ON THE PLIOCENE FOSSILS FROM TSUGARU STRAIT, WITH SPECIAL REFERENCE TO POST-PLIOCENE CRUSTAL MOVEMENT

By

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(with 5 Text-Figures)

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The present Japanese islands are separated by many straits and form a chain of numerous islands. The Tsugaru Strait between Hokkaido and Honshu Islands is about 200 m deep in most parts, but a ridge rises abruptly near the western mouth of this strait. The lowest part of the ridge is at about 130 m depth which is nearly the same as the depth of shelf margin. On the eastern and western sides of this ridge, there are three depressions; that to the west is 13 km across and about 200–450 m deep. Another to the east is 8 km across and has a depth of 200–350 m. The third depression is also on the Pacific side of the ridge and is very small and about 200 m deep (Text-fig. 1).

This strait is important in considerations of the migration of faunas since Pleistocene time and has been studied by many geologists and biologists.

From the viewpoint of biogeography, the strait has been called " BLAKISTON'S line " with respect to the distribution of birds and mammals. From the geological viewpoint, the origin and development of the strait has been discussed by geologists in connection with paleobiogeography and the fluctuation of sea level during the ice ages. MINATO and IZIRI (1963) clearly explained their veiw of this in the " Japanese Islands ". However, the paleogeography of this strait, at least during the Pliocene and older Pleistocene, cannot be explained by eustatic changes only. This problem must be explained by reference to data concerning the stratigraphy and paleontology of the Pliocene and Quaternary deposits developed in the Tsugaru Strait and the land area around this strait. Furthermore, oceanographic data from the strait has recently been reported by A. IZAKI (1962) and provides new information pertaining to this problem.

In 1963, OSHIMA, a graduate student at this University, engaged in an oceanographic survey of this strait on the surveying ship " Tansei-maru " of the Oceanographic Research Institute of Tokyo University, Japan. On that occasion, some molluscan fossils and sandy gravels from the bottom of Tsugaru Strait were collected.

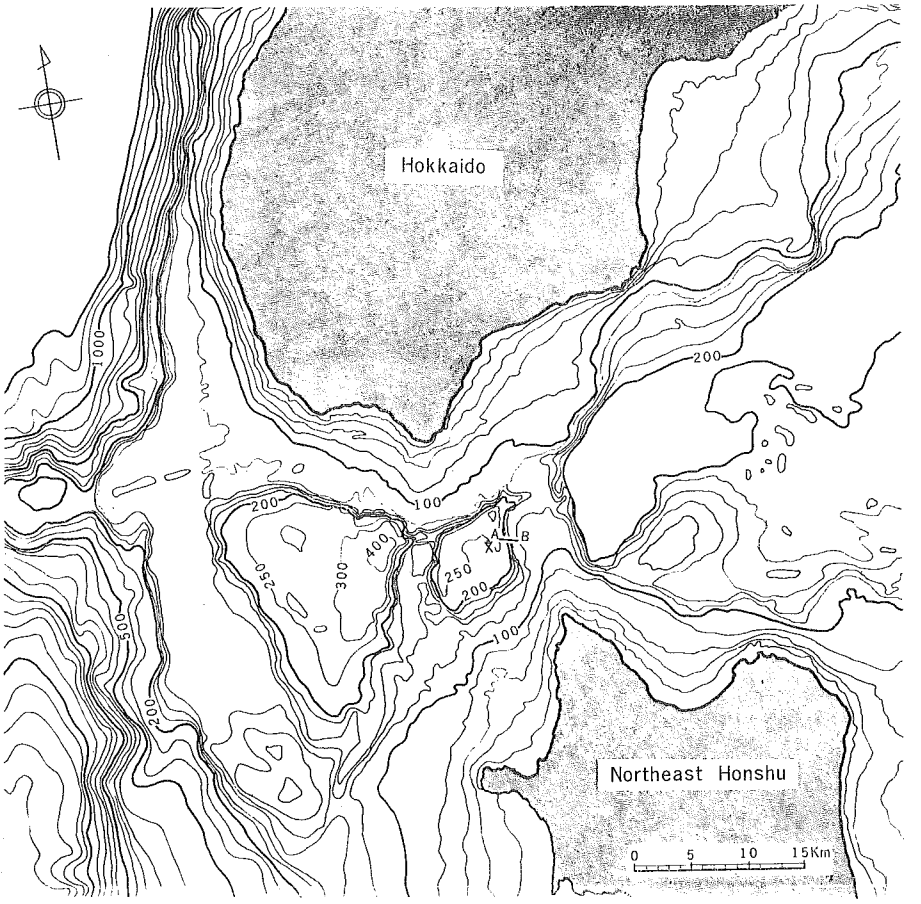

Fig. 1
Submarine topography of the Tsugaru Strait and geographic position of the dredging locality and seismic prospecting line: X: Locality of fossils and sandy gravel; A-B: Seismic prospecting line.

