initiated by COX *et al.* (1963) based on the Pliocene and Pleistocene lava flows it has been possible to date the changes in polarity of the earth's magnetic field through the past 3.5 million years. The bimodal distribution of the directions of magnetization of the lava flows has its origin in reversal of the earth's magnetic field, therefore, normally and reversely magnetized rocks as reference to the present direction of the earth's magnetic field can be expected to occur in alternating sequences traceable as precise time-stratigraphic units around the world. The longer intervals (on the order of a million years) of constant polarity have been termed normal and reversed polarity epochs; of shorter time duration (about a tenth as long) have been called events. The epochs have been named in order of increasing age (in million of years): the Brunhes normal epoch (0–0.7), the Matuyama reversed epoch (0.7–2.4±0.1), the Gauss normal epoch (2.4±0.1 to 3.35). Within the Matuyama reversed epoch, two short periods of normal polarity occurred at about 0.9 and 1.9 million years, termed Jaramillo and Olduvai events, respectively, and the latter having the duration about 0.1 million years. Within the Gauss normal epoch there was a short period of reversed polarity at 3.0 million years, called the Mammoth event. (Excerpted freely from HAYS and BERGRREN, *op. cit.*, in the chapter, "Radiometric dating, paleomagnetism and the Pliocene/Pleistocene chronostratigraphic scale").

2) Evolutionary transition of the planktonic Foraminifera, *Globorotalia tosaensis* to *Globorotaria truncatulinoides* was confirmed to occur near (about 15 feet above) the base of the holostratotype of the Calabrian Stage at Santa Maria di Castanzaro in southern Italy. The Calabrian has been accepted as the basal subdivision of the marine Pleistocene in Italy, following the recommendation made by an international body at the 18th International Geological Congress (Int. Geol. Congr. Repts 18th sess., 1948, pt. 10, 1950). Since the evolutionary transition from one species to another is an irreversal event that happens only once, *Globorotalia tosaensis*/*Globorotalia truncatulinoides* transition was taken as denoting isochroneity and considered to be the most satisfactory paleontological criteria for recognizing the Plio/Pleistocene boundary in mid latitudes. In the biostratigraphic zoning of the Neogene made by BANNER and BLOW (1965) using planktonic Foraminifera the transition marks the boundary between zone N21 below and zone N22 above.

3) The *Globorotalia tosaensis*/*Globorotalia*

truncatulinoides transition was found in a North Atlantic deep-sea core from the mid-latitude (BERGGREN *et al.*, 1967). The paleomagnetic study carried out for the core has shown that the transition occurred within the Olduvai normal event; the estimated age of the transition in the core was 1.85 million years old. Although paleomagnetic studies have not been made on the type Calabrian of Italy, the suggested age for the base of the Pleistocene in the Atlantic core is in a good agreement with the suggested age, 1.8 million years, by SELLI (1967) for the base of the Pleistocene in the Italian section.

4) Hays and Berggren was in the opinion that *Globorotalia tosaensis*/*Globorotalia truncatulinoides* transition has only moderate to poor value in recognizing the Pliocene-Pleistocene boundary in the sediments of the Equatorial zone for both are temperate species. The extinction of the Radiolaria species *Pterocanium prismaticum* has been used to recognize the Pliocene-Pleistocene boundary in the equatorial Pacific (RIEDEL, 1957; RIEDEL *et al.*, 1963). Recent works at Lamont Geological observatory was cited by HAYS and BERGGREN (*op. cit.*) to have shown that the species disappears consistently just above the top of the Olduvai event in four oriented cores from the equatorial Pacific; the species was thus taken as good indication to approximate the Pliocene-Pleistocene boundary in equatorial Pacific sediments; the somewhat earlier disappearance of discoasters (RIEDEL, *et al.*, 1963) was also considered as corresponding approximately with the Pliocene-Pleistocene boundary in the equatorial Pacific sediments.

5) Altogether (HAYS, 1965; HAYS and OPDYKE, 1967) six* radiolarian zones have been recognized for Antarctic deep-sea sediments. They are based primarily on the upward sequential disappearances of radiolarian species and are named from the youngest to the oldest in greek letters Ω (Omega), Ψ (Psi), X (Khei), Φ (Phei), Y (Ypsilon) and T (Tau). These radiolarian zones have been related to the paleomagnetic stratigraphy also established for the same series of cores (OPDYKE *et al.*, 1966) reproducing the scheme by COX *et al.* (1965). Using the known age of the reversals, the rate of sedimentation was calculated and on that basis, the approximated age of radiolarian zones have been estimated as follows (OPDYKE *et al.*, 1966; HAYS and OPDYKE, 1967): Ψ−Ω boundary 0.4–0.5 million years old; X−Ψ boundary, slightly more than 0.7 million years, Φ−X boundary about 2.0 million years, Y−Φ boundary 2.4 million years. The Φ−X boundary marked by the last common occurrences in Antarctic sediments of *Eucyrtidium calvertense* falls just below the base of the Olduvai event, and was considered to represent a close approximation of the Pliocene-Pleistocene boundary shown in North Atlantic cores which falls within the Olduvai event (BERGGREN *et al.*, 1967). For the combinations of the ranges of other species defining each zones the readers are referred to HAYS and OPDYKE (1967). X−Ψ boundary (slightly more than 0.7 million years old) bears the radiolarian evidence indicating a temperature change, from warmer below to cooler above, causing the disappearance of some arctic species at the boundary. On the other hand, the disappearance of *Clathrocyclus bicornis* and *Eucyrtidium calvertense* are synchronous with reference to the Olduvai event in the cores from the south of the Polar front and that from north of it at about 41°S, suggesting that the extinction of radiolarian species in that region is not necessarily due to the temperature change alone (HAYS and OPDYKE, 1967).

6) HAYS and BERGGREN (*op. cit.*) proposed five radiolarian zones for the North Pacific. Likewise those of the Antarctic sequence, greek letters designate each zone, with subscript "n" indicating their restriction to the northern hemisphere. They are in descending order, Ωn, Ψn, Xn, Φn and Yn. Three upper zones are considered Quaternary, the latter two are of Tertiary. Paleomagnetic data from the ten cores from the central North Pacific ranging in latitudes from 30°N to 50°N were said to be incorporated to their age interpretation.

Because of the lack of calcareous deep-sea sediments in that part of the North Pacific a radiolarian species, *Eucyrtidium matsuyamai*,

* the oldest one, T was not yet mentioned in Hays and Berggren (*op. cit.*)

was proposed to be the criterion to recognize the Pliocene-Pleistocene boundary in the mid and high latitudes of the North Pacific:

The Xn Zone is defined by the range in the North Pacific sediments of the new species *Eucyrtidium matsuyamai*. This species first appears near the base of the Olduvai event and disappears in the Jaramillo event. This range has been confirmed by an examination of ten cores that contain its full range. The appearance of this species within the Olduvai event roughly corresponds in time with the transition from *Globorotalia tosaensis* to *G. truncatulinoides* observed by Berggren in a North Atlantic core and therefore provides a criterion in the North Pacific sediments which can be used to identify the Pliocene/Pleistocene boundary. (from the chapter, North Pacific, HAYS and BERGGEN, *op. cit.*)

7) As to the climatic deterioration having been a major criterion for identifying the base of the Pleistocene, they wrote:

The onset of glaciation which has long been thought to be a major environmental change of sufficient magnitude to separate the Tertiary period from the Quaternary period has no value for world wide correlation. The world climate has apparently deteriorated gradually with glaciation beginning in high latitudes several million years before it reached temperate ragion. (in the chapter, Conclusions, HAYS and BERGGREN, *op. cit.*)

As cited by BERGGREN and HAYS, ice rafted debris in Arctic deep-sea cores has been dated in excess of 4 million years old (HAYS and OPDYKE, 1967). The earliest glacial till yet dated in Iceland occurs in the middle of the Gauss normal polarity epoch giving it an age of about 3 million years (RUTTEN and WENSINK, 1960; K-A dating, MACDONGALL and WENSINK, 1966). Foraminiferal evidence by BERGGREN *et al.* (1967) from the mid latitude cores from the North Atlantic (significant cooling commenced in the Jaramillo, 0.9 million years old), and temperature changes from warm to cold indicated by Radiolaria both in the Antarctic and mid latitude North Pacific, respectively, at the X−Ψ boundary (slightly below the Matuyama/Brunhes boundary, slightly less than 0.8 million years old) and at the Xn−Ψn boundary (in the Jaramillo, 0.9 million years old) were taken as the reflections in deep-sea sections of a world wide cooling associated with the first glaciation in Europe, that is the Donau glaciation which preceeded the classic four continental Glacial Stages of the Pleistocene in Europe.

When one accepts HAYS and BERGGREN and considers the upper limit of the range of the Radiolaria species *Pterocanium prismatium* to be a good approximate marker to identify the Pliocene-Pleistocene boundary in the Equatorial Pacific sediments, the Quaternary subdivisions by diatoms so far advocated in the western Equatorial Pacific needs revision. In correlating the diatom flora of the deeper layers of equatorial cores, MUCHINA (1966) mentioned two Albatross cores, SW58 (6°44′N, 129°28′W; depth, 4,440 m; length, 991 cm), and SW62 (3°00′S; 136°26′W; depth, 4,510 m; length, 1,479 cm). On the basis of *Pterocanium prismatium* as an approximate criteria the Pliocene-Pleistocene boundary* in the two cores are about at 8 m at SW58, and at a little above 12 m at SW62 (see RIEDEL *et al.*, 1963). MUCHINA (*op. cit.*) considered the base of both cores to be Quaternary in age, however, on the ground that Tertiary diatom species are few and the elements which invariablly called exotic or ancesters of modern species are characteristically present. The latter characteristics separated the lower and upper parts of the two cores at about 8 m in SW58 and at about 12 m in SW62; and also on the same ground the similarity of these lower flora with that of Horizon IV at USSR 3802 and USSR 3113 were mentioned. It appears (MUCHINA, *ibid.*, p. 110) that MUCHINA considered the Horizon IV at USSR 3802 and USSR 3113 to be "middle Pleistocene," while the lower flora at SW58 and SW62 "early Pleistocene" in ages. This age interpretation, which also involved an discussion against the

* The Pliocene-Pleistocene boundary drawn by ARRHENIUS (1952) on the basis mainly of the abrupt increase in calcium carbonate contents was at 395 cm at SW 58 with which 1,080 cm level of SW 62 was correlated. The estimate age of the boundary was slightly less than 1.0 million years at SW 58.

validity of the disappearance of discoasters as having been the criteria approximating the Pliocene-Pleistocene boundary (ERICSON *et al.*, 1963; RIEDEL *et al.*, 1963), has in tern been reflected to a considerable extent to the concept by JOUSÉ of the Pliocene diatom flora in the equatorial Pacific sediments (JOUSÉ, 1968b, c).

The extended correlation of the Pliocene-Pleistocene boundary of Italian section to the Equatorial Pacific as proposed by HAYS and BERGGREN (*op. cit.*) provides a reasonable chronostratigraphic control in the Equatorial Pacific region to which the sequential changes of the diatom species through younger Tertiary and Quaternary can be related. The examination of the records on the stratigraphic distribution of diatom in equatorial cores so far made available by Russian colleagues (see Table 1) and my personal working experiences of some equatorial Pacific cores makes me inclined to believe that there are a number of diatom species whose ranges may be tied successfully with paleomagnetic stratigraphy to serve as criteria for the chronostratigraphic correlations of the Quaternary and younger Tertiary boundaries. This is also true for mid and high latitudes of the North Pacific where time controls are needed badly. Some of the diatom criteria previously suggested may be proved to be useful, if not for its original sense, in time-correlation of the younger Tertiary and Quaternary sequences when the paleomagnetic and micropaleontological works have been done on more cores from the North Pacific.

For example, the disappearance of exotic or ancestral forms at certain core levels or Horizons have been frequently cited (JOUSÉ, 1968b, c; MUCHINA, 1963, 1966). An exotic or ancestral form, *Rhizosilenia praebergonii* was cited to have disappeared at 8 m in SW 62 (MUCHINA, 1966, Fig. 5) and at about 12 m in SW 62 (*ibid.*). As mentioned, the levels are approximately the Pliocene-Pleistocene boundary in the sense of HAYS and BERGGREN at both cores. The species is extinct in Horizon IV at USSR 3113 and at USSR 3118 at about the upper boundary of the Horizon II (MUCHINA, 1966, 1963). The lowest known occurrences of *Rhizosolenia praebergonii* is from the late Miocene of Oga Peninsula, Japan (KOIZUMI, 1968). The species related most morphologically to *R. praebergonii* is, as pointed out by JOUSÉ (1968a), *Rhizosolenia bergonii*, one of the common elements of modern thanatocoenoses of low latitudes of the world oceans (KOLBE, 1957); its earliest occurrence has not yet been satisfactorily confirmed, but judging from the available information (KANAYA, in press), it is most probably in the Pliocene in the sense of HAYS and BERGGREN (*op. cit.*). The zone of their concurrence and the transition in the zone in which only *Rhizosolenia bergonii* is present, when checked with reference to the Olduvai and older paleomagnetic boundaries, appear to me to serve as a workable criterion in low latitudes. *Fragilariopsis pliocena* and its close morphological ally *Pseudoeunotia doliolus* (KANAYA, in press) may form another set that may provide a criterion in tracing Pliocene time-levels from low latitudes to mid latitudes of both hemispheres.

There are numbers of other biostratigraphic boundaries and units of diatoms whose relationships with the magnetic polarity sequence of of past 3.5 million years appear to me to be worth considering for chronostratigraphic purposes. Among those previously mentioned by JOUSÉ (1968a) are: *Coscinodiscus nodulifer* f. *cyclopus*—*Coscinodiscus nodulifer* set for low latitudes; *Rhizosolenia curvirostris*—*Rhizosolenia alata* f. *curvirostris* set, and the extinction of *Actinocyclus oculatus* in mid and possibly subarctic latitudes of the North Pacific. Although the kinship is not readily apparent from morphological features, *Denticula kamtchatica* and *Denticula seminae* form a set that may be checked in subarctic Pacific cores. In this connection it will be of much interest, not necessarily for the constructions of chronostratigraphic framework in itself, but for the ellucidation of the histories of developments of the diatom plankton population in the North Pacific, to chronicle the changes having taken place in the structure of the diatom thanatocoenoses, like that detected by KANAYA and KOIZUMI (1966) in V20-130 as mentioned earlier, of different latitudinal or geographical zones. Their time relationship with the past polarity changes of the earth's magnetic field may give information as to the bearings of the polarity change on planktonic population.

Some of the works along these lines have already been started in the North Pacific. For the cores on which HAYS and BERGGREN based their North Pacific Radiolarian Zones (*op. cit.*), Jessie G. DONNAHUE of the Lamont Geological Observatory has been doing parallel works by means of the diatoms. Plaeomagnetic stratigraphy of four of these cores was published (NINKOVICH *et al.*, 1966), showing that three cores reached the Olduvai event, at core depths ranging from 9 to 13 m. JOUSÉ reported on the diatoms of one of these cores, V20–119, the result of which awaits publication (JOUSÉ in press). One oriented piston core of considerable length was raised for paleomagnetic purpose during the cruise of the Research Vessel Hakuho-maru, of the Ocean Research Institute, University of Tokyo (St. 15–2 of KH 68–3: 38°26′N., 165°58′E; depth, 5,492 m; length, 970 cm). A quick examination of the sample from several core levels of the sequence including the one from the core bottom appear to me to suggest that the core did not reach the Pliocene-Pleistocene boundary in the sense of HAYS and BERGGREN (*op. cit.*)

Efforts of establishing paleomagnetic stratigraphy on continuos marine sequence exposed on land has been started in Japan. From the continuous marine sequences ranging in age from Miocene to Pleistocene in the Bôsô Peninsula, H. NAKAGAWA and his colaborators at the Institute of Geology and Paleontology, Tohoku University have succeeded to reproduce COX *et al.*'s (1965) paleomagnetic stratigraphy, and in addition were able to identify, below the Gilbert reversed epoch, two normal and one reversed polarity intervals which they considered to be in the order of epochs (NAKAGAWA *et al.*, 1969). The interval representing the Olduvai normal event of the Matuyama reversed epoch was identified in the Umegase Formation approximately at the stratigraphic position at which the Pliocene-Pleistocene boundary was suggested earlier (ASANO *et al.*, 1958) from the studies of planktonic Foraminifera. Detailed micropaleontological works are in progress at the Institute dealing with the same series of rock samples on which paleomagnetic measurements have been made.

No single method, varieties of radiochronometric (ARRHENIUS, 1967), paleomagnetic and of fission tracks, is foolproof in dating a layer of deep-sea sequence which frequently involves stratigraphic hiatus and the products of re-deposition and of diagenetic alterlation; the need of cross-checking between the results obtained by different methods is apparent. In HAYS and OPDYKE (1967) cases were presented in which micropaleontological criteria, the radiolarian zones in that case, helped to interprete the alternating paleomagnetic polarity sequences of Antarctic cores. I support HAYS and BERGGREN and advocate that, when confirmed on more core sections as well as land based sequences, the dated sequence of polarities of the earth's magnetic field and biostratigraphic datum and zones by microfossils supplement each other to form a reliable chronostratigraphic framework that is reasonably workable for the younger Tertiary and Quaternary. It is only with a resonably reliable and workable framework of time-control that the numbers of geologic, climatologic, biologic and oceanographic events can be synthesized satisfactorily from the deep-sea records.

4. Concluding remarks

1) The study of paleomagnetic stratigraphy of fossiliferous deep-sea sequences is highly desirable for the western part of the North Pacific. In this general region siliceous microfossils (diatoms and Radiolaria) will prove to be useful as micropaleontological means to be tied with the sequence of polarity changes of the earth's magnetic field to form a chronostratigraphic framework. Although more information is always needed, the data so far accumulated for the geographical distribution of diatom species in modern thanatocoenoses of the Pacific will make broad interpretation of the past oceanographic conditions possible, should satisfactory time-control becomes available. It seems to me that a systematic study of the history of the Kuroshio current system from this approach deserves attention.

2) Inasmuch as thanatocoenoses in the bottom sediments represent only a fraction of the life that populated the water column, the discussions of the past plankton biocoenoses on the basis of preserved bottom records have limitations. At least the change of biocoenoses, however, should be reflected to a certain extent to bottom thanatocoenoses, so far as the comparisons are based on certain groups preservable through physico-chemical processes involved in sedimentation and diagenesis. Even within this limited sense, the sequential records in bottom sediments should provide more meaningful information regarding the developments of the diatom population and the fluctuation of the surface environmental factors as water temperature, if analysis of the assemblages have been more adequate. As is evident from the case of the core V20-130 (KANAYA and KOIZUMI, 1966), a direct analogy of species relationships in modern thanatocoenoses becomes less reliable when applied to deeper-layers even as young as Pleistocene in age. More rigorous analysis making use of modern statistical techniques is apparently needed to interprete the sequential changes of the diatom thanatocoenoses in deep-sea cores.

3) In the light of current progress in marine technology, the availability of deep-sea sequences significantly longer than that have been available by conventional piston-core technique will be in a foreseeable feature. As VAN ANDEL pointed out (1968) in outlining the JOIDES Project, reasonably continuous pelagic sediments dating possibly back to early Tertiary and even Mesozoic will become available to provide unpreceeded opportunity to marine micropaleontology; much improvements for biostratigraphic correlation and age dating by the use of planktonic organisms will be achieved; the evolutional lineages of plankton life can be evidenced in deep-sea records in the way that has never been done before; many other problems revolving around the evolutionary developments of planktonic organisms can be attacked in the way that have never been possible before; the remains of pelagic life and the nature of pelagic sediments undoubtedly provide information concerning the oceanic circulation of the more remote geologic past. The amount of works requiring micropaleontologists with a good background in both geological and biological sciences should become enormous in marine sciences. Preparation for this situation deserves serious consideration.

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北太平洋地域における珪藻の微古生物学的研究と深海堆積物の層位学

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要旨: 北太平洋の深海堆積物を対象として行なわれてきた珪藻遺骸の微古生物学的研究の経過を紹介し，北太平洋海域の第四系層序区分の問題点を指摘し，この種研究の将来の展望に触れた。すなわち，

1) 海の真光帯（euphotic zone）に浮遊生活を営む珪藻の珪酸殻は，死後多様な経路をたどって深海底に沈積し，深海堆積物の生物源構成メンバーとなる。これら底質中の珪藻遺骸の種構成は，海洋の表層水塊や海流の分布をよく反映することが帰納されている。

2) ピストンコアラーで柱状に採取される 10 m ±の堆積物は，100 万年以上の時間を代表するのが一般であるが，北太平洋においては，これら第四系の層位区分に珪藻解析が主要な手がかりとして使われてきた。しかしながら，深海コアーの第三系と第四系の境界（鮮新統と更新統の境界）を判定するのに用いられてきた珪藻の基準は，その根拠に誤りを含んでいる可能性が強い。

3) 異なった地点の層序を時間的に対比し，海洋の過去の事象（海洋学的・生物学的・地質学的）を時空的に意義づけるには，古生物地理区に制約されない同時面の認定が必要である。これに関連して，古磁気層位と微化石層位の連携から得られた第四系の下限と区分に関する最近の見解を紹介した。

4) 深海における新第三系～第四系の層位区分・対比の骨組みを確立してゆく上において，この期間に絶滅，あるいは出現した浮遊生物種を確認する必要がある。このために注目すべき珪藻種を例挙した。

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北西太平洋の海溝地形*

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Topographie des fosses au Pacifique du nord-ouest

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Résumé: La caractéristique topographique des fosses de Kourile-Kamtchatka, du Japon, du Japon du sud-ouest, de Nansei Shoto, de Philippine et de Bonin est expliquée. Un certain nombre de traits se trouvent communs à toutes ces fosses, bien que la grandeur du relief, la profondeur et la pente de la fosse soient plus ou moins différentes les unes des autres.