These fossils supply important data for the interpretation of post-Pliocene crustal movements in the vicinity of the Tsugaru Strait and of changes in the level of the sea since Pliocene time.

This report will present the geological age of the fossils collected and tentative conclusions regarding post-Pliocene crustal movements and changes of sea-level in the Tsugaru Strait and vicinity.

The writer wishes to express this deepest gratitude to Professor MASAO MINATO of the Department of Geology and Mineralogy, Faculty of Science, Hokkaido University, for his continous encouragement and supervision during the course of

this study. Acknowledgement is also due to Mr. OSHIMA for allowing the free use of his private collection. I also appreciate the courtesies and assistance extended by the crew of the Tansei-maru. Also, thanks are due to Assistant Professor FUMIO IWATA and SETSUO HUNAHASHI of the Biological Departement of this University, for cooperation in the collection of smaples, and to Mr. SIGESHI OTA and IETAKA WATANABE for supporting our laboratory work. The manuscript was kindly read and corrected lingustically by Dr. C. L. ROWETT, University of Alaska, for which the author also wishes to express cordial thanks.

Location and Geology

The molluscan fossils and sedimentary materials in question came from the sea floor at a depth of 248 m at 41°18′4″N, 140°14′2E″ in the Tsugaru Strait. This point is in the depression on the western side of the abovementioned ridge shown in Text-figure 1. The sedimentary materials are mainly composed of sandy gravel containing shells and shell fragments, and is unconsolided. The size distribution of this sediment was determined by mechanical analysis including sieve and hydrometer techniques and show a median diameter of 1.04 mm and 4.2 TRASK's sorting coefficient. The sediment typically is bimodal, in which one mode is in the sand range (0.25–0.40 mm) and the other within the range of gravel (above than 5 mm). The maximum diameter of gravel observed is 60 mm. These pebbles are regularly rounded and mainly consist of chart, diabase, quartzporphyry, andesite, propyrite and rhyorite, as well as rare subangular pebbles of sandstone and shale supplied from Tertiary formations. They thus include a wide variety of rock types in which the so-called " Mezozoic-Paleozoic pebbles " which compose the basement in southwest Hokkaido predominate.

The origin of the sediments in the depression of the Tsugaru Strait must be considered. It is noteworth that a small block of sedimentary rock was dredged together with gravels and sand. This block is composed of a yellowish grey tuffaceous coarse sandstone which contains fossil molluscan fragments and small pebbles; it is comparatively well consolided. The pebbles are similar to those of the sandy gravels in rounding and in sorting as well as in size distribution. These facts suggest that this block is not composed of reworked denudation products from the land. Moreover, the molluscan specimens are permineralized and similar to those from the Pliocene Setana Formation of southwest Hokkaido (Text-figure 3). Also, although some specimens are perfectly complete and others have disintegrated into small angular or subangular fragments, none are rounded. It thus can be inferred that these fossils were not transported by rolling or sliding along the sea bottom for any appreciable distance.

Taking into account both the fossil specimens and the enclosing sedimentary materials, the writer feel assured of the following conclusions:

1) The gravels, sands and fossils were directly derived from a Tertiary deposit which is composed of a coarse fossil-bearing sandstone-gravel.

2) This Tertiary formation is developed at or near the sampled locality.

3) It may be added, although tentatively, that these Tertiary deposits are widely developed at the bottom of the depression on the western side of the ridge in the Tsugaru Strait.

As to the last point, IZAKI's oceanographic data strengthens this possibility: his investigation consisted of a continous seismic profile and dredge samples of the submarine geology under the western passage of the Tsugaru Strait. His results conceaning the geology in the vicinity of our sampling locality were reported in 1962. IZAKI's sampling and seismic prospecting line are shown by line A–B in Text-figure 1, and are situated along the eastern slope of the same depression in which our sampling locality is located. Judging from his report, the sediment-

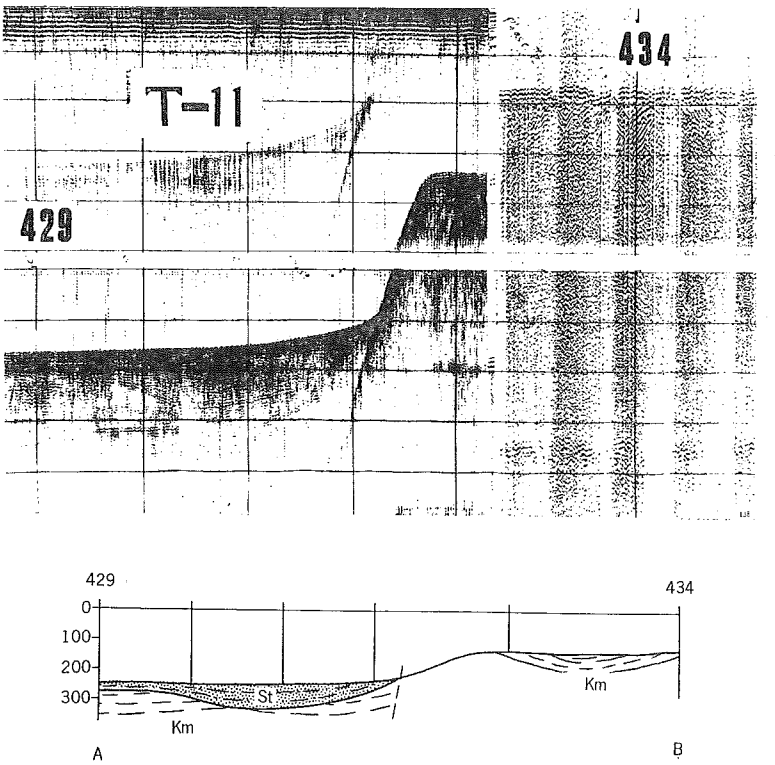

Fig. 2
Record of the continous seismic profiler along the line linking A–B in Text-figure; St: Pliocence Setana Formation consisting of sandstone and conglomerat; Km: Miocene Kuromatsunai Formation consisting of siltstone and fine sandstones (After A. IZAKI, 1962).

ary materials dredged are quite similar to our samples. His continous seismic record is shown in Text-figure 2, which indicates a comparative high density of reflecting surfaces in the uppermost sediments and suggests a stratified formation consisting of sandstone and conglomerate. This unit is underlain by an angular unconformity and siltstones and fine sandstones which are recored as strong continous reflecting surfaces at reguar intervals in the continous seismic profile.

The evidences thus suggests that our material may have originated from the stratified pebble-bearing sandstone that was recored as a conglomeratic facies by seismic prospecting and that such units may be rather widely developed in and around this depression.

Molluscan Fossils

The fossil specimens from the floor of the depression consist mainly of molluscs, bryozoa, and barnacles. Among these, mollusca are most abundant: some specimens are crushed into small pieces, and others are rather well preserved.

The fossils recognized in the material are as follows:

Pseudogramatiodon dalli (SMITH)
Pectunctella oblongata (A. ADAMS)
Chlamys islandica hindsi (CARPENTER)
Chlamys spp.
Patinopecten cf. *yessoensis* (JAY)
Anomia spp.
Astarte (*T.*) *borealis* (SCHUMADER)
Astarte (*T.*) *borealis placenta* MÖRCH
Astarte (*T.*) *alaskensis* DALL
Venericardia crassidensis (BROD.)
Balanus sp.

Among these, species belonging to the *Pectinidae*, *Astartidae* and *Anomidae* are represented by large numbers of individuals; *Balanus* is represented by specimens of unusually large size.

This assemblage suggest that the fauna may have occupied a rather cold, shallow sea. Further, the assemblage indicates a Pliocene age, since all of them are characteristic elements of the so-called " Omma " or " Setana " fauna, whose Pliocene age is the current view in Japan. The Omma Formation is typically developed in Ishikawa Prefecture in Central Japan, While the Setana Formation is well developed in southwest Hokkaido.

In the Text-figure 3, the geographic distribution of the Setana Formation is shown. Certain relationships can be observed to exist between the distribution of this unit and the present topography; specifically, the formation is not widely distributed, but occurs locally in rather narrow strips. Almost everywhere this