1. 緒　言

北西太平洋の大陸塊寄りには，カムチャッカ半島，千島列島，日本列島，南西諸島，台湾，フィリピン諸島と連なる一連の島弧がある。これらの島弧には，火山帯，地震帯を伴い，島弧の大洋側には，その周辺地域内で最も深い海溝を伴うのが普通である。千島―カムチャッカ海溝，日本海溝，西南日本海溝，南西諸島（琉球）海溝，フィリピン海溝などである。他方，大陸塊とは，明確に，大洋性地殻で隔離されている島弧と関連して，日本列島中央部沖から端を発し，伊豆―小笠原海溝，マリアナ海溝，パラオ海溝，ヤップ海溝などと連なる海溝がある。一般に，火山帯，地震帯を伴うことでは前記の海溝系と同じである。

近年，これらの海溝に関する地質学的研究も盛んになり，新しい事実もわかってきた。ここに，日本列島周辺の海溝を中心にして，レビューしてみることにする。

2. 各地の海溝

1. 千島―カムチャツカ海溝

カムチャツカ半島中部の東側沖合から端を発し，千島列島と平行に，北海道襟裳岬沖まで，この間2,200 kmにわたって連なる海溝である。この地域はソ連邦の科学者によって詳しく調べられているところで，海溝全体の地形については，すでに，UDINTEV (1955)[1] によって総括されている。

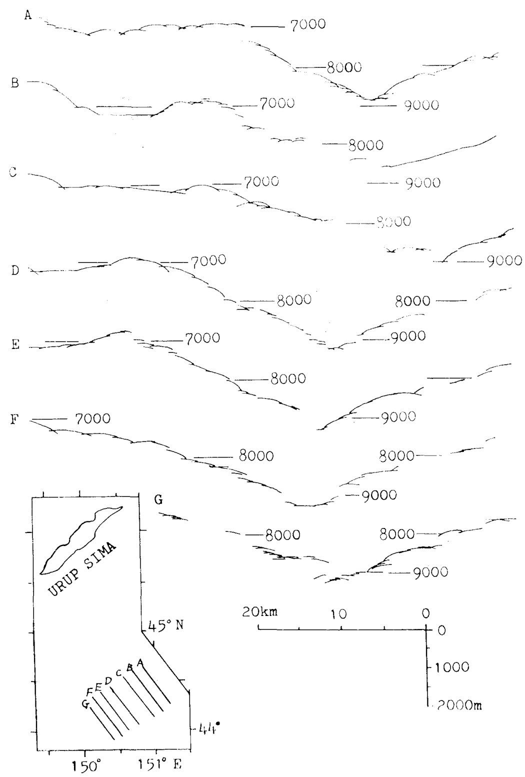

Fig. 1. Profiles traced from depth recordings of the Kurile-Kamchatka Trench south of Urup Sima.

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たとえば，カムチャツカ半島南部沖の斜面に分布する幅広い平坦面が，水深 3,500 m，5,000～5,500 m，7,000 m 付近に認められ，平坦面を結ぶ急斜面は，造溝断裂線に対応するものであるといわれている。

海溝最深部は，「VITIAZ」号の調査によると，Urup 島南方の水深 10,542 m といわれているが，1962年5月の「拓洋」によるこの最深部付近の調査では，9,550 m より深い地域は見つかっていない。このときの調査で，「拓洋」がえた海溝断面をFig. 1 に示す。

Fig. 1 を通観すると，水深 7,000～7,400 m に幅約20 kmの顕著な bench が認められる。bench の外縁部には，比高約 200～400 mの ridge をのせている。断面 B においては，benchの中央部が比深400 m ほどおちこみ，この間 6.5 km にわたって全く平らな海底になっている。このほか，規模の小さな分布の限られる bench が，陸側の水深 8,000～8,500 m，大洋側の 8,500 m 前後に認められる。また，大洋側斜面には，日本海溝の三陸沖で認められたと同様な small narrow depression (岩淵，1968)[2] が存在する。

ウルップ島側の水深 7,000 m から海溝底にかけての斜面の一般勾配は 5～9° ほどであり，大洋側では，海溝底に近い傾斜の急なところで 8°内外，その他では 3～4° 程度である。

2.　日本海溝

日本海溝は，全長約 800 km にわたって，東北日本に平行にわずかに弓なりになりながら南北に連なる。

海溝全体の地形を Fig. 2 に，また，なかでも調査の行きとどいている三陸沖の海溝断面を Fig. 3 に示す。東北日本東方の大陸棚と海溝との間の大陸斜面には，数段の深海平坦面が認められる。とくに，海溝北部地域で発達がよい。噴火湾の 800～1,400 m，三陸沖の 1,000～1,800 m 面は分布範囲も広く，かつ面上における起伏も少ない。幅広いところで50 km 以上，南北の拡がりは 110 km に達する。海溝南部地域の常磐沖，鹿島灘では，平坦面の規模は，北部地域に比べて 1/5～1/8 程の規模になっている。各平坦面の分布は，相隣る面と密接な関係にあり，上位面が張り出すところでは，下位面が狭く，上位面が狭くなるところでは下位面が発達するというように互に組合って分布する。

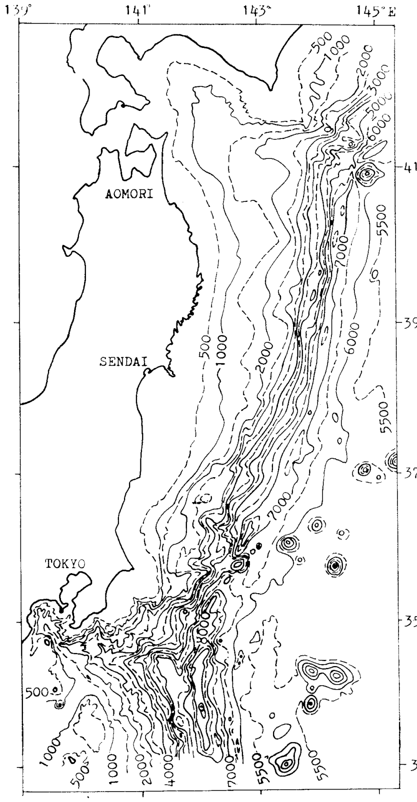

Fig. 2. Topography of the Japan Trench and its neiborhood.

南雲 (1968)[3] は，日本海溝に沿う海域に発生するM＝7以上の地震の余震域が，地域的に一つのブロック単位の造構造運動を行なうことを明らかにし，これらのブロックが，部分的にせよ，大陸斜面上の平坦面の分布とも，密接な関係にあることをはっきりさせた。

海溝地形 proper と大陸斜面との境界は，水深 2,400～3,400 m，大洋側とは 5,600～6,000 m である。日本海溝の海溝斜面は，他の多くの海溝と同様，斜面全体としての傾斜は，陸地側で急で，大洋側に緩い。三陸沖の場合，陸側で平均 6°，大

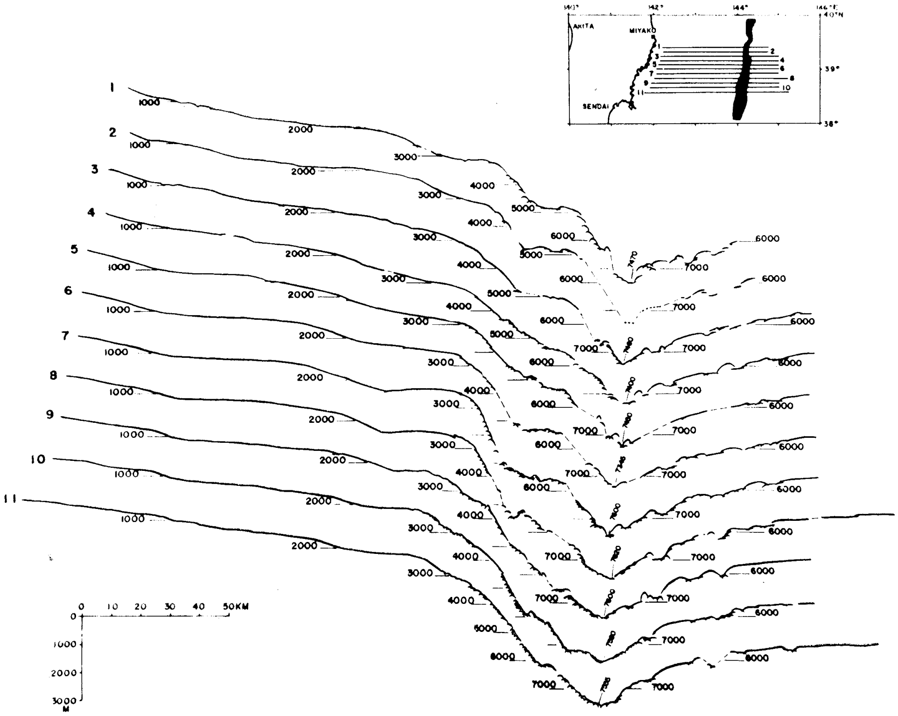

Fig. 3. Profiles traced from depth recordings of the Japan Trench off Sanriku District.

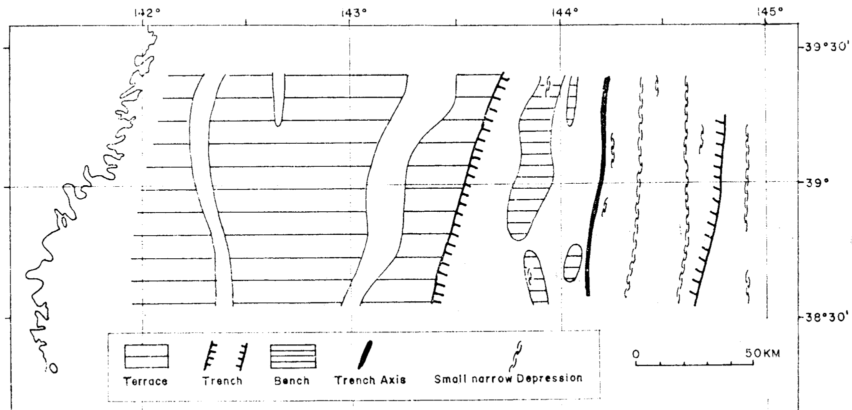

Fig. 4. Geographical chart of the Japan Trench off Sanriku District.

洋側で平均 4°，仙台沖で 4° と 1°，犬吠崎沖で，8° と 2° である。

海溝斜面には，bench と呼ばれる 棚状の地形や small narrow depression ともよぶべき地溝状の窪地が認められる（Fig. 4）。bench は一般に陸側斜面に顕著で，bench の edge に ridge（比高数百m）をもつものや，中央部で窪地になっているものなどがある。三陸沖の場合，4,700～4,800 m（幅16 km）が顕著である。南部になるにつれ，幅が狭くなるとともに，深さも 6,000 m と増大している。このほか，局地的なものとして，6,250 m（幅 2.8 km），6,600 m（幅 4.1 km），7,200 m（幅 8 km）

などがある。

small narrow depressionは，海溝の大洋側斜面および大洋底移行部の地形を特徴ずけている。これは，凹地としての地形の規模はさほど大きくないが，凹地の幅に比して，その長さが著しく長いものをいう。海溝軸に平行に数条認められる。三陸沖には，水深7,100 m，6,700 m，6,300 m，6,200 m 5,800 m付近に5条認められるところがある。水深7,100 m，6,300 mのdepressionは，90 km以上にわたって連なる。7,100 mのものは幅1.9 kmで，凹地に対して，大洋側にあたる高まりからの比深は400 m，海溝寄りの高まりからの比深は200 mで，地溝構造を示す。海溝斜面が大洋底に移る地域になると，凹地はさほど目立たなくなりまわりの海底より数10 m深くなるにすぎない。

日本海溝の海溝底はV字断面をしめし，広い平らな底が発達しているところは少ない。南部地域を除けば，厚い堆積物は期待できない。Fig. 5は海溝底の水深を南北にプロットしたものである。段階的に北から南へと深くなっているようである。

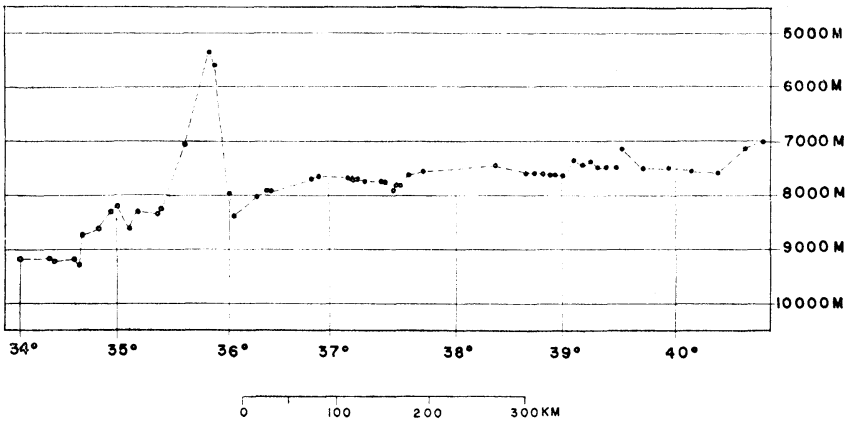

Fig. 5. Depths along the Japan Trench.

3. 西南日本海溝

遠州灘から日向灘に至る間の大陸斜面直下には，水深5,000 mを越える相対的に比深の浅い海盆があることから，田山 (1952)[4] はこれを南海舟状海盆と称した。星野 (1963)[5] は，この地形を西南日本弧に対応する海溝とみなし，新しく西南日本海溝と定義した。それによると，都井岬東方で九州－パラオ海嶺によって南西諸島海溝と境され，北東部の端は御前崎東方の駿河湾口で終るものとされている。

海溝地形の輪郭は，4,000～4,500 m 等深線で表現され，西南日本外帯にほぼ平行に，650 kmにわたって連なる。海溝斜面の勾配が大陸斜面で急であることは，他の多くの海溝と同様である。急斜部で約10°，緩斜部で2～3°である。大洋側の斜面はさらに緩く，海溝から大洋底（四国海盆）への移行が不明瞭になっているところもある。

海溝底は，全体的傾向として，北東端の水深4,000～4,600 mから南西端へと徐々に深くなり，4,600～5,000 mとなる。現在知られる最深部は，四国南方沖の5,014 mである。他の海溝に比して著しく浅い。海溝底は総体的に平坦で，急激な水深変化のみられるところはない。埋積作用の進んでいる海溝であることが了解される。

西南日本海溝の地殻構造としてはFig. 6がえられる。M面の深さは，大陸斜面（深海平坦面）下で16 kmであるのに対して，海溝下で12.5 kmと浅い。海溝では，5.1 km/sec 層を基盤とし，その上に，海溝地形充塡物（2.0～3.1 km/sec 層）が厚さ1.8 kmほどで存在する。かりに充塡物をとり除い

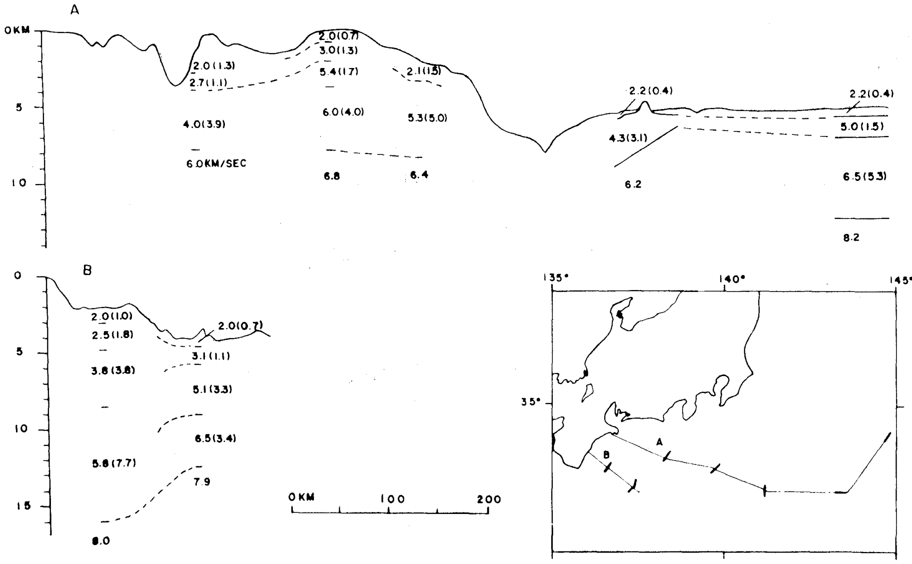

Fig. 6. Crustal structure sections across the Izu-Ogasawara Trench (A) and the Southwest Japan Trench (B), compiled with the data taken from MURAUCHI *et al.* (1964 and 1968)[6)9)] and LUDWIG *et al.* (1966)[14)].

たとしても，水深 7,000 m 足たらずで浅い海溝であることには変りない。

4. 南西諸島（琉球）海溝

海溝の北端は九州-パラオ海嶺に限られ，南端は台湾中部沖にまで追跡できる。この間，1,350 km にわたって，南西諸島島弧（南西諸島海嶺）と平行している（Fig. 7）。

南西諸島海嶺は，小西（1965)[8)] によって，互に並走する構造累帯に区分され，海嶺にみられる先中新世帯状構造は，西南日本外帯の地史と類似していることが指摘されている。さらに，先中新世帯状構造と斜交する構造として，新生代琉球火山帯が識別されている。また，先中新世帯状構造が，left-lateral transcurrent fault と解される構造線で切られているというが，これが海嶺の crest のずれとして地形上に表われている。

海溝の配列（とくに北半分において）は，先中新世帯状構造との並列関係は弱く，むしろ新生代火山帯との平行度が高い。

海溝底盆は，海溝を狭ばめている奄美大島東方の海山群，宮古島南東の海山群により，北部，中

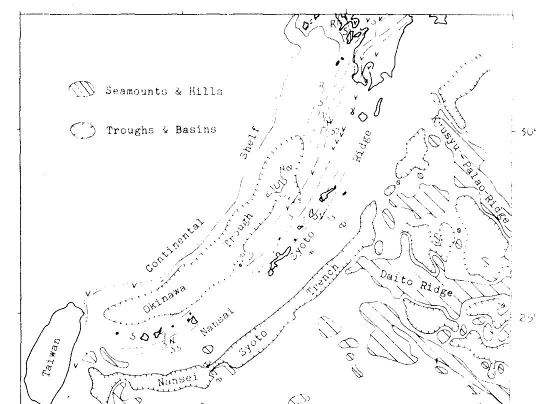

Fig. 7. Geographical chart of the Nansei Syoto (Ryukyu) Trench and its neiborhood.
Geological provinces of the Nansei Syoto Ridge and Kyusyu are based on KONISHI (1965)[8)] and ISOMI (1968)[7)].
R: Ryoke belt, S: Sanbagawa belt, T: Titibu belt, SN: North belt of Simanto, SS: South belt of Simanto, v: Ryukyu volcanic belt.

部，南部の各海盆に三分される。中部は狭長で，海溝中で最も深い地域で，最深 7,881m に達する。水深 7,300 m の海溝底における人工地震の結果（MURAUCHI *et al.*, 1968）[9] によると，4.4 km/sec 層を基盤に，その上に低速の堆積層（約2 km/sec 層）の厚さ 1.2 km の充填が観測されている。したがって，本来の海溝地形はさらに深いことになる。北部および南部の海溝底盆は，中部より浅く，一般に水深 5,000〜6,500 mの区域が広い。大洋底からの比深も1,000〜2,000 m 程度である。

海溝斜面の勾配は，音測記録が充分にとられていないので，はっきりしない部分も多いが，相対的に勾配の急な中部で，陸地側に約 8°，大洋側で 3° である。

5.　フィリピン海溝

海溝の方向は，NNW-SSE を示す。V 字型の海溝地形断面は，海溝北部の Luzon 沖で broad trouhg-like depression に移行している。海溝の南端は Halmahera 東方まで追跡できる。

フィリピン海溝の断面は，古くは KIILERICH (1956)[10] により，最近は IWABUCHI and SAIKI (1968)[11] によってえられている。1965年，1966年に「拓洋」によってえられた海溝地形の断面を Fig. 8 に示す。断面 A は Luzon 東方の海溝北端のもので，海溝地形に特有な narrow gorge は発達していない。Luzon 沖で海溝特有の地形を示さない理由には，ほとんど埋め立てられてしまった海溝であると共に，もともとが，西南日本海溝と同じように浅い海溝であったのかもしれない。

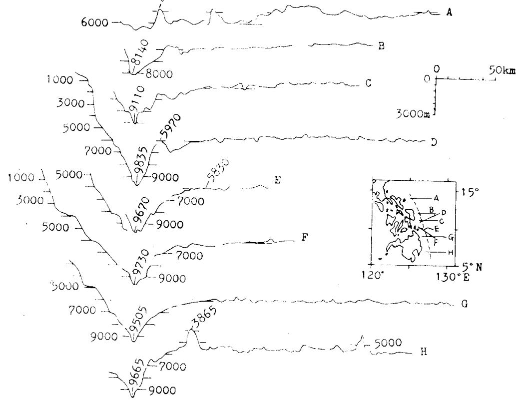

Fig. 8. Profiles across the Philippine Trench.

断面 B. C. D は Samar 沖，E. F は Cape Johnson Deep (10,497 m) より若干南側のものである。最も急斜の陸側斜面で 19°，大洋側の緩傾斜部で 5° となるが，地域により，大洋側の斜面が陸側より急になるところがある。

総じて，陸側海溝斜面には，幅 4〜12 km 程度の数段の bench が認められる。また，大洋側には，海溝を縁どる顕著な marginal swell は認められないが，日本海溝で認められたと同様な断層起源と考えられる small narrow depression や sea の scarp を伴う階段状の地形が認められる。類似の地形は，海溝地区を過ぎた Luzon 沖の troughの大洋側地域にも追跡できる。

海溝底は全体的に平坦化されていないことから，海溝を埋め立てている厚い堆積物の存在は期待できない。

6.　伊豆—小笠原海溝

日本海溝と伊豆—小笠原海溝の境は，房総半島のほぼ南方，相模舟状海盆の海溝区への出口に求められる。伊豆—小笠原海溝は，伊豆諸島，小笠原諸島を頂く海嶺と平行して，その東側に南北におおよそ850 km にわたって連なる。南端は Ogasawara plateau によって仕切られている。Fig. 9 に海溝北部地域を中心とした地形区分図を，また海溝の代表的断面を Fig. 10 に示す。

海溝に並走する海嶺の crest には，伊豆大島からはじまり火山列島に至る活火山帯をのせている。しかし，30°N以南では，活火山帯の東側には，小笠原舟状海盆をへだてて，さらにもう一つの crest（外弧—小笠原海嶺）があり，顕著な二重弧を示す。

30° N以北において，外弧がはっきりしない理由の一つには，外弧が北に行くほど内弧に接すると共に，crest としての発達が悪いために，内・外弧の crest 間の trough が，堆積物で埋め立てられるにつれ，地形上目立たなくなったことが考えられる。この間の事情の地形は，Fig. 10 に認められるように，深海平坦面と海溝斜面近くの rough 地形

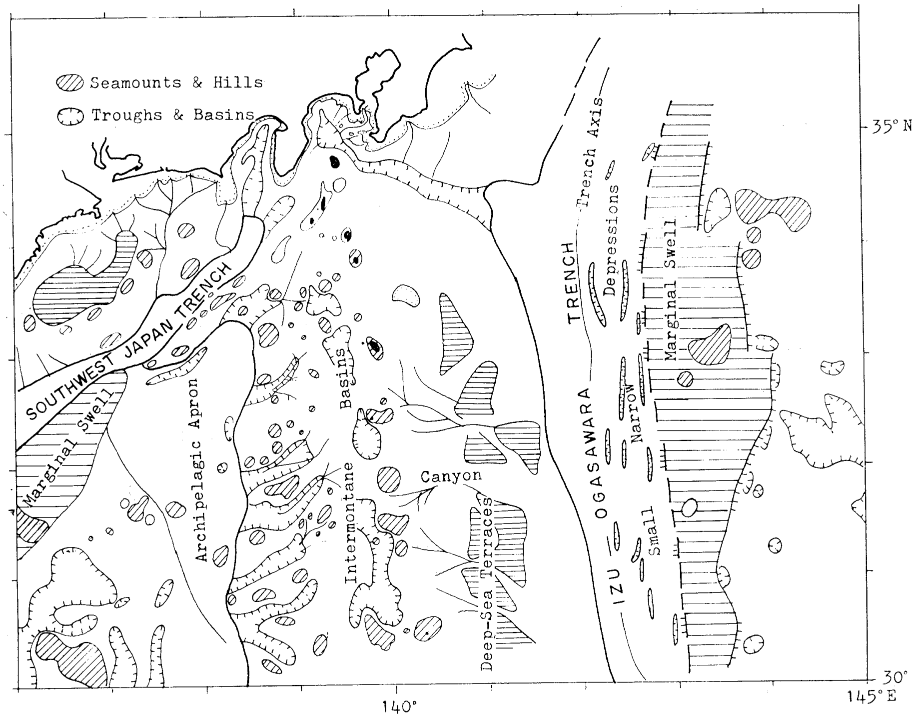

Fig. 9. Geographical chart of the northern part of the Izu-Ogasawara Trench and Ridge.

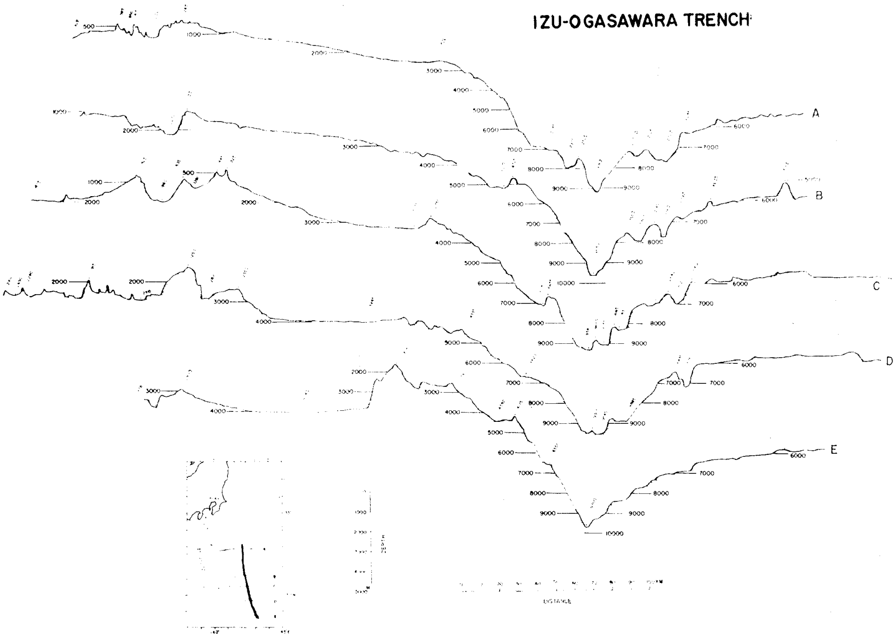

Fig. 10. Profiles across the Izu-Ogasawara Trench.

としてみられる。海溝地形は，伊豆―小笠原地区でも，新生代火山帯をのせる crest との並走関係が強い。

crest の西側の海嶺側面は，東側（海溝側）と対照的に，火山起源とみられる数多くの海山―海丘と，その間を占める intermontane basin と oblique trough のみられる複雑な起伏を示す地域になっている。

海溝と海嶺東側面（大陸斜面）との境は，伊豆七島沖では水深 2,000～3,000 m に求められるが，海溝の南部では深く，4,000～4,500 m となる地域もある。大洋側との境界は一般に漸移的であるが，急崖ではじまる斜面もある。水深 5,500～6,000 m が境になる。やはり南部地区に水深が増大している。

海溝陸側斜面に bench が認められ，その外縁に比高数百mの ridge をもつことや大洋側斜面に small narrow depression を伴うことは，日本海溝の場合と全く同じである。

marginal swell の大洋側端が，急斜面をもって大洋底に移ることは，この境界部に断層を想定させる (Fig. 9)。

伊豆―小笠原海溝は，日本海溝と類似の地形を示すというものの，海溝の水深が大であることと共に，起伏の規模が大きいという特徴がある。

3. 海溝の形成時期と形成機構

日本海溝の形成時期は，飯島・加賀美 (1961)[12] によると，女川沖の大陸斜面上の平坦面外縁付近の底質資料から late Pliocene～ early Pleistocene であるとされている。

また，西南日本海溝の形成期についても，若干の手懸りとなりそうな資料がある。紀州四万十帯団体研究グループ (1968)[13] によると，西南日本外帯の四万十地向斜における牟婁層群（古第三系ないし下部中新統）の堆積時に，少なくとも，現在の紀伊半島南部の海域に陸地の存在が考えられるという。しかしながら，現在の海底には陸地を予想させるような地形は見当らない。当時の陸地が現在の海底地形下へと消滅したのは，西南日本外帯沖の大陸斜面および西南日本海溝を形成した一連の規模の大きい造地形運動による結果と判断される。このことから，逆に西南日本海溝形成時期に対して，ある限定（中新世中期以降）が与えられるのではあるまいか。

他の海溝になると，形成時期を決める証拠は更に乏しいものとなる。南西諸島海溝については，海溝地形が先中新世の累帯構造との関連性に乏しいことから，中新世以降の形成による地形とみなしえよう。同様な見方は，伊豆―小笠原海溝についてもいえるであろう。

海溝地形の形成は，多少の時間的ずれはあるにせよ，日本列島周辺の海溝は，ほぼ同時期に活動していたのではあるまいか。そして，この活動は比較的新しい時代までつづいていると考えられる。このことは，表層の堆積層まで切る断層が，日本海溝の太平洋側斜面や marginal swell にかけてみられることからもうなずける (LUDWIG *et al.*, 1966)[14]。

海溝の形成にあたっては，海溝地形の特徴から単純に張力による断裂運動の結果であるとの解釈が可能である。しかし，近年，海溝を convection current によって説明しようとする試みが盛んに行なわれている。日本海溝についても，上田・杉村 (1968)[15] によって行なわれている。単一の海溝についての説明は魅力的ではあるが，ほぼ同時期に活動したと考えられる海溝（緒言でふれた海溝群）を，同時に統一的に説明しうるような convection current の経路を考えることは，現在のところむずかしい。

他方，星野 (1962)[16] は，海溝の凹地は，島弧の隆起をみちびいた，著しい玄武岩の上昇厚化を補償するために，海溝の部分で垂直的に沈降してできたものとしている。

いずれにしろ，海溝については，形成時期，形成機構をふくめて，今後解明されなければならない多くの問題が残されている。その意味では，北西太平洋地域の調査は，やっと緒についたばかりといえよう。

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Some Petrological Problems on the Seamounts and Ridges in the Northwestern Pacific*

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Abstract: Some conclusions and suggestive remarks can be summarized on the petrological problems of the seamounts and ridges in the northwestern Pacific as follows:

1) Distinctive differences are found between the tholeiitic rocks of Quaternary and Tertiary age. Furthermore the former is subdivided into minor three types.

Quaternary volcanics:
  RKK type (Ryūkyū, Kurile and Kamchatka)
  OMM type (Ōshima, Toshima, Niijima, Kōzushima, Miyakejima, Mikurajima, Hachijōjima, Aogashima, Torishima, Yuōtō, Uracas, Agriham, Pagan and Alamagan)
  Mixture type (Myōjinshō)
Tertiary volcanics:
  Mixture type (Bonin, Saipan and Guam)

2) Two ways of interpretation are possible on the evolution of the continental crust on and west of the Izu—Bonin—Mariana arc. One is considered to express the stage of generation of the continental block, and the other is considered to express that of diminution of the continental crust.

3) Exact situation must be re-examined of the so-called "Andesite Line". In the same meaning it must be re-examined whether the iceberg is the main factor to construct the rocks of the Emperor seamounts.

1. Introduction

There exist so scare mineralogical, petrological and petrochemical data available on the seamounts and oceanic ridges in the northwestern Pacific that it is impossible to discuss their problems fully. But on the basis of the petrological and geophysical data hitherto obtained on the island arcs and oceanic ridges, it is possible to guess and suggest some basical problems to clarify the future direction of researches on the seamounts and oceanic ridges.

In this paper I intend to summarize the present status and give some suggestions on petrological problems in the northwestern Pacific, in close combination to the information on the islands and some dredged samples.

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2. Island arc and oceanic ridge system

The geological setting of the island arc and oceanic ridge system in this area has been given in detail by such eminent geologists as HESS (1948), TAYAMA (1952) and DIETZ (1954), so here only the brief outline relevant to present discussion is presented on geological environment of the island arc and ridge system.

1. Ryūkyū, Honshū, Kurile and Kamchatka: They are situated along the marginal part of the northwestern Pacific and are the member of so-called "Circum-Pacific Suite". Plentiful petrochemical data are available.

2. Izu-Bonin-Mariana island arc: Towards southward from Izu Peninsula, the the well-known Izu-Bonin-Mariana arc extends in order of Ōshima, Toshima, Niijima, Shikinejima, Kōzushima, Miyakejima, Mikurajima, Hachijō-jima, Aogashima, Myōjinshō (Bayonnaise), Torishima, Bonin, Yuōtō, Uracas, Pagan,

Saipan and Guam. The first five are arranged subparallel to the main structure of the Japanese islands to be pointed out as echelon structure. On the other hand, the rests are distributed with "Fossa Magna" trend, forming long lines of small islands. MURAUCHI *et al.* (1968) measured the value of 5.5 km/sec in the seismic velocity near Yuōtō of this arc.

3. Kyūshū-Palau and Oki-Daitō ridges: The former is developed with the N-S trend from off of Kyūshū, through the boundary portion between the Philippine and Shikoku basin, to Palau islands. While Oki-Daitō ridge is situated in the Philippine basin, just west of the Kyūshū-Palau ridge. MURAUCHI *et al.* (1968) reported the layers of 5.6 and 6.0 km/sec in seismic velocity on the Kyūshū-Palau and Oki-Daitō ridges respectively. A significant discovery.

4. Nishishichito and west Mariana ridges: Parallel to the Izu-Bonin-Mariana arc, these ridges are formed in the eastern part of the Shikoku basin, ending near the Yap-Mariana trench.

5. Emperor seamounts: They are running from the neighbourhood of the Aleutian islands towards the Hawaiian islands. KUNO *et al.* (1956) reported a lot of rock fragments from the Jimmu seamount.

6. Marcus-Necker ridge: Of particular interest is its structural relation to the Izu-Bonin-Mariana arc. Near Yuōtō where they are encountered each other, the water depth becomes shallower.

3. Major division of rock types

Tholeiitic rocks series on the Kamchatka territory, the islands such as Ryūkyū and Kurile, and the Izu-Bonin-Mariana arc can be tentatively classified into several major rock types, on the basis of the petrochemistry. According to my opinion (AOKI and ITO, 1968a, 1968b, 1969), the so-called high-alumina basalt proposed and thereafter modified by KUNO (1960, 1965, 1966, 1967, 1968a, 1968b) is erroneous. Hence it is included into the tholeiite member.

1. Quaternary volcanic rock
   1) RKK type: Ryūkyū (KUNO, 1962), Kurile (ЗРЛИХ, 1966) and Kamchatka (TOMKEIEFF, 1949).
   2) OMM type: Ōshima (TSUBOI, 1917; IWASAKI, 1935; NAGATA, 1941; TSUYA and MORIMOTO, 1951; TSUYA *et al.*, 1952; SAWAMURA, 1952; NAGASHIMA, 1953; Geological Survey of Japan, 1957; KATSURA and NAKAMURA, 1960; KUNO, 1962; ISSHIKI *et al.*, 1963), Toshima (BACHER, 1914), Niijima (BACHER, 1914; TSUYA, 1929; KANI, 1939 and KUNO, 1962), Kōzushima (TSUYA, 1929), Miyakejima (TSUYA, 1937, 1940, 1941; HAGIWARA, 1941; KAWANO and AOKI, 1959; ISSHIKI, 1960, 1964; MATSUDA and MORIMOTO, 1962), Mikurajima (TSUYA, 1937), Hachijōjima (TSUYA, 1937; KATSURA, 1956; ISSHIKI, 1958, 1959, 1963), Aogashima (TSUYA, 1937; ISSHIKI, 1955), Torishima (TSUYA, 1937; TANAKADATE, 1940b; KUNO, 1960), Yuōtō (TSUYA, 1936; IWASAKI, 1937), Uracas (KAISER, 1903; TANAKADATE, 1940a), Agriham (SCHMIDT, 1957), Pagan (TANAKADATE, 1940; SCHMIDT, 1957) and Alamagan (SCHMIDT, 1957).
   3) Mixture type of RKK and OMM: Myōjinshō (NIINO *et al.*, 1953; TSUYA *et al.*, 1953; HAMAGUCHI and TATSUMOTO, 1953; SUWA, 1953; MORIMOTO *et al.*, 1955).
2. Tertiary volcanic rock
   Bonin (HOBBS and HUNT, 1926; TSUYA, 1937; IGAWA and IWASAKI, 1938), Saipan (TSUBOYA, 1932; SCHMIDT, 1957; CLOUD *et al*, 1956) and Guam (SCHMIDT, 1957; STARK, 1963).

The main difference between RKK and OMM types may be summarized as follows:

The former tends to maintain higher SiO_2, Na_2O, K_2O and total alkali and lower TiO_2, FeO, total FeO, MgO and CaO than the latter. There seems to be no regular distribution trend in Al_2O_3 and Fe_2O_3 between both types. The oxidation state predominates in RKK type. The rocks from Tonga islands (RICHARD, 1962) in the southwestern Pacific seem also to belong to OMM type.

Mixture type is characterized by the occurrence of both RKK and OMM types in each

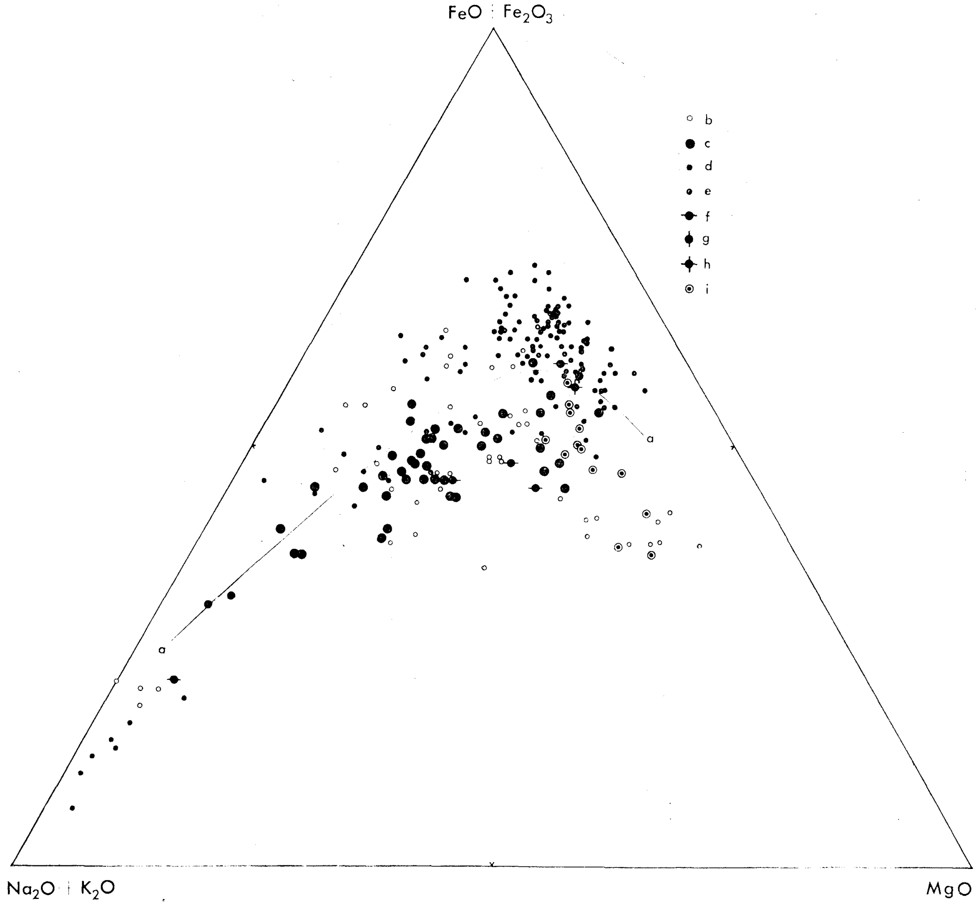

Fig. 1. MgO−FeO+Fe_2O_3−Na_2O+K_2O diagram for tholeiitic rock series in the northwestern Pacific. For the sake of comparison, those from the southwestern Pacific and East-Pacific Rise are also indicated.

a-a: Boundary line between pigeonitic rock series (above a-a) and hypersthenic rock series (below a-a) in the Izu-Hakone region.

b: Mixture type of the Tertiary volcanic rocks in Bonin, Saipan and Guam.

c: RKK type of the Quaternary volcanic rocks in Ryūkyū, Kurile and Kamchatka.

d: OMM type of the Quaternary volcanic rocks in Ōshima, Toshima, Niijima, Kōzushima, Miyakejima, Mikurajima, Hachijōjima, Aogashima, Torishima, Yuōtō, Uracus, Agriham, Pagan and Alamagan.

e: Mixture type of the Quaternary volcanic rocks in Myōjinshō.

f: Emperor seamount (Kuno *et al.* 1956)

g: New Britain trench (ПЕТЕЛИН, 1964)

h: Vitiaz deep (Yagi, 1960)

i: East-Pacific Rise (Engel and Engel, 1964; McBirney and Aoki, 1966; Bonatti, 1967)

island or islands. The most famous examples are the rocks of Myōjinshō in the Quaternary age and those of Bonin, Saipan and Guam in the Tertiary age.

Trachyandesite is found on Yuōtō where the Izu-Bonin-Mariana arc is encountered with the

Marcus-Necker ridge, as already mentioned. Except of trachyandesite, the rocks from Yuōtō are included in OMM type.

Here the diagram is presented only for the $MgO-FeO+Fe_2O_3-Na_2O+K_2O$ relation to demonstrate the characteristics distinct in each rock type (Fig. 1). For the sake of comparison, the dredged samples are also shown from Emperor seamount (KUNO *et al.*, 1956), Vitiaz deep (YAGI, 1960), near New Britain (ПЕТЕЛИН, 1964) and East-Pacific Rise (ENGEL and ENGEL, 1964; MCBIRNEY and AOKI, 1966; BONATTI, 1967).

4. Rocks dredged from the northwestern Pacific

Very scanty rocks are hitherto dredged and chemically analysed from seamounts and oceanic floors in the northwestern Pacific.

1. Emperor seamounts: KUNO *et al.*, (1956) reported rock fragments dredged from Jimmu seamount, one of Emperor seamounts, and rendered their origin to the Pleistocene iceberg which transported them from the Kurile and Kamchatka territory. They are andesitic and basaltic rocks, gneiss, tuff, and sedimentary rocks. Petrochemically the volcanic rocks evidently belongs to RKK type. In the cruise of R/V Hakuhō in 1968, I dredged biotite-hornblende granite with 29×18×17 cm in size and rounded form from Suiko seamount of Emperor seamount (unpublished data). Though the volcanic rocks, gneiss and granite belong evidently to rock types characteristic in "Circum-Pacific mobile belt", it is not yet distinct that all rocks were transported by the iceberg from the marginal belt of the north Pacific. I believe that there exists alternative possibility yet for some of them to be formed *in situ* for their ultimate origin.