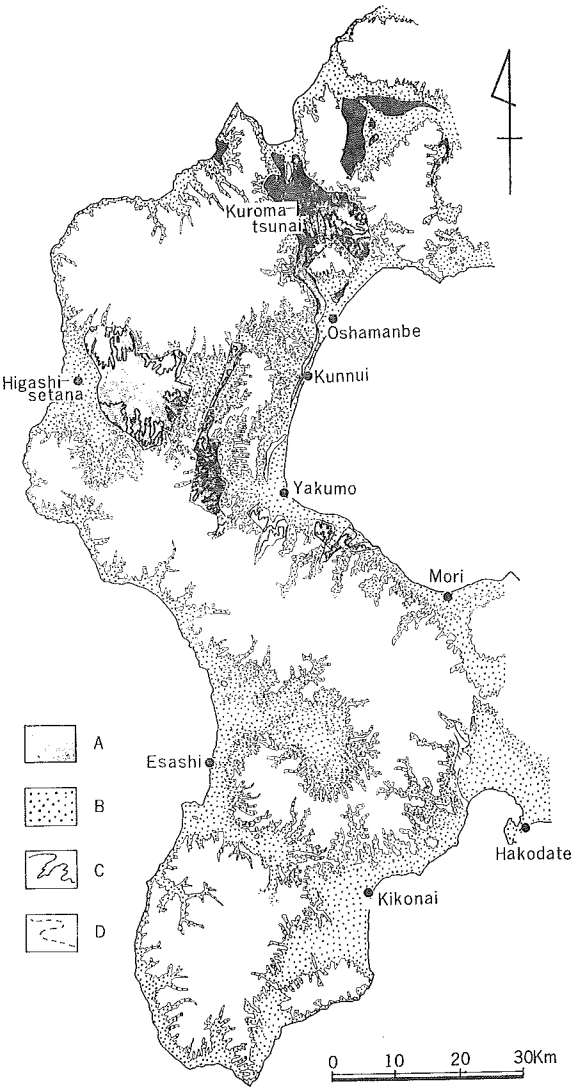

Fig. 3
Relationship between the geographical distribution of the Pliocene Setana Formation and the present topography of southwest Hokkaido.
A: Pliocene Setana Formation; B: Lowland, less than 200 m in elevation; C: 200 m contour-line; D: 100 m contour-line.

formation is restricted to areas less than 200 m in elevation. Also, this formation is remarkably similarity in lithologic facies throughout its distribution. For the most part it is composed of tuffaceous coarse-grained sandstones, with common intercalated conglomerates and fossiliferous beds. These facts suggest that the shallow sea surrounded by higher land. In the other words, the Setana sea, as a result of upwarping, was restricted in area and invaded only the topographically lower areas of a Pliocene landmass that may have somewhat resemble to the present topography of this area.

To summarize, it may be said that this Pliocene Formation now exposed on land and under the Tsugaru Strait were deposited under the same environmental conditions and the distribution of these deposits was in response to the Pliocene palaeo-topography.

Tentative Concluding Remarks with Reference to post-Pliocene Crustal Movements

If the presumption stated above is true, it seems that the relative difference in elevation (500 m) between exposures of this formation on land and those under the Tsugaru Strait have resulted from tectonic disturbances after their lithification and rocks in both areas were deposited under the same condition-*i.e.*, a shallow Pliocene sea.

Thus, the kind of geologic movement that occurred since Pliocene time must also be considered. This problem is related to the origin and development of this strait.

In this connection the following three processes must be taken into account:

1) If the sea level did not fluctuated from Pliocene to the present time, the movements of crustal blocks may have resulted in the subsidence of a portion of these Pliocene deposits to a depth of about 250 m below present sea level in the Tsugaru Strait.

2) Under the same assumption concerning sea level, and if the continental margin is unstable, the relative difference in the height of these deposits may have been caused by the periodic downwarping of the seaward part of the deposits. BOURCART in France and JESSEN in Germany are the chief protagonists of this view.

3) The difference in the relative height of these Pliocene deposits may have been caused by differential updoming of the continental slope. HOSHINO (1962) is of the opinion that the post-Miocene upwarping of land and seafloors is world-wide. However, the presence of Pliocene deposits below sea level indicates that a rise in sea level far exceeded any crustal upwarping in the Tsugaru Strait area.

Also, according to the submarine geomorphologic data from the Tsugaru Strait, it is quite clear a Neogene anticlinal high extending from the northern peninsula of Honshu Island (Tsugaru peninsula) expands northward midway into this strait, and there is no evidence that diastrophism has dislocated the axis of this structure

of broken it into blocks.

Relief forms of younger Neogene deposits are directly related to folding and faulting. This relationship is even better expressed under the sea where erosion is not as a rule as intensive as on land. It is therefore reasonable to regard this submarine ridge as an anticlinal structure.

Consequently, the following assumptions can be made:

1) There is no evidence of downfaulting which dislocated the submarine anticline in the Tsugaru Strait.

2) From knowledge concerning Pliocene tectonic disturbances on land, the Neogene submarine anticline must be due to positive rather than negative movement.