2. Vitiaz deep: YAGI (1960) described the doleritic block from the bottom of the Vitiaz deep of Mariana trench and contributed its origin to "Circum-Pacific Suite". But I am led to the conclusion against his interpretation. The doleritic rock has higher contents of TiO_2, MgO and low content of K_2O, and resembles to the so-called oceanic tholeiite. It is clear, that; if it is *in situ*, then "andesite line" must be redrawn.

Though the basaltic rock (ПЕТЕЛИН, 1964) dredged from the New Britain trench in the southwestern Pacific seems to belong to OMM type in some respects, but resemble to the rock from the Vitiaz deep in many respects except of the low contents of Al_2O_3 and TiO_2.

5. Suggestive remarks

The data available on the seamounts and oceanic ridges are too few to give full discussion on their origin. In spite of scanty data, with aid of the information on the islands, some suggestive remarks can be given on the present status and future direction of oceanic petrology in the northwestern Pacific. These are as follows:

1. Rocks on Kamchatka territory and islands in the northwestern Pacific are tentatively grouped into three major rock types, namely RKK, OMM and Mixture types. The Tertiary volcanic rocks belong to Mixture type on Bonin, Saipan and Guam, while the Quaternary volcanic rocks tend to be seperated into RKK and OMM types. But rocks from Myōjinshō belong to Mixture type. Of particular interest is the problem to be solved in future study whether the characteristics of each rock type are continuous or not on the adjacent oceanic ridges such as Nishishichitō ridge and west Mariana ridge.

2. It is obvious for the continental blocks to exist on and west of the Izu-Bonin-Mariana arc. It must be decided from what kinds of rock types the layer with 5-6 km/sec in seismic velocity on the Kyūshū-Palau and Oki-Daitō ridges is built up. This study will surely contribute to the solution of the evolution of this area.

3. As evident from the re-examination of doleritic rocks from the Vitiaz deep, the Andesite Line must be re-examined to get the correct position. It is clear for the Andesite Line not to be so simple as hitherto accepted one. This suggestion is harmonious with the already mentioned working hypothesis that the rocks of the Izu-Bonin-Mariana arc are made up of various rock types such as RKK, OMM and Mixture types.

4. Myōjinshō and Yuōtō seem to hold one of the keys to solve the island arc problem. The latter has the significant position where the Marcus-Necker Ridge encounters with the Izu-Bonin-Mariana arc and trachyandesite occurs.

5. The generally accepted conclusion that the iceberg is the main factor to transport the RKK type from the "Circum-Pacific Suite" must be reconsidered on the basis of the detailed floor survey. At least the basement rocks must be dredged out. If RKK of the Emperor seamount is the basement rocks, interesting problems arisen on the oceanic petrology.

6. According to my opinion (AOKI, 1969), two possibilities exist on the evolution of the continental crust on and west of the Izu-Bonin-Mariana arc. First is the stage of generation of the continental block. Second is the stage of diminution of the continental crust due to such factors as "oceanization" (БЕЛОУСОВ, 1968) and/or erosion. This fundamental problem must be researched on the basis of the quantitative oceanic petrology.

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北西太平洋の海山・海嶺の岩石学的諸問題

青　木　　斌

要旨: 北西太平洋の海洋岩石学的な諸問題を検討し，つぎの結論をえた。

1) 第三紀火山と第四紀火山の性質は異なり，第四紀火山はさらに三区分される。

第四紀火山

RKK型（琉球・千島・カムチャッカ）

OMM型（大島・利島・新島・神津島・三宅島・御蔵島・八丈島・青ケ島・鳥島・硫黄島・ウラカス・アグリハム・パアガン・アラマガン）

混合型（明神礁）

第三紀火山

混合型（小笠原・サイパン・グァム）

2) 伊豆—小笠原—マリアナ弧以西の大陸地殻の現状について，二つの考えが可能である。すなわち，各海域に散在する大陸地殻は，大陸の発生段階を示すのか，あるいは，大陸の消滅段階をとどめているのかという問題である。

3) 安山岩線の意義を再検討しなければならない。この観点にたつならば，天皇海山の大陸性岩石を氷河に要因を求める従来の考えは，再考を要する。

La mer (Bulletin de la Société franco-japonaise d'océanographie)
Tome 7, N° 3, Août 1969

西太平洋縁海の海底地形*

茂　木　昭　夫**

Topographie sous-marine de mers bordières du Pacifique d'ouest

Akio MOGI

Résumé: L'auteur décrit la particularité de la topographie générale des mers bordières du Pacifique d'ouest. Elle est détaillée, à titre d'exemple, pour la mer du Japon et la mer de Philippine.

1. 日本海

1. 地形区分

日本海は中央部をほぼ ENE-WSW の方向に走る大和海嶺，朝鮮海台（中央海嶺）によって，北側の日本海盆と，大和海盆・対馬海盆からなる南側海盆との二つに分れる。

北部海盆では朝鮮および沿海州に沿って，狭い単調な大陸棚と大陸斜面が縁どっているが，南側海盆では，日本島弧に沿う多数の礁・堆・小海盆が発達していて，continental borderland の地形を示している。北部海盆は地震探査の結果大洋性地殻を示し，南部海盆でも亜大洋性地殻を示すが，中央部の大和海嶺は大陸性地殻を示す。

2. 礁・堆の分布

1) 中央海嶺

［大和海嶺］日本海中央部を ENE-WSW 方向に走る比高約 2,500 m の山体。大和堆・北大和堆の二つのブロックに分れ，その間に地溝を挟む。大和堆は約 300 m，北大和堆は約 500 m に削剝された平坦面を有し，基盤の花崗岩・安山岩の上に薄い砂礫層をのせる[2)3)]。大和堆，北大和堆の各地塊の方向は海嶺全体の方向に斜交し，互に雁行した配列を示す。

［朝鮮海台］大和海嶺の正に西南西延長にあたる。水深 700〜1,000 m で，海台上に削剝面を有するかどうかは明らかでない。大和海嶺の様に ENE-WSW方向の地溝によって矢張り二つの地塊に分れる。

2) 大陸縁辺 (Fig. 1)

［奥尻海嶺］佐渡付近から粟島・飛島・新礁・奥尻島等を通って，北海道西方武蔵堆付近まで続く長大な海底山脈[4)]。多数の独立した堆が断続しながら続き，渡島半島から北では神威海嶺等の 3 条の小海嶺に分岐する。日本島弧にほぼ平行し，各堆は雁行配列しているが，その雁行の重なりは小さく，従って全体的に狭長な山脈を形成している。

［佐渡海嶺］奥尻海嶺の外側にこれに平行に配列する堆群で，佐渡から向瀬・瓢箪礁・最上堆と続いて，男鹿半島北西沖で消失する。各堆は互に重なり合って配列し，そのため全体的に延長の短かい幅の広い海嶺を形成している。各堆は断層によって境されているから，雁行の重なりの大きい配列と見る事ができる。

全体的に NNE-SSW の方向に走るが，個々の堆はこれとやや斜交する。

［若狭海嶺］若狭湾口に見られる松出し，玄達瀬から経ヶ岬に向う堆列で，ENE-WSW の方向をとる。個々の堆はわずかに雁行するが重なりが小さく断続的である。

［隠岐海嶺］隠岐の東方を ENE-WSW 方向に走

* 1969年5月4日受理
** 水路部 Hydrographic Department, Japan

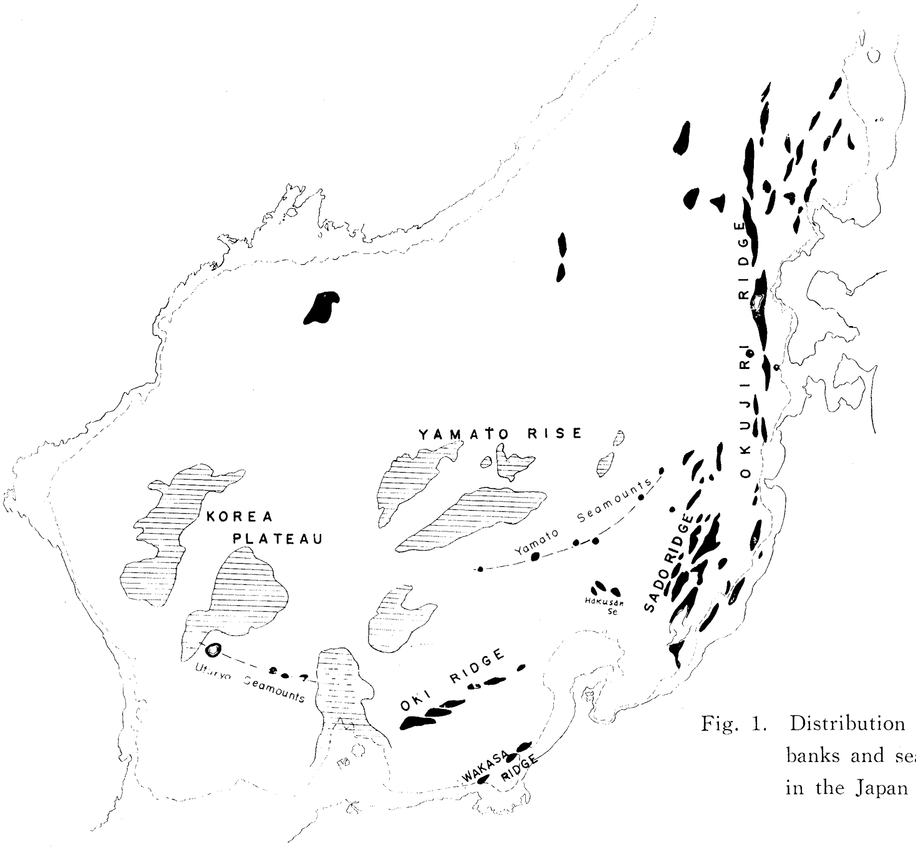


Fig. 1. Distribution of reefs, banks and seamounts in the Japan Sea.

る堆列で，水深約300 mに削剥された数個の堆の雁行したものである。個々の堆はほぼ東西の方向を指向し海嶺方向と斜交する。各堆の雁行の重なりは大きく佐渡海嶺と似る。

［白山堆群］能登半島の沖にあり，3個の堆が雁行して配列しているものである。その方向はNW-SE 方向で，日本海の大陸縁辺に見られる多数の堆の中で唯一の特異な方向を示す。

［北海道北西部隆起帯］北海道神威岬以北の海底には，NW-SE 方向の数条の隆起帯がある。これらは前記の礁・堆からなる海嶺と異なり，輪郭が不鮮明で，緩く盛り上ったような地形を示している。この部分で3条に分岐した南北方向の奥尻海嶺と交叉するため，更に複雑な地形を示す。

3.　隠岐陸棚と海山群

［隠岐陸棚］隠岐島をのせて北方に半島状に突き出した陸棚。水深約300 mで通常の陸棚の深さに比べて深く，その方向は日本海の諸堆の方向と異なって全く異質である。

［海山群］大和海盆，対馬海盆には線状に配列する弧立山体がある。大和海盆ではほぼ中央部をENE-WSW 方向に縦断するもので，円錐形又は楕円形の山体を示し，局部的に地殻熱流量が高い所もある。これを大和海山群と仮称する。対馬海盆ではうつりょう島から竹島を経て新藤礁に至る線状に配列した数個の島又は円錐形の孤立した堆がある。これをうつりょう海山群と仮称する。

4.　礁・堆の配列に見られる諸関係

以上日本海に見られる礁・堆群の配列を概観して，そこに見られる諸関係をまとめれば下記の通りである。

1）渡島半島以南の諸海嶺は地塁の配列したものであるが，以北のNW-SE方向の隆起帯は連続した輪郭の不鮮明な隆起帯である。

2）内側の奥尻海嶺・若狭海嶺は雁行の重なりが小さく，断続的な配列を示すが，外側の佐渡海

嶺・隠岐海嶺は雁行の重なりが大きく密集して配列する。

3) 渡島半島以南では堆の方向は対岸の第三系の褶曲軸の方向とほぼ一致する。

4) 北海道北西域では奥尻海嶺と陸上の第三系との関係は見られず，むしろNW-SE方向の数条の海底隆起帯と陸上褶曲構造との関連が見られる。

5) 奥尻海嶺の南端は弥彦山地に連続する可能性があり，佐渡海嶺の南端は佐渡堆を通って米山に連続する可能性がある。佐渡海嶺の南端が急激に南の方に折れ曲るのは，グリーンタフ地域の第三系が，フォッサ・マグナの近くで伊豆・マリアナ方向に折れ曲るのと軌を一にする。

6) 大和海嶺と朝鮮海台とは間に 2,000 m の海盆を挟むが大体連続する。いずれも中央部にNE-SW 方向の地溝を有し，これにより二つの地塊に分かれる。

7) 大和海嶺付近の山地と海盆の配列関係は，朝鮮海台—海盆—大和海嶺となっており，その南では海盆(対馬)—隠岐陸棚—海盆(大和)となっていて，互に補い合う関係になっている。

5. linearity (Fig. 2)

海底では侵食作用がほとんど無視できるから，

Fig. 2. Fault map based chiefly on sea floor topographies in the Japan Sea.

構造運動で形成された地形は，一部堆積によって埋まることはあっても破壊されずに残る。従って海底地形にあらわれた線構造は断層・褶曲などのあらわれと見てよい。Fig. 2 はこのような観点から海底地形に見られる線構造を示したものである。これらの内，長距離にわたって直線状に続く地形としては，沿海州の陸棚斜面，大和海嶺と朝鮮海台の南北両側の斜面，長距離にわたって線の密集した佐渡から北海道北西海域に至る区域および能登沖から隠岐島に至る区域があり，これらは大体 ENE-WSW の方向で互に平行している。これに対しほぼ直交する同様な線構造が認められる。すなわち朝鮮の東側の陸棚斜面，朝鮮海台の東側斜面と隠岐陸棚の西側斜面を連ねた線，大和海嶺の西側斜面と隠岐陸棚の東側斜面を連ねた線，フォッサ・マグナ，富山舟状海盆・大和堆の東端を連ねた線がそれである。これらは互に平行関係にあり，前者と格子状を形成していて，前記大和海嶺・朝鮮海台・隠岐陸棚の配列関係が，これらの構造線に沿って移動したことによって生じた事を推定させる。

西日本では，大和海嶺・朝鮮海台・隠岐海嶺および西日本が互に平行関係にあるだけでなく，いずれもNE-SW 方向の小規模な線構造が卓越していて極めて類似しているが，東日本では NE-SW, N-S, NNE-SSW, NW-SE 等の多方向の線構造が見られる。これはフォッサ・マグナを境として西方では大きなひずみを受けていないが，東方では著しいひずみを受けた事を暗示する。

6. 海　盆

日本海の海盆は，地形の配列から見て前記の ENE-WSW 方向の大構造線による rift と考えられる。これを裏付けるものとしては，これらの海盆が大洋性地殻又は亜大洋性地殻からなること，地殻熱流量が高い[6] ことなどがあげられる。大陸縁辺には多数の小海盆がある。これらは舟状海盆と海盆に分けられ，前者は内側海嶺(奥尻・若狭)と外側海嶺(佐渡・隠岐)との間，又はフォッサ・マグナ延長上に見られるもので，深海盆への出口を有していることが多い。小海盆の連結したもの

で，埋積のため階段状になっている。小海盆は種々の方向の構造線に沿って陥没したために生じたものと思われ，東北日本に著しく多い。特に北海道北西部では3条の奥尻海嶺とNW-SE方向の隆起帯の交叉によって，多数の海盆を形成している。海盆底は，日本海盆，対馬海盆，大和海盆等の外洋性のものでは深海平原である。大陸縁辺内では，ゆるやかな微起伏を示し一般に陸側から外洋へ向って緩傾斜する。大陸斜面下部にはしばしば扇状地が見られ，富山舟状海盆や最上舟状海盆のようなdeep sea channelの発達している所では海底自然堤防が発達し，海盆の出口には深海扇状地が見られる。

7. 海底谷

日本海には大陸斜面を刻んで多数の海底谷が発達しているが，これらは長大な谷と短小な谷とに分けられる。前者はいずれも舟状海盆に形成されているもので末端水深は −3,000 m に達し，自然堤防・深海扇状地を伴う。谷は海盆底を100m以上刻み，多小断続しながら数 100 km にわたって続く。短小な谷は小海盆に注ぐもので，末端水深はそれぞれの海盆底の深さである。小海盆は沖側を海嶺(堤)で閉ざされているため海底谷は海盆内で終るのである。海底谷の成因を解くには未だ資料不足であるが，次の様に要約できよう。

1) 小海盆では現在埋積の過程にあるため，海盆内で終っているが，海盆底が sill depth に達すると溢流を生じて谷の形成(延長)が期待される。

2) 自然堤防や深海扇状地は混濁流による形成を暗示する。

3) 富山湾の湾床では粗粒砂や浅海性有孔虫殻が発見されており，自然堤防や深海扇状地からも粗粒堆積物が得られている[7]。

4) 富山湾の諸海底谷は明らかに基盤の第三系と洪積・冲積両層を同時に刻んでいる。

5) deep sea channel は舟状海盆内で現堆積層を刻んでいると推定される。

6) しかし日本海の大陸縁辺では鮮新世以来数100 m の沈降があることも事実であり[8]，混濁流が現在の谷の形成に関与しているとしても，初原的に沈降谷が存在した事を否定することにはならない。

2. フィリピン海

1. 地形区分

フィリピン海は北西縁を日本列島・琉球列島・フィリピン諸島，東南縁を伊豆・小笠原海嶺・マリアナ・ヤップ・パラオ・トコベイの諸海嶺によって取囲まれた一つの大きな地形単元を形成している。これら四周の諸海嶺は，いずれも大洋側に海溝を有し，火山帯・地震帯・重力異常帯を伴い，西太平洋に典型的に見られる孤状列島を形成している[9]。フィリピン海の中央を南北に走る九州・パラオ海嶺によって，西のフィリピン海盆と，東の四国海盆・西マリアナ海盆とに分れるが，更にフィリピン海盆には南北に走る大東―ルソン海

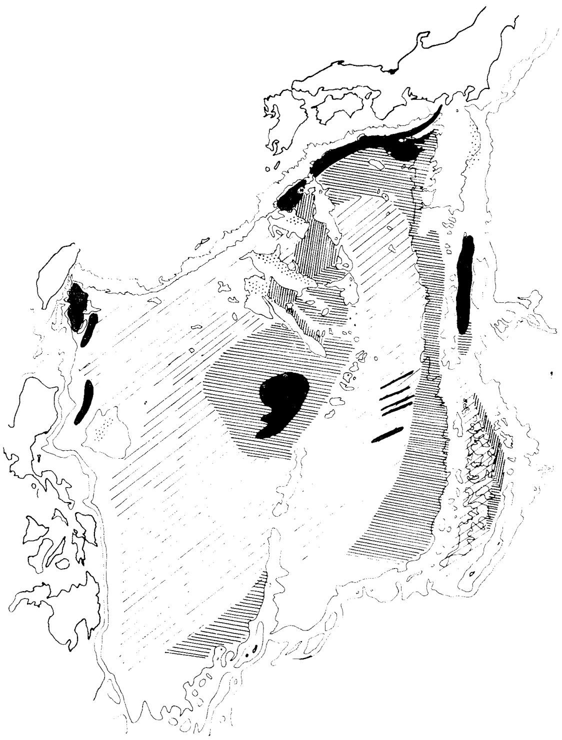
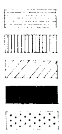


Fig. 3. Map of geomorphological classification of the sea floor of the Philippine Sea.



gently undulated plain (I)
gently undulated plain (II)
abyssal hills
abyssal plain
deep sea terrace

膨，四国海盆には同方向の紀南海山群がある。このような南北方向の諸海嶺に対して，異質なものは，フィリピン海盆の北隅にある大東海嶺群で，ここでは東西の方向に走る。

2. 海盆底（Fig. 3）

1) 深海平原

Fig. 3 に音測断面から作った海盆底の分類図を示した。ほとんど起伏のない深海平原は，フィリピン海の海盆底では意外に少なく，かなり局部的な分布を示している。小笠原舟状海盆は完全な深海平原で，南のマリアナ舟状海盆とは全く対照的である。南海舟状海盆とその東南部の伊豆海嶺北部に接した部分は深海平原である。南海舟状海盆では駿河湾から海盆に沿って流れる deep sea channel があり，伊豆海嶺北部西側には数条の deep sea channel がある。台湾の東の琉球海溝とルソン島に挟まれた三角地帯及び3条の大東海嶺の間にはさまれる小海盆は，いずれも深海平原である。九州・パラオ海嶺中央部に接する西側海底は，平坦な海底で深海平原と思われる。ごく局部的なものとしては，四国海盆と西マリアナ海盆の境にある NE-SW 方向の深海丘群の間にはさまる地溝状の海底である。

上述のような深海平原の分布を見ると，いずれも陸地又は島に近接した所にのみ見られ，しかも海盆の様にポケットになっていて，堆積物のたまり易い環境を有している事は，深海平原の成因について一つの暗示を与える。南海舟状海盆や伊豆海嶺北西部，台湾東部の deep sea channel の存在は，堆積物の供給路を示すものとして注目される。

2) 微起伏面

波状の小規模な起伏を有する海底面で，かなり広範囲な分布を示す。その代表的な例は四国海盆北部から硫黄列島・西マリアナ海嶺の西側に沿って見られるものである。西マリアナ海嶺の西側では，海嶺から深海丘群にかけてこの面が grade しているが，四国海盆北部では南の深海丘群を埋めるように階段的に深海丘群に移っている。伊豆海嶺の西方から硫黄列島にかけて，この微起伏面が断層と思われる急斜面を境に2段になっている。この様な地形は更に南のパラオ・トコベイ海嶺北側の微起伏面にも見られる。この微起伏面は，マリアナ舟状海盆の東側，九州・パラオ海嶺西側にも見られ，いずれも海嶺の西側に沿ってのみ分布するという非対称性を有する。又いずれも海嶺に沿ってのみあらわれることは注目すべきである。

3) 深海丘群

深海平原・微起伏面を除いた区域は深海丘群で，最も広範な分布を示す。起伏量は 500 m から 1,000 m にわたり，時に 1,000 m をこえることがある。所々に大きな溝（trough）や急斜面を有し，断層などの構造地形を暗示する。特に起伏量の大きい区域は，マリアナ舟状海盆，四国海盆と西マリアナ海盆との境界付近，琉球海溝南部から九州・パラオ海嶺南部にかける central basin fault に沿う一帯に見られる。これらは多分に破砕帯と見なすことができよう。

深海丘群の分布のも一つの特徴は，いずれも海盆の西側を占めるということであろう。東側は前述した微起伏面によって占められ，顕著な非対称分布を示している。海盆全体で見ると深海丘の発達する西側で深く，微起伏面の占める東側でやや浅いから，深海丘群の東側が埋められて微起伏面を形成したと考えられ，その場合堆積の供給源が海嶺であるとしても，混濁流等による堆積物によるか（深海平原），火山噴出物によるか（archipelagic apron）は今後の課題である。

4) linearity（Fig. 4）

フィリピン海をとりまく弧状列島は，海溝によって示される大構造線に沿っているが，これに平行な多数の構造線が弧状列島内に推定される。たとえば伊豆海嶺[10]では，線状に配列している火山島を連ねた線，伊豆海嶺の西端を限る直線状の地形界線等がそれであり，いずれも海溝に平行する。又小笠原海嶺は西側に急斜面を有し，東側に緩斜面を有する傾動地塊を示しており，西マリアナ海嶺は逆に東側急斜面，西側に緩斜面を有する非対称断面を示す。これらの事実から見ると，一般に舟状海盆の内側に急斜面を向けているらしい。

四国海盆では，九州・パラオ海嶺の北端から小笠原海嶺とマリアナ海嶺との屈折点に向う，NW-SE 方向の構造線が断面から推定され，この構造

Fig. 4. Fault map based chiefly on sea floor topographies in the Philippine Sea.

} fault line based on sea floor topographies

abyssal hill area with large relief

線を軸に北東側の四国海盆底は南に向って傾いている。フィリピン海盆にはNW-SEからW-E方向の多数の構造線が推定される。その代表的なものはHESS[11] によって指摘された central basin faultで，琉球海溝の南端から，九州・パラオ海嶺が南部で西方に彎曲する地点に向って走る。起伏の大きい海嶺を形成し，その頂部に深い溝として存在する。この central basin fault と南大東海嶺の間に階段状の急斜面があり，やはり WNW-ESE 方向に走る。多分断層であろう。大東海嶺群には WNW-ESE 方向の多数の線構造があり，同海嶺がこれらの断層によって輪郭を決定したことがわかる。同海嶺上にある多数の様々の深さにある平坦面は，多分これら断層による変位によってもたらされたものであろう。四国海盆の南東側およびフィリピン海盆の南東側に発達する微起伏面を2段に変位させている急斜面は，多分断層であろう。この構造線は四国海盆北端で南海舟状海盆をずらしており，伊勢湾・若狭湾の地峡を指向している。この付近で深発地震帯とほぼ平行関係にあることも見のがせない事実である。

minor faultを示すと思われるものは，四国海盆と西マリアナ海盆の境付近に見られる深海丘から示唆されるものである。この付近で深海丘は線状に延びており，深海丘と深海丘との間には地溝状の溝があって，これらは成因的に構造性のものであることを暗示する。その方向はいずれも NE-SW で前述した大規模な構造線とは直交又は斜交する。又，伊豆海嶺西半にも同方向の10数条の雁行したridgeがある。フィリピン海の linearity を総括して，次の事実を指摘することができよう。

1) 推定構造線は弧状の海嶺の屈折部又は不連続部に集中する傾向がある。たとえば四国海盆をNWN-ESE 方向に走る構造線は，伊豆・小笠原海嶺とマリアナ海嶺との屈折部に向い，マリアナ海嶺の北西延長にあたる。又，central basin fault は，琉球海嶺の南端と，九州・パラオ海嶺南部の屈折部を結んだ位置にあり，この断層を境に，北側の弧が南東に張り出している。

2) フィリピン海に見られる推定構造線が，海溝又は舟状海盆と交わる所では，しばしば海溝軸のズレを起している。前述した四国海盆東側の構造線と南海舟状海盆の関係はこの例であり，九州・パラオ海嶺を境に見られる北側の南海舟状海盆と南側の琉球海溝とのズレ，北大東海嶺北側の構造線を境に見られる琉球海溝のズレ等がその例である。これが断層による offset 構造かどうかは今後の研究に待たなければならないが，構造線に沿ってこの様なズレが見られることは注意すべきであろう。

3) 大東・ルソン海膨はフィリピン海に見られる唯一の海膨である。最近の調査によると，この部分で地殻熱流量が高いらしい。前記の諸構造線が，大体においてこの海膨方向に直角方向であることは興味深い。

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寄　　稿

Some Geological Problems on the Western Pacific Region*

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Foraminifera in Relation to the Marine Geology of the Western Pacific

Living planktonic foraminifera are generally classified into three major groups, namely, warm-water fauna, transition fauna, and cold-water fauna. They are distributed latitudinally, and their boundaries almost coincide with the geographic boundaries of the surface water masses. Within each faunal zone the member species are cosmopolitan except for a few of the warm-water fauna. Good correspondence in distribution is found between the faunas living in the water and the dead assemblages in the bottom suface sediments. The same type of distribution pattern may be traced into the geologic past. Previous discussions on the Quaternary climatic fluctuations and correlations between deep-sea cores and mostly based on the promise that the cold-water fauna migrated equator-ward during the glacial age. Recent studies on the Late Tertiary planktonic foraminifera in Japan revealed two distinct types of faunas, each of which is analogous to that exhibited by modern faunas. One of the two faunas may be termed a warm-water fauna, and the other a cold-water fauna. During the Early Miocene time the warm-water planktonic assemblages are similar in composition and disstributed ubiquitously throughout the marine deposits of the Japanese Islands. The faunal composition is similar to the faunas recorded from the Caribbean and other tropical-subtropical regions. Since the Middle Miocene a cold-water fauna migrated into northern Japan from the boreal Pacific, whereas a warm-water fauna continued to survive in parts of southern Japan. Similar climatic deterioration is inferred from the Neogene planktonic foraminiferal sequences in California on the eastern North Pacific. Detection of paleogeographic dispersal pattern of these types of faunas and the location of the transition zones may be effective means for reonstructing paleoceanography.

Paleoclimatic trends within the Late Cretaceous to Cenozoic interval were inferred from the paleogeographic distribution of the *Globotruncana*- and *Globorotalia*-faunas (BANDY, 1960). On the basis of the evolutionary lineages of the warm-water planktonic species, the Cretaceous and Cenozoic biostratigraphy was carried out on land, and 60 zones are currently recognized on a worldwide scale including the ocean floors (BOLLI, 1966). This planktonic zonation is, however, conditioned to be effective in principle within the latitudinal limit of the warm-water region, such as the *Globorotalia-Globotruncana* line delineated by BANDY (*op. cit.*). In other words, different criteria are necessary for the biostratigraphy of cold-water deposits, in which a limited number of longeval

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species are found dominantly. Among the trochospirally coiled planktonic foraminifera there are some species, in which the coiling direction of the shells are obviously controlled by temperature. Of them *Globigerina pachyderma* is a diagnostic species for a cold-water fauna. Its left-coiling populations dominate in cold-water currents, and the right-coiling ones in warm-water currents. Fluctuations of the coiling ratios of this species in the younger Cenozoic sequences are consistent over wide areas, and have been proved to be useful for correlation at least on a regional scale (TAKAYANAGI and OBA, 1965; and others). Based on the chronologic change in the morphologic traits of species, biostratigraphic zonation can be established for the younger Cenozoic sediments formed outside the warm-water region. Moreover, these zonations of different concepts may be synthesized in a transitional area between the warm-water and cold-water faunal provinces.

The formation of the Sea of Japan is one of the remarkable events in the Neogene geohistory of the western North Pacific. The general foraminiferal sequences in relation to the paleogeographic change of Northeast Japan have been already outlined (ASANO and TAKAYANAGI, 1966), and the change in faunal facies is typically represented in the benthonic foraminifera. For instance, the benthonic faunas of the Pliocene of Japan are grouped into two types, Japan-Sea type and Pacific type (ASANO, 1939). The former is distributed in deposits of Japan-Sea coastal area of Hokkaido to Central Japan, and the latter in the Pacific coastal area of southern Kwanto and westward. Further, another type of fauna (so-called Tatsunokuchi fauna) is distributed along the Pacific coast of Northeast Japan and the meridional zone of Hokkaido. In the light of our present knowledge, however, this is considered to represent a nearshore bay fauna of the Japan-Sea type. These two major types are nothing but a branch of the boreal Pacific fauna (cold-water fauna) and that of the Indo-Pacific fauna (warm-water fauna), respectively. On the other hand, in the Pliocene of California, in the eastern North Pacific, the benthonic faunas consist of the boreal Pacific and West Indian faunas. Accordingly, the Californian fauna has a close relationship not with the fauna of the Pacific coast of Japan but with that of Japan-Sea coast. Benthonic foraminifera will substantiate the historical development of the oceanic margin areas, because they are mostly common and variable on the continental shelves and slopes. Previous studies on benthonic as well as planktonic foraminifera in the seas surrounding Japan are local, but have never been organized on a nation-wide scale. From a uniformitarian point of view, it seems to be a matter of urgent necessity to investigate systematically the Recent foraminiferal faunas of the western Pacific.

In practice there are many difficulties in prosecuting paleontological studies of deep-sea sediments as already discussed by various authors. Above all the solution of calcium carbonate in deep seas is considered to be the important factor affecting foraminiferal faunas secondarily. According to the field experiment, appreciable solution occurred below 1,000 m and increased rapidly below 3,000 m and 5,000 m (BERGER, 1967). The compensation depth, a depth below which all calcareous matter is essentially dissolved, is generally about 4,000 m in the Pacific but changes locally. The solution works selectively to species, and changes the species composition and size distribution of the fauna. It will thus more or less ruin the exactness of the original fauna as a paleontological record. Nevertheless, we may derive rather valuable informations on paleoenvironments from the fossil fauna affected by the solution.

Another difficulty may concern mixed faunas. Recent progress in biostratigraphy of deep-sea sediments has divulged that pre-modern sediments ranging from the Cretaceous to Quaternary in age are distributed on the Pacific ocean floor. It is not unusual to find that older fossils are mixed with younger fossils or Recent faunas in the materials obtained either by coring or dredging. So far as the state of preservation is concerned, it is not always easy to distinguish the reworked older fossils from the younger. Such mixing may be caused mechanically by some sedimentary processes as turbidity currents, and also biologically by mud-eaters, though on a small scale. In any case the distinction of the mixed fauna is to be the first step for further research.

To search into the geohistory of the western Pacific Ocean, biostratigraphic studies of the calcareous pelagic sediments will play an important role. Among the calcareous microfossils planktonic foraminifera have been most useful for correlation and age assignment of the sediments. There is, however, a great obstacle in the way of the planktonic foraminifera to prove their merits in the Pacific Ocean. The area covered with calcareous sediments in the North Pacific is fairly limited in distribution, because most of the ocean floor is below the calcium carbonate compensation depth. The extent of investigation will be thus inevitably concentrated to the areas near continents or topographic highs above the compensation depth. However, as PARKER (1967) remarked, the displacement of sediments are prevalent near continents and any topographic high on the ocean floor may provide the source for displaced material. This fact is naturally led to that a large time gap may be caused in the sedimentary sequence of these areas by such displacement. Careful biostratigraphic examination will be needed for the evaluation of the resulting hiatus, because of the slow rate of accumulation on the deep-sea floor. In the non-calcareous sediments of the North Pacific, the siliceous microfossils such as radiolarians and diatoms occupy a fairly large proportion, and their biostratigraphic zonations have been performed more in the deep-sea sediments than on land. Under these circumstances, the linkage of the planktonic zonations of calcareous and siliceous microfossils is considered necessary for the vast application to the western Pacific.

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On the Deep-Sea Terrace

HOSHINO (1961, 1966) was the first to postulate that the deep-sea terrace developed world-widely on the lower part of the continental slope is the flat plain that was formed near the coastal line of late Miocene and hence it was once the erosion base for submarine canyons. It is distributed in depth of about 2,000 m as the result of the upheaval of sea level that was caused from the expansion of the oceanic crust after its formation.

Afterward, UOZUMI (1967), based on the study of crustal movement of Pliocene Series, supported Hoshino's hypothesis and FUJITA (1968), from the study related with the origin of Japan Sea, was also led to the conclusion similar to that of HOSHINO.

It is hitherto generally accepted that the deep-sea terrace, including Aleutian Bench, has the topography that was formed by the deposition of the recent sediments transported by the turbidity current. But MURAUCHI *et al.* (1965) in their seismic observation have pointed out that the material constituting the deep-sea terrace is the layer with about 2.0 km/sec in seismic velocity. This value of wave velocity seems to correspond to that of Neogene sediments. The similar conclusion can also be obtained from the evidence of fossils collected there (IIJIMA and KAGAMI, 1961; HOSHINO, 1965). Furthermore the distribution area of deep-sea terrace is genetically connected with that of the epicenter of shallowest earthquake (HOSHINO, 1967, 1969; DEN, 1968). This relation is also suggesting the existence of Neogene sediments constituting the deep-sea terrace, and disfavors that of recent sediment transported by the turbidity current.

Recently HOSHINO (1968) presented the recognition that the circumstance under which the marine Pliocene Series is deposited is similar to that of the marine Holocene Series and that both series are the strata formed as the result of the upheaval of sea level.

From the standpoint of marine geology in the western Pacific, some fundamental problems can be summarized as follows:

1. The deep-sea terrace well corresponds to the world-widely developed low sea level in late Miocene. This feature is analogus to the character that the depth of continental shelf edge indicates the low sea level in Maximum Würm. Hence it is expected that the detailed examination on the depth of deep-sea terrace will shed light on the problem concerning the crustal movement of ridges and sea-mounts since late Miocene. For example, towards northern Izu—Mariana ridge, the depth of deep-sea terrace tends to become shallower, suggesting the upheaval of the northern part of the Izu—Mariana ridge.

2. It is necessary to re-examine the theory concerning the origin of coral reef and guyot that are usually attributed to the subsidence of oceanic basin. Though both the coring data on Eniwetok Atoll and fossils collected from the top of guyot in the central Pacific demonstrated the evidence of the subsidence of Pacific basin since Cretaceous, there exists some evidence negative to the wholly subsidence. The terrace topography has been reported from many islands, showing the upheaval of crust since late Tertiary. So it is concluded that the problem on the wholly subsidence of Pacific basin remains unsolved. HESS (1946) was the first to propose the subsidence of guyot that was caused by the upheaval of sea level due to the deposition on the ocean floor. Following him, many geologists ascribed the origin of guyot to the increase of volume of sea water. Nevertheless HOSHINO presented the idea that is well harmonious to the general geological features as follows:

The fundamentally important points are the balance between the upheaval of sea level and the rise of oceanic island. If the former is greater than, is equal to and less than the latter, then the guyot, atoll and terrace topography on the land will be formed, respectively.

It is quite evident from the above-mentioned facts that the deep-sea terrace will provide the key to solve the crustal movement of island arc, guyot, coral reef, etc. and to explore the deep-sea oil field. In this connection, detailed research is needed on the deep-sea terrace from the geological and geophysical point of view.

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Problems about Guyots in the Western Pacific

HESS (1946) had discovered the strange flat-topped seamounts from the Mid-Pacific, named "Guyot", and made the interpretation that they were drowned ancient islands. This was so exciting that many geological expeditions and researches about guyots were carried out. In 1950, the Mid-Pacific Expedition set out to test this hypothesis by exploring guyots, and integrated such reef fauna of Middle Cretaceous age as reef building corals, rudistids and stromatoporoids, were dredged from the tops of five guyots west of Hawaiian Islands. HAMILTON (1956) concluded that the guyots of the Mid-Pacific had been truncated by wave erosion and drowned since late Cretaceous age. Similar drowning of ancient islands were confirmed by the thickness of coral cap in atolls. At the Eniwetok Atoll, drilling of 1,400 m long penetrated the whole cap coral of shallow water fauna, and the actual material of platform was basalt. The limestone just above the basalt basement was of Eocene age (LADD *et al.*, 1953).

In following paragraphs, the writer will describe the facts recently reported concerning to the guyots near to Japan and propose some problems;

The Emperor Seamounts in the Western Pacific contain many guyots. Foraminiferal fossils of Neogene age were reported by NIINO (1961) from the Kammu Guyot one of them, and guyot (G 52-170) was found at just axis of the Alutian Trench (MOGI, 1953). Similar guyot in trench was described at first from the Aleutian Trench near the Gulf of Alaska (MENARD and DIETZ, 1951).

Recently the Erimo Guyot (called Sysoev Seamount by the Russians) sited just conjunction of the Kuril-Kamchatska and Japan Trenches was sounded and dredged (TSUCHI, 1966). The depth of trench bottom is about 7,000 m and the top of the guyot is 3,678 m deep where Plesioptygmatis, one of the late Cretaceous Nerinea fossil and some calcareous algae were dredged. The truncation of the Erimo Guyot may be older than the formation of the Japan Trench considering various informations. The depth difference between ocean floor and the bottom of trench is about 1,500 m and the top of the guyot is about 1,500 m deeper than the average depth about 2,000 m deep of the Mid-Pacific guyots. This difference is in the same order. Similar case is known concerning to the Kashima Seamount at the axis of the southern Japan Trench.

Many guyots have been found from the area near to the Marshall and East Caroline Islands of coral reef archipelagoes (SATO and MOGI, 1965). The existence of guyots in such coral reef islands area have been confirmed in the Austral Islands in the Southeast Pacific.

The Koshu Seamount (in old days called Kinan Bank) of the Shikoku Basin, is also guyot from which calcareous algae fossils of shallow water species were dredged. However, the age of the fossils is not determined yet (IWABUCHI *et al.*, 1963). Extremely deep flat-topped seamount of 3,787 m deep has been recognized from the Philippine Basin (SATO and AO, 1961). Shallow flat top of about 700 m deep is found at the seamount on the Kyushu-Palau Ridge (oral communication from Dr. MOGI).

Although the origin of flat tops of guyots is generally assumed as the results of wave erosion, two ways of explanations are probable concerning to the subsidence of guyots to present depths; one is the theory of the constant seawater volume during geological ages and other is the gradual increase theory. MENARD (1964) proposed the hypothesis of the Darwin Rise and the evolution of oceanic rises based on the first viewpoint. If the flat top of guyot indicates the ancient sea level, the height of guyot above ocean floor means the depth of ancient ocean. He made palaeo-submarine topography of the Mid-Pacific Basin in 1 billion years ago, and found the palaoe-oceanic rise "Darwin Rise." This is an exciting hypothesis.

However, the writer considers the necessary of further detailed surveys in the Western Pacific rather than the hypothesis. Now he wants to propose following problems and surveys:

1. The writer was engaged in the compilation of the bathymetric charts of the Western Pacific (J. H. O. Charts No. 6301—6304), and found very scarce soundings in this area. Probably 10^2 guyots exist in the Western Pacific, among which only ten or less guyots were sounded and dredged in detail. He hopes detailed surveys of much more guyots in this basin.

2. It is unknown whether the Mid-Pacific guyots and/or the Marcus-Necker Seamounts elongate to further west of the Mariana Trench or not. The northern part of the Mariana Trench is divided into several small trenches by the seamounts in trench. If the formation of trenches in the Western Pacific is younger than that of guyots in the Mid-Pacific, the continuation of guyots into the West Mariana and Philippine Basins is propable. However, guyots in these basins may be very scarce. Taking ocean spreading theory, the Mariana Trench might be just digesting the Mid-Pacific guyots. He considers that to clarify the ages of formation of submarine relieves is important especially in the case of crossing of large scale relieves. (T. SATO)

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Southwest Honshu Arc in the pre-Neogene Time, with Reference to Problems of its Oceanic Side

It has been demonstrated that the pre-Neogene Honshu arc, including SW Hokkaido, Honshu, Shikoku and Kyushu islands, was differentiated into two major island arc systems since the Neogene period. These systems are referred to as the east Japan arc system and the west Japan arc system (MATSUDA *et al.*, 1967). In the Neogene-Quaternary period the latter system is in general less active than the former with respect to the volcanism, submarine subsidence, tectogenesis and some other features. Therefore, the pre-Neogene features of the Honshu arc is better preserved in SW Japan.

With reference to the pre-Neogene geologic process, the NE Honshu arc and the SW Honshu arc* have some important features in common. (1) Presence of pre-Late Paleozoic basement rocks, (2) extensive development of Late Paleozoic Honshu geosyncline, (3) Late Paleozoic-Early Mesozoic Honshu tectogenesis, (4) development of Late Mesozoic geosynclines on the outermost (oceanic) side, and (5) Late Mesozoic diastrophism, accompanied with large amount of acidic igneous activity are important common features (for details, see MINATO *et al.*, 1965).

However, several notable differences can also be recognized between the two arcs, concerning the actual process and the resultant geotectonic structure. For example:

1. The dominantly acidic Cretaceous-Paleogene igneous activity is confined to the inner (northern) side of the Median Tectonic Line in SW Honshu arc (ICHIKAWA *et al.*, 1968), whereas in NE Honshu arc it was extensive also on the Pacific side. In the latter region such clear-cut tectonic line as the Median Tectonic Line is not distinctly developed.

2. The outer side of the SW Honshu arc shows a characteristic zonal structure of the Sambagawa, Chichibu and Shimanto belts. General aspect of its folding style is somewhat different from that of the outer side of the NE Honshu arc, namely the eastern Abukuma and the Kitakami belts (cf. KIMURA, 1968).

3. In the outermost belt of the SW Honshu arc (Shimanto belt), the dominant subsidence and folding lasted until the mid-Cenozoic (about 20 million years ago). In the outermost belt of the NE Honshu arc (Outer Kitakami belt), they came to an end already before the late Early Cretaceous, accompanied with extensive granitic activity of about 110–120 million years old. The late Early Cretaceous and still later sediments suffer little folding.

These differences must be attributed to certain differentiated situation of the two segments, which took place particularly in the Late Mesozoic and lasted until the mid-Cenozoic. They cannot be a result of the hypothetical bending of the Japanese islands, (KAWAI *et al.*, 1961), which, if it really occurred, is inferred to be of post-Mesozoic age. They are due to the mutually differentiated condition of the basement complex of the older arc and its frontal area, now under the sea, and/or the tectogenetic pattern undergoing them.

Here some problems of the frontal area of the SW Honshu arc will be mentioned.

1. In the past it was vaguely suggested that the difference may be partly due to the particular condition of the major unit, now occupied by the Philippine Sea ("Philippinia"). Whether this concept is invalid or not should be examined through future research. Recently, the crustal structure of the Philippine Sea has been clarified considerably (MURAUCHI *et al.*, 1968). This sea includes various basins and ridges, where the crustal structure of basins has a fairly normal oceanic character (*op. cit.*). The submarine topography and structure in front of the SW Honshu arc and the Nansei Shoto arc, including troughs, Shikoku basin and various ridges and plateaus, are much more complicated than those of the Philippine basin proper and also those in front of the NE Japan arc. How old is the origin of that complexity? It remains to be investigated whether the region under the Philippine Sea was essentially similar to the Pacific Ocean proper in the pre-Neogene period. Our knowledge about the geologic age and nature of sediments under these regions is still insufficient.

2. The Nankai trough or the Southwest Japan trench may have a pre-Neogene origin, since it seems to have received a thicker pile of sediments than the Japan trench. Ages of these sediments must be determined together with those of the continental slope along its

* The bounday between NE and SW Honshu arc in the pre-Neogene time is not the Itoigawa-Shizuoka line, but is located eastward beyond the Kanto mountains. They are now, secondarily separated from each other by the Kanto tectonic line in broad sense. They are regarded as two sub-arcs within the Honshu major arc.

northern margin.

3. At deep-sea terraces off Kii and Shikoku very thick pile of sediments is present, according to seismic studies. Its thickness is more than 6 km at Kumanonada (V_p: 2.00-3.84 km/sec) (MURAUCHI *et al.*, 1964) and attains even more than 11 km off Shikoku (V_p: 2.04-4.58 km/sec) (DEN, 1968). Recent investigation of orthoquartzite-bearing Early Cenozoic strata in south Kii (southern part of the Shimanto belt) shows presence of an ancient land of certain extent, composed of possibly Precambrian rocks, on the oceanic side (TOKUOKA, 1967; Kishu Shimanto Res. Group, 1968). Partial supply of clastic material from the south in the Early Cenozoic (-early Miocene) of the same belt was also suggested from South Kyushu (SHUTO, 1963) and Shizuoka (KIMURA, 1966). What is the relationship between these provenances and the very thick sediments found off Kii and Shikoku? Certainly much more investigation is needed for the sake of clarifying the site and extent of the above-mentioned ancient land. This will greatly advance our knowledge about the growth process and structure of the older arc system.

4. In order to elucidate these problems, it is necessary to make more extensive and detailed research of the crustal structure from the outer side of SW Japan, through the Nankai trough, to the Philippine sea and then to carry out core-sampling of the bottom sediments at selected stations where various velocity layers are directly exposed, respectively. (K. ICHIKAWA)

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Some Problems of the Mineral Resources Exploration on the Continental Shelves in the West Pacific

Today, the interest in the exploration of the underground mineral resources on the continental shelves of Asia and its adjacent island area seems to be going to grow explosively. The Congress of Submarine Resources Cooperative Expedition belonging to ECAFE carried out the expedition after having five meetings, and obtained quite many important information. Although the most fundamental requirement of exploring the submarine resources is to assure the existence of the resources, the other geological, physical, and social factors are not less important and should be examined thoroughly, at the same time, the water depth, the distance from the shore, the state and its change of the sea, the facilities of the port, and the conditions of the available supplies are but few of them. In case of a continental shelf connecting two or more countries, there might be another type of problems which would restrict the research activities in that area, as far as International Laws are concerned.

1. Mineral resources in sediments

Unconsolidated marine sediments on continental shelves may be classified into two groups, (a) recent sediments and (b) Diluvium sediments. As these sediments are generally assumed to be land-originated, it is very important to examine coastal sediments in order to get better idea of the distribution of useful resources on the sea bottom. Therefore, countries separated by a strait would better exchange the necessary bathymetrical and sedimentary data. Besides these, the information about the topography of the base rock, covered by the layers of sediments, should be distributed through international means, for the base rock topography is closely related to the distribution patterns of mineral-resources on the ocean floor.

2. Mineral resources in base rocks

Although every kind of mineral resources are found in the base rocks, fuel resources such as coal, natural gas and petroleum especially attract our attention today. Airborne instruments are very effective for the primary geophysical surveying. However, vessels are needed for the detailed research. As the data should be collected at every point of the sea, the supplementary material gained by the ordinary fishing boats, ocean liners, and navy ships must be reported to the data collecting agencies. For this to be done, a foundation may be effectively used to pay proper amount of money for the reported information. This foundation should be operated by an international organization, otherwise the narrow nationalism and territorial troubles might jeopardize its data gathering activities.

3. Mineral resources on continental slopes and banks

The mineral resources on the continental slopes and banks may be classified into two groups, (a) resources in the sediments, and (b) resources in the base rocks, as in the case of the resources on the continental shelves. Some parts of the continental slopes and banks have been intensively investigated, however, most of the regions are still waiting for the coming research work. As these areas may provide us with very important clues helping to solve the geological tectonics of the continental shelves, international cooperation is desired urgently in this field. (H. NIINO)

総　　説

Present State of Japanese Investigation of the Western Pacific Ocean Floor and a Proposal for Future Studies*

Sub-committee for International Cooperative
Studies of the Ocean Bottom
in the Western Pacific,
Special Committee for Ocean Research,
Science Council of Japan

1. Introduction

Geophysical, geological and geochemical investigation of the western Pacific ocean floor is now carried out actively by the scientists of many nations. But the present state of high scientific activity in this vast area has been brought about only rather recently. Although the famous gravity measurements made by late Prof. Vening MEINESZ in the water around the Indonesian Island Arc pioneered the marine geophysics in as early as 1930's, major endeavours of marine geophysics after the World War II have been focused on the studies of the world encircling system of mid-oceanic ridges. Through the energetic surveys made on a number of expeditions, the mid-oceanic ridges have disclosed various characteristic features that are of the topmost importance in understanding the development of oceans and continents. Based on these investigations, the hypothesis of ocean floor spreading was proposed to explain the history of the development of the ocean floor.

Non-ridge part of oceans, the western Pacific being the typical, seems to be characterized by features that are in contrast to those in the ridge part. It is now believed that intensive studies of this relatively unexplored part of oceans will provide not only the crucial key information on the validity of the ocean floor spreading hypothesis but also some entirely new type of knowledge on which the more basic theories on the origin of the major surface features of the globe may be developed.

In order to promote the investigation, a well planned international cooperative program appears to be highly desirable. In this report, a review and analysis of the present state of the investigation, mainly by the Japanese, of the western Pacific will be presented. The analysis will be subdivided according to disciplines rather than to geographical areas.

In what follows, the term western Pacific will be used to mean the part of the Pacific ocean and adjacent seas west of the 170°W.

2. Bathymetric studies

A systematic bathymetric investigation of the western Pacific is being carried out by the Hydrographic Department, Maritime Safety Board of Japan as a part of GEBCO program. The GEBCO (General Bathymetric Chart of the Ocean) program, which aims the compilation of 1:10,000,000 world's bathymetric chart in 24 sheets, published its first version in 1904. Since then, revisions have been repeated and in 1952 a resolution was made at the International Hydrographic Congress to publish the fourth version. It was agreed that hydrographic offices of 17 nations will provide 1:1,000,000 work-sheets for the seas around their countries and the fourth version of GEBCO charts will be compiled on these sheets by the GEBCO Committee composed of representatives from ICSU, IAPSO and IHB.

Most of the western Pacific region is covered by A-III (0°-46°40′N, 90°E-180°) Chart of

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At the sub-committee's request this paper was compiled by M. HOSHINO, K. KAWAKAMI, K. KOBAYASHI, S. MURAUCHI, T. SATO, Y. TOMODA, S. UYEDA and M. YASUI

GEBCO. Of the region covered by A-III Chart, the Hydrographic Department of Japan is responsible for the compilation of the area (18°-48°N, 120°E-180°). As to the other areas in A-III region, the Hydrographic Department is expected to make due adjustments on the parts compiled by Australia, England, India, Indonesia and Holland.

Based on the most up-to-date data the Hydrographic Department published in 1965 four sheets of 1:3,000,000 Bathymetric Charts of the adjacent seas of Japan. These charts, (No. 6301-6304) which are to replace the existing chart No. 6901, are highly more reliable compared with any existing charts of the area. But if one examines the density of soundings closely, it can be found that the basins away from the coasts still suffer a great need of data, especially those based on the modern echo-sounding data. In these areas, therefore, extensive surveys should be made, using the modern techniques of position fixing, such as Loran C. or satellites navigation and narrow beem echo-sounders.

It was found in the process of the compilation of the new charts No. 6301-6304 that the following aspects should be pursued in the western Pacific: 1) regionality in the distribution of the thickness of sediments; 2) possible existence of fracture zones similar to those in the eastern Pacific; 3) detailed topography of seamounts and ridges in relation to the possible subsidence of the Mid-Pacific ocean floor; 4) complexities in the topography of deep sea trenches, especially that of Mariana and Nansei-Shoto trenches which are separated in pieces by shallows; 5) the distribution and structure of the deep sea terraces on the continental side of trenches. These problems are not merely topographic but are of wider interests in the general geology and geophysics of the ocean bottom. We strongly emphasize that the future bathymetric surveys should be conducted simultaneously with various other measurements, such as gravity, geomagnetism, and seismic reflections.

Such a comprehensive type of survey has been done by the Hydrographic Department in limited areas off the coast of Japan Sea and the areas of Sagami-Bay and south of Hokkaido by taking tracks with 2-4 miles spacings. As a result, our knowledge on the sub-bottom topography underneath the unconsolidated sediments has increased enormously. Also, the correlation of the sediment-thickness with the gravimetric and magnetic data has become possible. At the present stage, it is planned that this type of work will be made around the whole Japan from the coast to as far as the continental slope. But, for the future work, we strongly recommend that similar surveys be made in the whole western Pacific area, in connection with the five points of interest cited above. Marine geological considerations on these matters will be discussed in a later section, too.

3. Gravity measurement

Submarine gravity measurements were made in the Indonesian waters by Vening MEINESZ and in the Pacific off Japan by MATUYAMA (1934) in 1930's. Afterwards some more pendulum measurements were added (TSUBOI, 1934; KUMAGAI, 1953; WORZEL, 1965). But, new era was opened by the advent of the surface

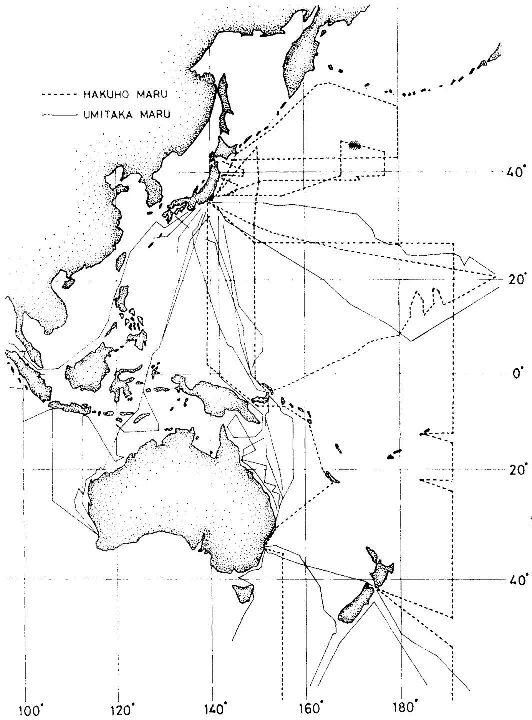

Fig. 1. Ship's tracks during which continuous gravity measurement was conducted. (in the Western Pacific)

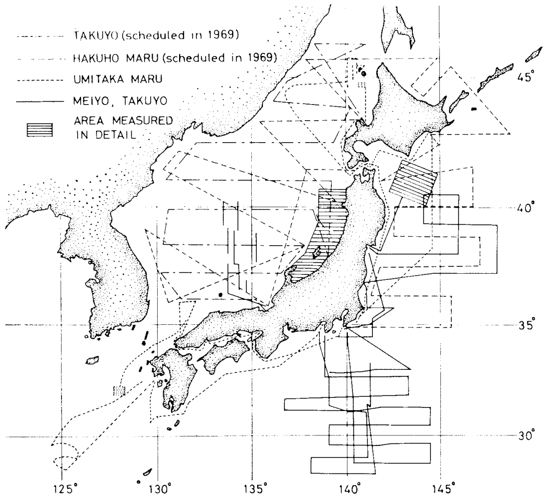

Fig. 2. Ship's tracks during which continuous gravity measurement was conducted. (in the vicinity of Japanese Islands)

ship gravity meters in early 1960's. Since 1963, T.S.S.G. (Tokyo Surface Ship Gravity Meter) type gravity meter has been in use by TOMODA and his colleagues (TOMODA, 1958, 1959, 1960; TOMODA and KANAMORI, 1962; TOMODA, 1966, 1967; TOMODA and SEGAWA, 1966, 1967; TOMODA and OZAWA, 1965; TOMODA *et al.*, 1968; SEGAWA, 1967, 1968). During the early years, data were obtained only on about 50% of the total tracks. But, with the improvements of the machine, useful data were obtained on more than 90% of tracks in the period 1966-1968 (Fig. 1, Fig. 2). Thus, gravity data in this area are expected to be accumulated quite rapidly in the future.

Until 1967, however, the gravity survey has not been made on a cruise specially planned for it. It has been made mainly during the cruises of UMITAKA-MARU, Tokyo University of Fisheries, of which main objective was the training of fisheries-students. Since 1967, a new research vessel HAKUHO-MARU operated by the Ocean Research Institute, University of Tokyo has become available for gravity measurements. The same type of apparatus is used by the Hydrographic Department. Another type of surface ship gravity meter has been developed by the Geographical Survey Institute of Japan, and some measurements have been made by TAJIMA and his colleagues.

In order to interpret the gravity data correctly, a large amount of computational work is needed. Electronic computers are used for this work, but much of the processing of data before as well as after putting into computers still requires considerable manual manipulations, so that it is still difficult for a non-specialist to handle the data. Improvements are being made to remedy this drawback.

Following points have so far been established.

1. Trenches and island arcs:

1) As for the Japan Trench, the minimum of free air gravity anomaly is displaced slightly but definitely toward the land from the axis of the topographic trench. This fact suggests that, in addition to the negative anomaly due to the trench itself, there is an equally pronounced negative free air gravity anomaly belt west of the topographic trench. This "gravity trench" is a strong indication of either a thickened crust or sediments on the landward side of the trench.

2) Free air anomaly shows a notable difference in the northern and southern portions of Japan Trench, *i.e.* Japan Trench off Hokkaido is far more isostatically compensated than that off Boso Peninsula.

3) Of the trenches so far surveyed, Mariana Trench and Aleutian Trench (at about 180°) are most markedly out of isostatic compensation.

4) Free-air anomaly in the Izu-Bonin arc area reflects the bottom topography very closely, showing the absence of tendency to the local isostasy as found in the landward side of Japan Trench. Existence of a gravity trenches in the case of the island arc having a continent on its inner side and non existence of such a gravity trench in the arc having oceans on both sides may be of considerable tectonic significance.

2. Continental margins without trenches:

There are continental margins where there is no trench but a strong negative free air anomaly. Typical examples are the Bungo Suido and Hyuganada areas, and the west coast of New Zealand. In the southwestern coast of Australia, such a negative belt can be observed in the inland area.

3. Area of subsidence:

Subsided areas in Indonesia. Makassar Strait and Bachi Channel seem to be out of isostasy, the free-air anomaly closely reflecting the bottom topography.

The gravity program now underway at the Ocean Research Institute, University of Tokyo, is as follows:

1. A fairly accurate chart of gravity in the seas adjacent to Japan (30°N, 43°N-130°E, 150°E) will be completed in one to two years.

2. From the relationship between the topography and free-air anomaly and the apparent density of the bottom materials, the degree of isostasy will be assessed for each topographic relief. This will provide useful information about the state of isostasy over the Pacific ocean and/or the possible regionality in the mean density of the bottom materials.

Important future problems would be:

1. Origin of isostatic anomalies. It would be a matter of time to clarify, from the observations made so far, the state of local isostatic anomalies. But the origin of these anomalies would be the important future problem. If the origin of the isostatic anomalies lies at a depth of 100-200 km, it would be necessary to estimate the density at these great depths. For this to be done, regional anomalies over an at least 1,000 km wide area must be measured. Considering the drift of the instruments, one line of measurements should be completed within 10-20 days and, moreover, a geodetic marine gravity network must be established by the calibrations against pendulum measurements at base stations. In relation to this problem, the area to be investigated with highest priority would be the Izu-Mariana Arc. The north-south variation of regional anomaly should be traced along the Kyushu-Palau Ridge also. If sufficiently high accuracy can be attained, the difference in the north and south of 27°N should be pursued in the area east of 150°E.

To be more specific, we propose to make the following work.

1) Establishment of gravity test field around Bonin Islands and also Hawaiian Islands.

2. Linear measurements along about 25°N.
,, 20°N.
,, 160°E.

3. Detailed survey over selected seamounts in the area of the Darwin Rise.

4. Geomagnetism

Results of marine geomagnetic measurements in the western Pacific region by Japanese groups have been reported by UYEDA *et al.* (1964, 1967), MATSUZAKI (1966), MATSUZAKI and UTASHIRO (1966a, b), YASUI *et al.* (1967a, 1967b, 1968), SEGAWA *et al.* (1967), SEGAWA (1967, 1968), TOMODA and SEGAWA (1967), TOMODA (1966, 1967) and TOMODA *et al.* (1968). Tentative isodynamic total force anomaly chart of the area (28-56°N—130-164°E) is as shown in Fig. 3. In this figure, measurements by the Lamont Geological Observatory, the Scripps Institution of Oceanography and the U.S. Hydrographic Office have also been incorporated. The anomaly values have been obtained so far only graphically. But now they are computed digitally using various reference fields. Since most of the data were taken during cruises which were originally planned for other purposes, ships' tracks are quite unevenly distributed. But still the investigations made to-date show the following characteristic features of the geomagnetic field of the northwest corner of the

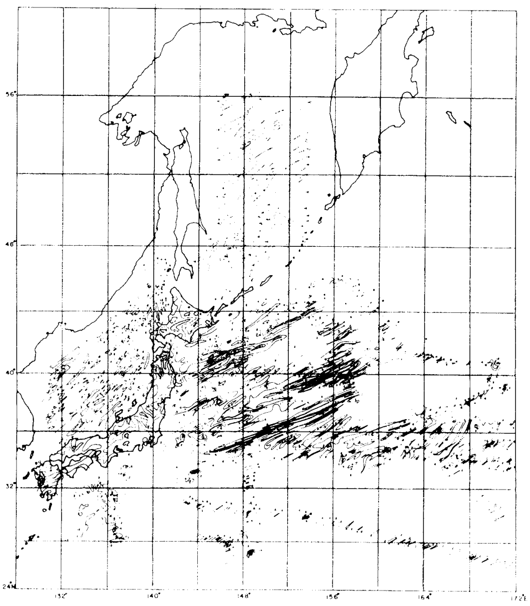

Fig. 3. Magnetic chart for the total intensity anomaly in units of 100 gammas.

Pacific.

1. Prominent NEE-SWW trending linear magnetic anomaly belts exist off northeast Japan. These lineations are similar in nature to those found in the eastern Pacific but on the whole much less persistent spatially. They become vague as approaching the trenches and do not exist inside the trenches. The lineations are not correlated with the bottom relief.

2. Although less remarkable, similarly trending anomaly patterns may exist in the Japan Sea and the Sea of Okhotsk. But, the results of the earlier aeromagnetic surveys by Russians in the Okhotsk Sea (SOLOVÝEW and GAINANOV, 1963) do not perfectly agree with the Japanese results.

3. Shikoku and Philippine Basins do not show the linear trends.

4. 14 seamounts located in the seas around Japan have been surveyed in detail and their magnetizations computed (UYEDA & RICHARDS, 1966; VACQUIER & UYEDA, 1967). The results indicated that the northwest Pacific ocean floor might have drifted northward by a few tens of degrees since the time of formation of these seamounts, which is believed to be Mesozoic. These attempts are considered to be useful as a method of palaeomagnetic study of the ocean floor as will be shown later.

It may be easily noticed that the way how the lineations off Japan are connected or unconnected with those in the eastern Pacific is a matter of great importance. U.S. surveys have recently disclosed that the lineations in the eastern Pacific changes their trend from N-S to E-W south of the Aleutian Trench (HAYES and HEIRTZLER, 1968; PITMAN and HAYES, 1968). If these lineations are connected with those off Japan, the age of the lineations would increase southward, which is just opposite to the case when the lineations were produced in the southern sea and have traveled northwards. The key area on this problem (40°-50°N, 160°-180°E) must be surveyed thoroughly immediately.

TOMODA and his colleagues have made linear measurements of the total magnetic force over various world's oceans (see the references cited above). They find that the magnetic characteristics of various parts of oceans are quite varied, *i.e.* some basins such as the area off NE Japan, are full of anomalies whereas in some others, such as the large area of the western mid-Pacific, there are no remarkable anomalies except those due to surface topography. To clarify the origin of such a drastic difference from basin to basin, we emphasize that the future survey should be of composite nature including gravity, seismic reflection and refraction and heat flow measurements. The magnetic anomaly pattern in the Darwin Rise area would be most valuable in testing or extending the hypothesis of ocean floor spreading.

We propose that the surveys in the following areas should be undertaken:

1. 15°N-50°N—150°E-180°
   20°N-30°N—130°E-150°E
   (possibly by the aid of the air-borne method)
   05°S-20°N—125°E-140°E
   (possibly by the aid of the air-borne method)
   and East and South China Seas.
   (possibly by the aid of the air-borne method)
2. Darwin Rise area.

In relation to the palaeomagnetism of seamounts, detailed surveys over selected seamounts should be made in and around the area of the Darwin Rise.

3. The crustal structures should be investigated by explosion seismology in the deep sea area with small magnetic anomalies: for example,
   15°-20°N—140°-135°E
   10°-15°N—165°-175°E
   0°-05°N—165°-170°E

and also in the area with strong anomalies: for example,
   40°-42°N—145°-150°E
   45°-48°N—175°E-175°W.

5. Terrestrial heat flow

Since 1961, the terrestrial heat flow has been intensively studied in the seas around Japan by several agencies. UYEDA *et al.* (1962, 1965), YASUI *et al.*, (1967, 1968a, 1968b) and VACQUIER *et al.* (1966), have published data measured at 327 stations. Beside these the Lamont Geological Observatory and the Academy of Sciences, U.S.S.R. have made some measurements. Taking account of 42 measurements on land of the Japanese Islands (UYEDA & HORAI,

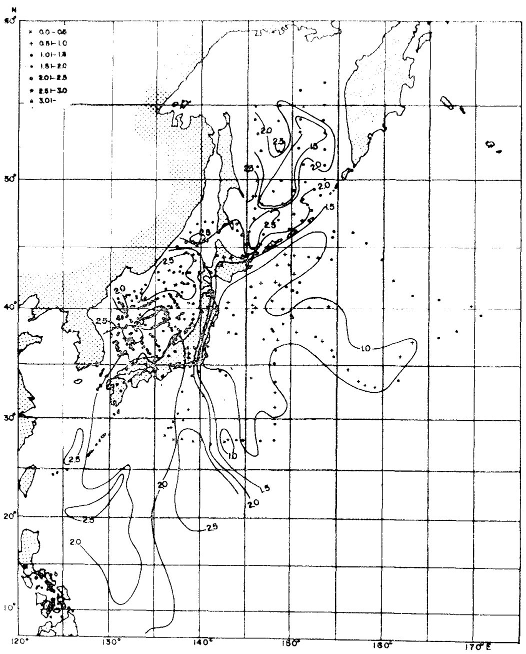

Fig. 4. Heat flow values in units of 10^{-6} cal/cm^{2}sec in and around Japan.

1964), this area can be considered as one of the most well surveyed areas in the world geothermally. Nevertheless, many more data are needed in Shikoku and Philippine Basins, off Kamchatka area, East China Sea and most of the southwestern Pacific. There is no measurement in the South China Sea and the Australian-Asian Mediterranean Sea.

The published data in and around Japan are summarized in Fig. 4 by symbols. From the figure, the heat flow in this area can be characterized by the following three major features; (a) the uniformly sub-normal heat flow in the area east of the Kuril-Japan-Izu-Bonin Island Arcs, (b) the high heat flow area in the continent side of the Island arc and in the Japan Sea and the Okhotsk Sea, and (c) the area west of the Izu-Bonin-Mariana Ridge. The last area has not been surveyed well but preliminary data indicate that heat flow there has a complicated distribution.

In the first area, one may notice that the heat flow over the major topographic relief, such as the Emperor Seamounts and Shatsky Rise, is also subnormal. In this manner, these topographic features in the northwest Pacific are in a sharp contrast to those in the east Pacific including the East Pacific Rise (VON HERZEN & UYEDA, 1963; VACQUIER *et al.*, 1967). The complicated heat flow distribution in the Philippine Basin may be related to its equally complicated physiographic structure. The basin is not only situated behind the Izu-Mariana Arc but also has another island arc system at its western margin, *i.e.* the Ryukyu Arc. It must be noted that thə heat flow is high above both Kyushu-Palau Ridge, which supposedly ceased the tectonic activity long time ago, and strikingly the Nankai Trough (WATANABE, 1969). High heat flow in a trough in the size of the Nankai Trough has not been found anywhere else.

The high heat flow in the marginal seas behind the island arcs presents interesting problems. The results of the seismic refraction studies show that the crustal structure beneath the Japan Basin and Kuril Basin, where the heat flow is extremely high, is semi-oceanic or oceanic. It means that the heat from radioactive substances in the crust cannot be the origin of the high heat flow. MURAUCHI (1966) presented the hypothesis that the Japanese Islands have been separated from the Asiatic continent, the Japan Sea being a developed rift with high heat flow. YASUI *et al.* (1966) inferred that the excess heat was transported by the upward intrusion of magma beneath the bottom. WATANABE (1966) considered the possibility that a tectonic deformation of the crust in the past resulted in the anomaly of heat flow at present. MENARD (1967) points out that the marginal sea which has the oceanic or semi-oceanic crust may be in the transient state from a continent to an ocean. If so, disturbances during the oceanization process could affect the heat flow at the surface for a fairly long period. UYEDA & VACQUIER (1968) pointed out the possible correlation between the deep focus earthquakes and the high heat flow. MCKENZIE & SCLATER (1968) estimated the effect of various heat sources which could be the origin of high flow in marginal seas and concluded that none of them could be large enough to explain the excess heat in the area.

It would be an important matter to examine the generality of high heat flow in the marginal seas behind island arcs. In the Bering Sea, WATANABE and EPP (private communication) obtained high values in the western part whereas FOSTER (1962) reported low values in the eastern part. Recently, Scripps and Japanese groups made an extensive survey in the Melanesian region. High values were obtained in the North and South Fiji Basins, but low values were also found, especially in the South Fiji Basin. Apparently the situations are highly complex and require much further work.

Heat flow in the Darwin Rise region has been studied by U.S. groups so far and show normal to subnormal values. This supports the idea that the Rise ceased its activity long time ago. But, it may still be worth reexamining this point, since the measurements made to-date are small in number.

Considering the above points we propose to make extensive heat flow expeditions in the following areas:

1) The marginal seas, *i.e.* the Philippine Sea, East and South China Sea, Sulu Sea, Celebes Sea, Java Sea, Banda Sea and Coral Sea.

2) Caroline Basin and to the area of Darwin Rise.

3) Pacific-Antarctic Ridge area.

It would be rewarding to make expeditions comprehensive so that not only heat flow but magnetic, gravity and profiler surveys are made simultaneously. At some stage of investigation, areas of special interest should be selected for really concentrated survey.

6. Palaeomagnetism and rock magnetism

Palaeomagnetism of rocks obtained from the ocean bottom should resolve the relative movements of the ocean floor, or yield a key to test the ocean floor spreading hypothesis. Although it is very difficult to obtain orientated samples from the ocean floor, samples obtained from islands in the Pacific Ocean can be used to examine the relative displacements of the ocean floor on which the islands rest. Unfortunately, ages of islands in the Pacific Ocean which have so far been dated radiometrically are rather young and palaeomagnetism on these islands would only yield information of recent movements of the islands or the underlying ocean floor. Hence, to begin with or in parallel with the palaeomagnetic study, K-Ar dating reconaissance survey should be undertaken on as many islands in the Pacific Ocean as possible. Extensive palaeomagnetic study should then be made on islands whose ages turned out to be sufficiently old, say older than 5×10^7 yr. As one of the rewarding sampling sites for these purposes, we suggest Tahiti Island where 150 m.y. of basalts were found, although its location is not in the western Pacific. The K-Ar reconaissance survey on the islands in the Pacific Ocean would also be very interesting to see if the age pattern obtained for these islands are accordant with that expected from the ocean floor spreading hypothesis.

Seamounts yield the second approach for the palaeomagnetic study of the ocean floor. As stated in **§ 4**, it is possible to compute the the direction and intensity of magnetization of seamounts from their topographical and geomagnetic total force data at the sea surface (VACQUIER, 1962). The palaeomagnetic direction and intensity of 14 seamounts in the Western Pacific region was obtained with this method by UYEDA and RICHARDS (1966), VACQUIER and UYEDA (1967) and YASUI *et al.* (1967a). These results show that the inclination of magnetization is generally shallower than that of the present geomagnetic field at the location of seamounts. If the conventional palaeomagnetic assumptions are accepted, this fact would mean that the seamounts in this region, in particular those in the Pacific out of the Izu-Bonin Arc were originally formed at localities nearer to the geomagnetic equator than the present locations. It is consistent with the hypothesis of northward drift of the ocean floor. The magnetization of seamounts in the Japan Sea and the Sea of Okhotsk so far investigated has not shown systematic evidence of the northerly creep.

The depositional remanent magnetization of ocean sediments is useful in the palaeomagnetism at sea. First published report on this type of work in the western Pacific is by NINKOVICH, OPDYKE, HEEZEN and FOSTER (1966). From the large number of Lamont cores taken in the sea west of the date-line zone, 24 cores were chosen for preliminary analysis and it was found that four of them, three from stations along the date line zone in 43°N to 48°N and one from the flank of the Emperor Seamounts, have actually reached the deeper strata than that of the last reversal of the geomagnetic field. It is notable that the occurrences of reversals in the geomagnetic field proposed from the terrestrial palaeomagnetism was ascertained by the ocean sediments. In particular, it was suggested that each complete reversal of geomagnetic field occurred in less than 1,000 years.

The epoch of the last reversal of the earth's magnetic field (Matuyama Epoch) is reportedly from 700 thousand to 2.4 million years ago (*e.g.* COX, 1968). Dividing the core length from the surface to the uppermost part of the sediment of the Matuyama Epoch, the mean rate of sedimentation was obtained; 0.7 cm/1,000 yr. in the date-line zone and more than 1.5 cm/1,000 yr. in the 156°E meridian zone.

The sedimentation rate in the western Pacific region was studies by measuring the γ-ray intensity ratio of ionium to thorium (MIYAKE and SUGIMURA, 1961, 1965 and 1968, SUGIMURA and MIYAKE, 1966). In the Pacific, the value obtained by them ranges from 0.05 cm/1,000 yr. to 0.25 cm/1,000 yr. with the exception of a little larger value of 0.63 cm/1,000 yr. from the east flank of the Japan Trench. These rates are about one tenth of the above-mentioned values obtained from the magnetic stratigraphy. Whether the difference between them is geologically meaningful or is merely due to the difference in the methods applied is vitally important. In the northeast Pacific, HARRISON (1966) presented a sedimentation rate of 0.3 cm/1,000 yr. from the palaeomagnetic stratigraphy. This is in the same order of magnitude to those obtained by the Io/Th ratio method in the western Pacific. Extensive determination of the distribution of the sedimentation rate would be an extremely useful information for the study of palaeo-currents and palaeo-climate. Higher rate of sedimentation has been presented in the marginal seas. This higher rate will be convenient for detailed palaeomagnetic stratigraphy of the recent era.

Paleomagnetic study of deep-sea sediment cores has been conducted at the Ocean Research Institute, University of Tokyo since only 1967 (KOBAYASHI and KITAZAWA 1969). Such a late start of this type of work was mainly because long, undisturbed samples of sediment cores had not been available among Japanese researchers. However, a technique of piston coring has recently been established in the R/V HAKUHO-MARU and some 10 m cores were collected every 5-10 degrees between 30°N and 70°S on the longitude of 170°W during the last cruise in the Southwest-central Pacific (Ocean Res. Inst., 1969). Magnetic, radiometric and variety of chemical analyses are being conducted with the collected samples.

As to the magnetic properties of rocks of the ocean bottom OZIMA *et al.* (1968), and KOBAYASHI and KITAZAWA (1969) have started some studies. It has been found so far that:

1. The ferromagnetic minerals in oceanic rocks usually contain more titanium than those in continental rocks. They often indicate various degree of low temperature alterations. Degree of oxidation seems to control the magnitude of saturation magnetization and Curie point. Intensity of natural remanent magnetization ranges from 10^{-3} emu/gr. to 10^{-5} emu/gr.

2. The magnetic properties of most oceanic basalts changes greatly by heating to 300-600°C. The reason for this phenomenon and its possible bearing with the local magnetic anomaly of the ocean bottom are still to be investigated.

3. Some basalts from the ocean floor exhibit self-reversal of natural remanence upon heating.

Mituko OZIMA (1967) studied the magnetic properties of manganese nodule dredged from the Pacific area. She found that manganese nodules are paramagnetic, whereas they become strongly ferromagnetic upon heating to 400°C ($Js \fallingdotseq 50$ emu/gr). Hence, this magnetic property may be used as a geothermometer to resolve if any manganese nodule or the ocean floor where the manganese nodule was obtained from has ever been heated up to 400°C.

In summer of 1968 the R/V HAKUHO-MARU had a northwest Pacific cruise during which a comprehensive investigation was conducted on a seamount called 'Emperor Suiko' in the Emperor Seamountain Range. The survey included detailed mapping of topography, gravity and magnetic field as well as collection of more than one hundred of hard rocks by the dredge hauls

(Ocean Res. Inst., 1968). The analyses of the results are now in progress.

For the future research we propose to make a comprehensive study on selected seamounts and ridges in such a manner as was done with the 'Suiko' Seamount. A number of hard rocks, preferably with orientation, should be collected to be examined from the basic petrological and magnetic viewpoints. In addition to the use of conventional dredge hauls, handy deep-sea core-drills, which will be capable of collecting some 20 cm long hard oriented rock cores, are highly needed and being developed at the Ocean Research Institute.

Following sites are considered for the first phase of the future study:

1. Seamouts in 10°N-25°N along 150°E, as a representative of magnetically quiet areas.
2. Seamounts just outside of Japan Trench off northeast Japan as a representative of areas of magnetic lineations.
2. Seamounts of Shatsky Rise and the Emperor Seamounts.
4. Seamounts in marginal seas.
5. Seamounts on and around the Darwin Rise.

We also propose to take many long cores over the area of red clays in the western Pacific. Cores should be taken from both where the sedimentation rate is high ($\simeq 10\ mm/10^3\ y$) and low ($<1.0\ mm/10^3 y$). Former cores will be used for the study of detailed magnetic secular variation and the behaviors of the field during reversals, while the latter cores will serve for palaeomagnetism and magnetic stratigraphy of a longer time span. Basic study on the magnetic ingredients of these cores will provide some clues to their origin and consequently to the development of the ocean bottom.

Samples recovered should naturally be shared with scientists of varied interests and should be used for international exchange also. Actual shipboard operations would be much facilitated by cooperation of scientists of various disciplines, such as palaeontologists, and petrologists.

7. Explosion seismology

The Japanese group conducted a seismic refraction work in the sea south of the central part of Honshu in 1962, in cooperation with the American group (MURAUCHI *et al.*, 1964). The same group has extended their project to the sea east of the northern part of Honshu (LUDWIG *et al.*, 1966), the Japan Sea (MURAUCHI *et al.* unpublished), the sea off Shikoku (DEN *et al.*, 1968), the Philippine Sea to the East China Sea (MURAUCHI *et al.*, 1968). The locations of the refraction profiles are summarized in Fig. 5. In Fig. 6, cross section of the crustal structure along the lines B-B′ in Fig. 5 is demonstrated.

Ocean Basins: Both of the northwest Pacific Basin and the Philippine Basin differ in the thickness of the second layer from the average structure of the western North Pacific (RAITT, 1963). The depth of the upper surface of the second layer in the Parece Vela Basin is almost constantly at about 6 km from the sea surface and, therefore, the sea bottom relief is formed mainly by the variation in the thickness of the first layer. The Shikoku Basin also can be considered as having the oceanic structure.

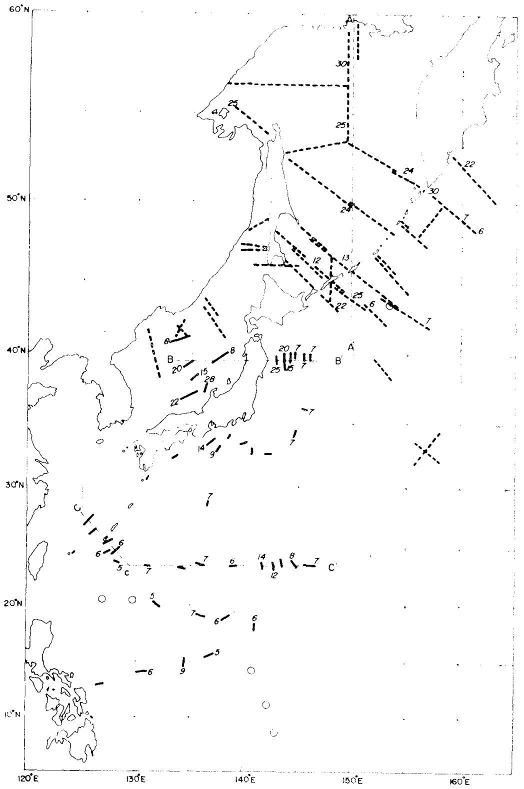

Fig. 5. Distribution of lines of marine refraction studies. (broken lines are by USSR scientists).

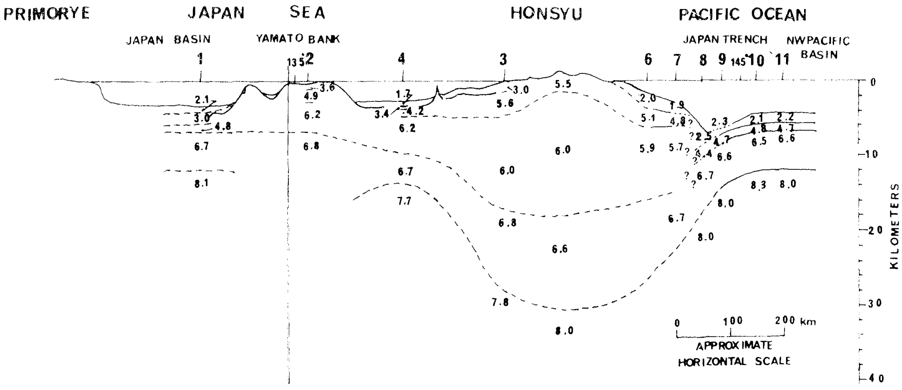

Fig. 6. Crustal cross section along the line B–B′ in Fig. 5.

Trenches: The series of the Kurile-Japan-Nanseishoto Trenches has a similar structure; that is the crust is quite oceanic in the ocean side of the trenches and is continental in the continental side. As a matter of course, their detailed characteristics are different from each other. Beneath the Kurile Trench, down-warpings of the Moho-discontinuity between the trench and the island arc are remarkable according to the Russian works. In the Japan trench, a succession of grabens and step faults were observed along the seaward slope.

The Mariana Trench has a little different structure from those of other trenches. Namely, the structure of the ridge west of the trench is not continental but rather oceanic.

Ridges: The Kurile, Japan and Nanseishoto Arcs have a typical continental crust. A thick granitic layer exists between the sedimentary and the third layers, and the Moho-discontinuity is depressed down to a few tens of kilometer. Beneath the Oki-Daito, Kyushu-Palau and Mariana Ridge, an increase in the thickness of the 3.5 km/sec layer and an appearance of the 6.0 km/sec layer are found. These factors result in the crustal thickening under the ridges, in spite that the thickness of the basaltic layer remains rather uniform. These ridges of course are in many ways different from the mid-oceanic ridges.

Marginal seas: The structure of the Japan Basin, Yamato Basin, and Kurile Basin is semi-oceanic or oceanic. In the Japan Basin, the Russian scientists (KOVYLIN and NEPROCHNOV, 1965 and KOVYLIN, 1966) found a 2.0 km thick sedimentary layer directly overlying the basaltic layer. This structure can be conceived as being typical oceanic. The Japanese group (MURAUCHI *et al.*, unpublished) observed three layers (2.0, 3.0 and 4.8 km/sec) with 4.5 km total thickness above the basaltic layer. This structure is almost the same with the structure beneath the Kurile Basin where the basaltic layer is directly beneath the 3.5 km to 4.0 km thick sedimentary layer. The Yamato Basin has a structure almost similar to those in the above described basins though the wave velocity of the second layer is as great as 5.5 km/sec. On the other hand, beneath the Nanseishoto Trough the layer with the wave velocity of 6.0 km/sec, presumably a granitic layer, is as thick as 10 km between the 3 km thick sedimentary layer and the 7.2 km/sec layer. It is interesting that all the basins in the marginal seas show high heat flow.

The part of the Okhotsk Sea excluding the Kurile Basin has a three layer structure, sedimentary, granitic and basaltic, as thick as 20 to 30 km. Namely, about eighty percent of the Okhotsk Sea consists of the continental crust. The Yamato Rise, one of the major banks around Japan, also seems to have a granitic layer and a thick basaltic layer. However, further exploration is necessary for a definite interpretation because of the complicated topography.

Studies of sedimentary layers by the reflection techniques have revealed a number of interesting features. According to MURAUCHI, on the continental slope in the Pacific side of the island arcs in the western Pacific, the upper surface of 2.5 km/sec layer almost always shows a flat terrace at a fairly great depth. This may be the same one with the deep sea terrace reported by HOSHINO (1962), who postulates that a global rise of sea level was the main cause of these terraces (See §**2** and §**9**). The depth of the deep sea terrace ranges from 2,000 m to some 3,000 m, though it sinks down to nearly 4,000 m along a Aleutian Trench and the Lombok Straits. Along the Japanese coast facing the Japan Sea, the deep sea terrace can also be recognized at the depth of 1,000 m and so. The difference between the depths along the Pacific and the Japan Sea is unexplained.

Though it is yet to be published, the U.S.-Japan cooperative group has made some refraction profiles in the Sulu Sea, East and West Caroline Basin, Solomon Sea, Bering Sea, the sea just west of Luzon Island over the Shatsky Rise. However, the vast area such as the main part of the South China Sea, the Yellow Sea, is left unsurveyed. These area are important in clarifying the structure of the island arcs. As was mentioned in the section of geomagnetism, the crustal studies in the central Pacific area would be of a great value.

8. Seismicity

Seismicity is an indication of the presence of present-day tectonic activity. Seismicity in and around the land areas has been known rather well as shown in Figs. 7 and 8. Shallow shocks are most concentrated in the outer zone of the island arc and deep shocks are located more or less regularly on a curved surface dipping toward the continent. The area away from land, however, cannot be covered sufficiently with seismic network on land, especially in the case of micro-earthquakes. The observation of earthquakes in the western Pacific Ocean will supply essential materials for the geo-tectonics of this area. The seismic activity in this area will be obtained in a short time by ocean-bottom seismograph observation for small-and-micro-earthquakes.

The interesting areas are (1) trenches, (2) deep earthquake zones, (3) oceanic ridges and rises. The deep basin itself must also be studied

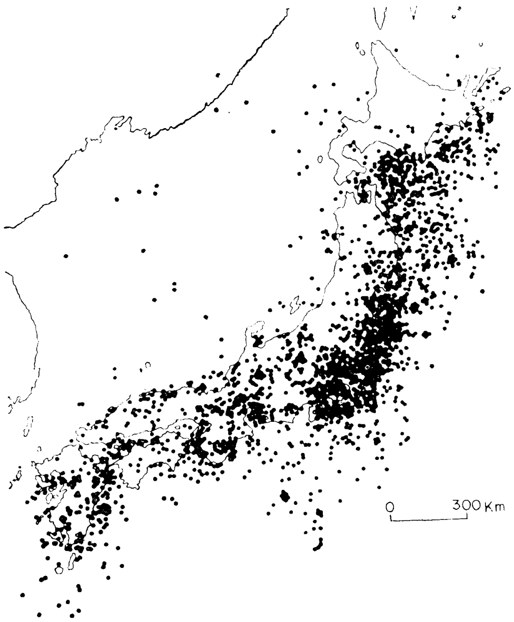

Fig. 7. Epicenters of the 3147 conspicuous and moderately conspicuous earthquakes during 1900～1950 period.

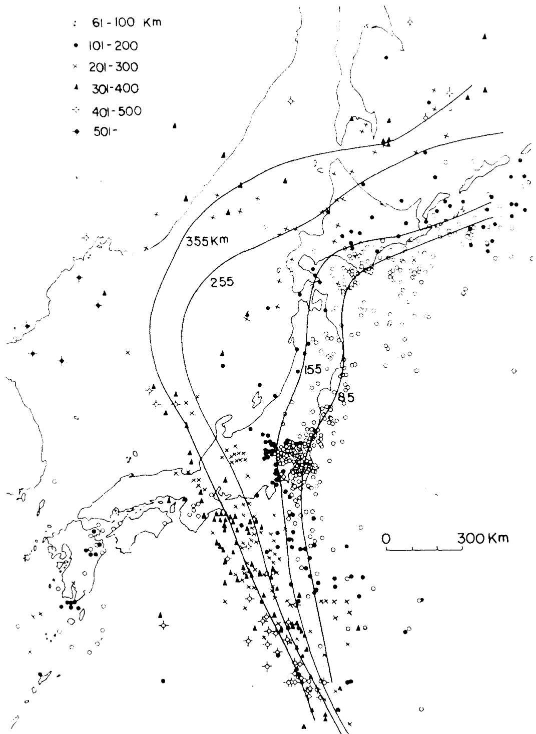

Fig. 8. Epicenters of the deep and intermediate focus earthquakes during 1926～1956 period.

to see if there is any earthquakes at all.

Three dimensional distribution of earthquake epicenters in and around Japan trench will reveal deformation and stress concentrations associated with trench tectonics.

Deep-focus earthquake zone along Izu-Bonin-Mariana Arc is an indication of large scale tectonic movement which extends deep into the mantle. The precise survey of seismicity in these areas will supply interesting information for testifying the hypothesis of mantle convection.

Oceanic ridges and rises such as Emperor Sea-mountain chains, Hawaiian ridge, Marcus-Necker rise, and their associated ridges are the important features for clarifying the history of the Pacific Ocean. The variation of the tectonic activity from the southeastern part of the Hawaiian ridge, which is active at present, northwestwards to the Emperor Sea-Mountains, which is thought as a Cretaceous feature, will be revealed by the observation of seismicity along this structural trend. Temporary seismic stations on islands, including Hawaiian Islands, will be useful for this study. The present-day stability of oceanic rises such as Shatsky Rise and Kapingamarangi Rise and the great fossil rise (Darwin Rise) will be examined by the investigation of seismicity of small earthquakes.

For the future investigation, development of ocean bottom seismometers now underway at the Earthquake Research Institute, University of Tokyo, should first be expedited.

9. Geology, petrology, and geochemistry

Andesite Line: The position of the andesite line, originally defined as the border between the continental and oceanic crusts, has become vague after the discoveries that marginal seas also have oceanic crust. The problem is related to that of trenches which are numerous in the western Pacific region. Formerly, the andesite line was taken as coincident with the trenches in location. But the trenches exist two to three fold in some areas of the western Pacific. The problem is also closely related to the fact that metamorphic rocks exist on the Marianas and Yap Island and that plutonic acidic rocks exist in the Eastern Marshall Islands. Petrogenetically also the andesite line problem has a basic importance. In this regard, sampling of as many rocks as possible on trench walls as well as on seamounts must be attempted.

Problems related to the vertical movement of the crust and the variation of sea level: The Pacific ocean floor, which formerly was believed to have been stable throughout the geological history, has been found to be mobile in vertical as well as horizontal directions. Vertical movements of the crust that can be measured in the unit of 10^3 meters have been suggested through the studies of guyots and atolls. Both of these marine uplifts are largely characteristic of the western Pacific and clarification of the processes of their formation would be one of the most important objectives of the geology of the western Pacific. At the present time, submersion of guyots is believed to have occurred in the post-Cretaceous time and this view is supported by the finding of the drilling at Eniwetok Atoll. However, Miocene fossils are often found on the top of guyots. Although there are a number of guyots in the western Pacific, only a very few of them have been investigated closely. A systematic survey of these important features of the ocean floor would be extremely informative for the crustal movements of the Pacific Ocean floor.

Deep-sea terraces, that are developed on the continental slopes and on the insular slopes in open oceans, are important in the investigation of this kind of problems. Some geologists consider that these terraces were formed by burial of lower parts on the slopes due to turbidities, while others postulate that these deep sea terraces represent, as continental shelves do, the past shore lines. Those who maintain the former view consider that the subbottom depressions in which the turbidities settled were related causally with trenches, whereas those who take the latter view may be divided into two classes, one attributing the present depth of these terraces to the rise of sea level, others attributing it to the subsidence of the crust.

It will thus be an matter of the topmost significance for the geology of the Pacific Ocean to perform a comprehensive surveys on guyots, coral reefs, and deep-sea terraces from a unified point of view.

Deep-sea sediments: The western Pacific is one of the areas where the investigation of deep sea sediments has been least advanced. Correlations between the ocean-current systems which are intense in this region and the deep-sea sediments should be investigated. Special efforts should be made on the study of palaeo-current systems by means of deep-sea sediments. Distribution and the rate of deposition of various types of sediments with different sources must be determined in detail. This problem is important from purely academic point of view, but it will have an equally great importance in the future development of the exploitation of ocean floor resources.

Establishment of stratigraphy in the western Pacific is an important palaeontological objective by itself. But it will also have a key importance to check the validity of such an up-to-date problem as the ocean floor spreading theory which predicts that the western Pacific is the oldest part of the oceans.

Sr and Pb isotope studies: Many geophysicists take the view that island arcs have been formed upon the descending site of the mantle convection current. If the mantle convection carries the overlying crustal layer, the mantle where the convection current descends may be contaminated by the crustal materials. Hence, Sr and Pb isotopic ratios of basalts erupted in such downwelling site of the convection current may show more crustal characteristics than those found in the upwelling site. It is then particularly interesting to compare the Sr and Pb isotopic compositions of basaltic rocks from the island arc regions with those from the mid-oceanic ridges such as the East Pacific Rise. Such a test may give a crucial information about the above-mentioned hypothesis that the island arcs were formed upon the downwelling site of the mantle convection current. Conversely, if we accept the above hypothesis, a systematic measurement of Sr and Pb isotopic compositions of basaltic rocks from the entire Pacific area would elucidate the pattern of the mantle convection current.

In this respect, it is particularly interesting that Ferrar dolerites (absolute age is about 1.7×10^8y) which is believed to extend from the Antarctica to Tasmania has a remarkably high Sr^{87}/Sr^{86} (about 0.711) (COMPSTON *et al.*, 1968). The uniformity of the unusually high Sr^{87}/Sr^{86} seems to indicate that the whole mantle region where the Ferrar dolerites were derived from was contaminated by the crustal materials. This may be due to the dragging of the crustal materials into the mantle by the mantle convection. In order to test this speculation, it is very desirable to carry out other geophysical measurements such as heat flow, gravity and seismic measurements in this area.

Preliminary experiments to measure Sr^{87}/Sr^{86} in dredged basalts from the western Pacific area are now underway at Geophysical Institute, University of Tokyo.

Absolute ages of submarine rocks and rocks from islands: The ages of submarine rocks and rocks from islands in the Pacific Ocean should indicate the minimum age of that part of the ocean floor. However, as submarine rocks are generally heavily altered, much care should be paid to evaluate the validity of the obtained experimental age results. Laboratory experiments such as extensive examination of thin sections of each rock specimen, argon retention test under differential heating should first be undertaken to obtain more reliable age results. It is also important to study the effect of the hydrostatic pressure on the trapping of the environmental rare gases in rocks, since it is recently advocated that high hydrostatic pressure prevailing under the deep ocean bottom would greatly enhence the trapping of primordial argon in erupted rocks, giving erroneous K-Ar ages.

Several dredged basalts from the western Pacific seamounts have been dated by K-Ar method (OZIMA *et al.*, 1968). The ages range from 20 m.y. to 90 m.y. In most cases, rocks are heavily altered and the K-Ar ages should be regarded to be rather qualitative. However, one of the samples gave a concordant K-Ar ages of about 80 m.y. both for the separated plagioclase and the whole rock sample, suggesting that the true age of this seamount (28.22°N, 148.12°E) should not differ much from the experimental value. The K-Ar ages so far obtained does not contradict with the view of the youthfulness of the ocean floor. More ages of submarine rocks and rocks from the islands in the Pacific Ocean should be obtained to see if the age pattern is in accordance with that expected from the ocean floor spreading hypothesis.

In addition to the K-Ar ages of submarine rocks, dating of the rocks from Izu-Bonin-Mariana islands should be particularly interesting for the following reasons. WILSON (1964) suggested that systematic change of the ages in the Hawaiian islands is a manifestation of the mantle convection, which carries away the islands in analogous way to a conveyor belt. A systematic change of the K-Ar ages of the Izu-Bonin islands would be expected if a similar conveyor-belt mechanism was operative to form these linear arrangement of islands. On the other hand, similar ages should be expected if these islands were formed as an accumulating scum upon the downwelling of the mantle convection.

10. Summary

As has been described in earlier sections, the problems that we face may be summarized into the one related to the island arc tectonics, including that of marginal seas, and the one related to the tectonics of the western Pacific basin, *i.e.* the history of the Darwin Rise. Both problems are closely connected with the ocean floor spreading hypothesis, that has been developed so far mainly from the studies in the other side of the Pacific, *i.e.* the East Pacific Rise area.

Investigation of the first problem should check the validity of the spreading floor hypothesis because island arc areas are the possible terminus of the movement of the ocean floor, whereas the second problem is expected to be related to the pre-history of the proposed spreading Pacific floor.

For the practical point of view, the investigation should be carried out in three lines of approach. The first one is by cruises of research vessels concentrating on the type of work that requires no station-time, *i.e.* areal survey of gravity, geomagnetic field and bottom and sub-bottom topography. The second one is by expeditions requiring stations, such as heat flow, coring, dredging, bottom seismometry, and seamount survey. The third one is mainly for the refraction studies of the crust, which normally needs two ships. Of course, other types of measurements (gravity, magnetics and profiling) should always be made while steaming not only for the purpose of general survey but also for the better results of station works, as emphasized repeatedly. Satellite navigation must be employed by all the ships so that exact reoccupation of track lines and stations can be made.

Rough estimate gives that, if five ships are in full time service, complete survey of the area we propose would be made in 10 years. The size of the project certainly appears to require an internationally organized operation, and an extremely efficient system of data processing and exchange. It would perhaps be most appropriate that the project be carried out as a part of the scheme of international cooperation now under consideration by the International Union of Geodesy and Geophysics, and the International Union of Geological Sciences for the period after the termination of the present Upper Mantle Project.

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録　　事

1. 昭和44年9月10日午後1時より，このたび来日されたマルセーユ大学教授 J. シュトウ博士の「講演と映画の会」が，東京商工会議所大ホールにおいて，本学会主催，(社) 海中開発技術協会・海洋産業研究会協賛，日刊工業新聞社後援で開かれた。

佐々木本学会会長の挨拶に引き続き，「プレコンチナン計画について」と題してシュトウ教授の講演が行なわれた。続いて，シュトウ教授が持参された16ミリカラーフィルム「プレコンチナン第3次実験記録」2本が上映された。当日は約300名の参加者を得て盛会であった。

2. 下記の諸氏が入会された。

正会員

氏　名	所　属	紹介者
岡本　　博	横浜電機 KK	佐々木忠義
山本　俊之	海上保安大学校	〃
貞方　　勉	東水大	〃
加曽利元博	石川島播磨重工業 KK 技術開発本部	大柴五八郎
インド支那銀行東京支店		〃

賛助会員

深田多満男	深田サルベージ KK	佐々木忠義

3. 退　会

賛助会員　株式会社泰和電器。

4. 会員の住所，所属の変更。

氏　名	新住所又は新所属
張　善　徳	東京都品川区五反田5-1-6 松原方
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矢部　　博	清水市日之出町　静岡県水産試験場

5. 死　亡

正会員植松健児氏は，療養中のところ昭和44年7月24日逝去された。慎んで御冥福を祈る。

6. 交換および寄贈刊行物

1) Spe. Contri. Geophys. Inst. Kyoto Univ., No. 8, 1968.
2) 宇佐臨海実験所研究報告，**15** (2)，1968，**16** (1)，1969.
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5) Bull. Ocean Res. Inst. Univ. Tokyo, No. 3, 1968, No. 4, 1969.
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7) 神戸海気象報，No. 182, 1969.
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9) Sci. Rep. Whales Res. Inst., No. 21, 1969.
10) 港湾技研報告，8(2)，1969.
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12) 港湾技研要覧，1969 年度版.
13) 海洋機器開発（日本舶用機器開発協会)，8，1969.
14) Cahiers Océangr., XXI^{e} Année N° 5～7, 1969.
15) Science et Pêche, N° 181, 182, 1969.
16) Revue des Travaux de l'Institut des Pêches Maritimes, Tome XXXIII, Fasc. 2, Juin, 1969.

菊地真一，鬼頭正隆，草下孝也，斎藤泰一，佐々木幸康，杉浦吉雄，高木和徳，高野健三　辻田時美，冨永政英，奈須敬二，西村　実，根本敬久，半沢正男，松尾邦之助，丸茂隆三　森田良美，山中鷹之助　　　　（50音順）

監　　事　三宅泰雄　高山重嶺

評 議 員　赤松英雄，阿部友三郎，阿部宗明，新崎盛敏，池松正人，石野　誠，市村俊英，井上直一，井上　実，今井丈夫，今村　豊，入江春彦，岩崎秀人，岩下光男，岩田憲幸，上野福三，宇田道隆，内田清一郎，宇野　寛，江上不二夫，大内正夫，大島泰雄，大柴五八郎，大村秀雄，岡部史郎，小沢敬次郎，梶浦欣二郎，金谷太郎，川合英夫，川上太左英，川村輝良　川村文三郎，川口守一，川原田　裕，神田献二，菊地真一，鬼頭正隆，木村喜之助，草下孝也，楠　　宏，国司秀明，黒木敏郎，黒沼勝造，久保田　穣，小林　博，小牧勇蔵，近藤　仁，西条八束，斎藤泰一，斎藤行正，坂本市太郎，佐々木忠義，佐々木幸康，猿橋勝子，椎野秀雄，柴田恵司，下村敏正，庄司大太郎，末広恭雄，杉浦吉雄，須藤英雄，高野健三，高橋淳雄，高山重嶺，高木和徳，田畑忠司，田村　保，千葉卓夫，辻田時美，土屋靖彦，寺本俊彦，冨永政英，鳥居鉄也，中井甚二郎，中野猿人，永田　正，永田　豊，永野泰一，奈須敬二，奈須紀幸，南日俊夫，新野　弘，西村　実，新田忠雄，根本敬久，野村　正，花岡　資，速水頌一郎，半沢正男，半谷高久，菱田耕造，日比谷　京，桧山義夫　平野敏行，深沢文雄，福島久雄，淵　秀隆，藤田亀太郎，星野通平，増沢譲太郎，松井　魁　松江吉行，松尾邦之助，松崎卓一，松平近義　松平康男，丸茂隆三，溝口哲夫，三宅泰雄，宮崎千博，宮崎正衛，元田　茂，森川光郎，森田良美，森安茂雄，安井　正，矢部　博，山路　勇，山中鷹之助，山中　一，依田啓二　渡辺貫太郎，渡辺精一，渡辺信雄　（50音順）

モーリス・アンコントル，マルセル・ジュクラリウス，イヴ・ド・ムクシー，ロジェ・ペリカ，コンスタンタン・エコノムー

お　知　ら　せ

東京大学海洋研究所研究集会

深海用計測器の繋留法

日　時：昭和44年12月18日，19日 9.30～17.00
場　所：東京大学海洋研究所　大講義室

12月18日（木）

開会の辞　　海洋研究所長

座　長：梶浦欣二郎（東大地震研）

浮き上り方式その他　I. 南雲昭三郎（東大地震研）
II. 渡辺　精一（理研）
III. 安井　正（舞鶴海気）

座　長：寺本俊彦（東大海洋研）

外国の例　　高野　健三（東大海洋研）
繋留装置の設計，回収，操船　佐藤　孫七（東海大）

座　長：友田好文（東大海洋研）

総合討論

12月19日（金）

座　長：南日俊夫（気象研）

ブイ・ロボットの繋留法　　赤松　英雄（気象庁）
水路部におけるブイ観測　　岩佐　欽司（水路部）

座　長：瀬川爾朗（東大海洋研）

海底地震計の繋留　I. 田　　望（北大・理）
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III. 南雲昭三郎（東大地震研）
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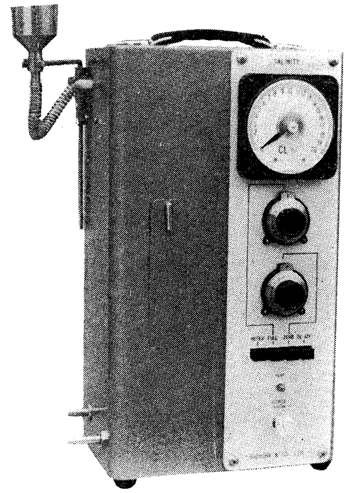
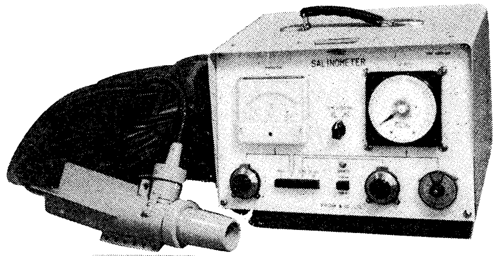
（50 音順）

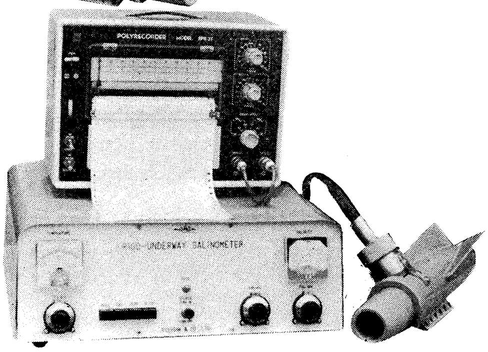
交直両用・オールトランジスタ
0～20‰ Cl直読リゴーサリノメーター（塩分計）



実験室（AC100V）：携帯用（DC12V）兼用
塩素量 0～20‰ Cl 直続
温度補償回路付
2704A RIGO-SALINOMETER



曳航式　ケーブル 50 m
塩素量0～20‰ Cl 水温-5～35°C
現場用（DC12V）.
2704B UNDERWAY-SALINOMETER



曳航式　ケーブル 50 m
記録計（2 ペン）装備
塩素量 0～20‰ Cl：水温-5～35°C
2704C UNDERWAY-SALINOMETER

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