3) If fault blocks with displacement of over 500 m were assumed to exist in the Tsugaru Strait, the possibility of displacement of the sea floor by N-S trending faults might be considered., However, there is no evidence for such major faults either in the positive anticlinal area or on land near the Tsugaru Strait.

4) It might also be assumed that the depressions in the seafloor of the Tsugaru Strait, outside of the anticlinal area were formed as a result of block faulting since Pliocene time. However, the view that these depressions are due to faulting which lowered the Pliocene deposits to a greater depth than the surrounding submarine plane requires comparatively recent displacements of about 500 m in the relative height of the Pliocene deposits on the land and under the strait. This amount of recent displacement is very difficult to accept as a satisfactory interpretation.

The foregoing considerations tend to preclude the possibility of the first assumption, and suggest that only gentle warping movements need be reckoned with.

The second hypothesis, advocated by BOURCART in 1938, ascribes the apparent changing level of the sea to up- and downwarping of the continental margins. However, HOSHINO has denied the possibility of such movement near the continental margin on the basis of much recently acquired oceanographic data (1962, 1965) which is not nessecary to give in detail here. It is true that small scale and local upwarping and downwarping near of the continental margin might be explained by the BOURCART hypothesis. But such cases are exceptional, and the present writer has no data which supports this hypothesis from the region under consideration here.

Pertaining to the third assumption, HOSHINO arrived at the following general conclusion concerning crustal movement and changing sea level since late Tertiary time: a worldwide uplift of the crust, including both continental areas and ocean-floors, has caused sea level to rise from the late Neogene to the present. The present geomorphological outlines and relations of sea and land are due to differences in the magnitude of the rise of continent compared to that of the sea

floors. The deep sea terrace, 2000 m depth and world-wide in distribution thus may been formed at or near the sea level of late Miocene time.

There is a great deal of data which indicates that vertical movement of considerable magnitude have taken place across wide areas since late Miocene subsidence. For example, the general expansion of the sea has been shown in paleogeographic maps which illustrate the " Geologic development of the Japanese Islands ", published by MINATO et al. Also, the Pliocene sediments of Hokkaido and northwest Honshu consist of coarse material of shallow sea and lacustrine origin, while Miocene deposits are represented by homogeneous pelagic shales and siltstones everywhere they have been recognized. Moreover, it is well known the Pliocene marine deposits have been uplifted by about 500 m in central Hokkaido and 200 m in southwest Hokkaido during post-Pliocene time.* Tectonic uplift of the crust thus is a real factor and must be taken into account**.

The present writer is inclined to favour HOSHINO's assumption that upwarping of the oceanfloors may be similar to that of continents, and variations in this movement have cause sea level to fluctuate since the late Miocene.

The possible causes of the net increase in the level of sea are many and varied. In addition to the melting of ice and the consequent isostatic adjustments of parts of the earth's crust, they include the thermal expansion of water, the filling of the ocean basins with sediment and the addition of "*juvenile*" water from rocks brought to the surface by volcanic eruptions. However, there is no clear geologic evidence as yet that permits calculations of the relative magnitude and importance of each of these processes and their individual effects on the changing levels of the sea since the Pliocene. It nevertheless is possible to state several tentative conclusion concerning post-Pliocene changes of sea level and crustal movements of the continental slope of southwest Hokkaido.

The Pliocene sea invaded the present land area of southwest Hokkaido over a broad gentle submarine slope. This sea left behind shallow marine deposits as it retreated to the position far from the present shorelines. The maximum retreat of the sea in that time may have been far beyond the 300 m depth line on the present bathymetric maps of the Japan sea continental slope off southwest Hokkaido. The flat submarine slope at about 140–200 m depth below present sea level off southwest Hokkaido may have originated as a composite surface formed by deposition and erosion of shallow Pliocene marine deposits. Thus a lowland which was in part covered by Pliocene marine deposits must already have existed in the present position of the Tsugaru Strait in Pliocene time.

The foregoing considerations of post-Pliocene changes in sea level and crustal

* The problem of the magnitude of upwarping since Pliocene will be discussed in another paper.

** Pliocene deposits developed near recent volcanos have been displaced upward by about 1000 m in some cases in Hokkaido.

movements in southwest Hokkaido provide a basis upon which to extend this discussion to the continental slope off other coasts of Japan. IIZIMA and KAGAMI have pointed out that the late Pliocene shoreline approximately coincided with a present depth of 2200 m from their study of gravel samples from the continental slope off the Sanriku coast, northeast of Honshu. This gravel bed seem to be synchronous with Pliocene deposits called the " Takikawa Formation " in Hokkaido, or to reworked materials from the deposits, judging from the stratigraphic sequence and the reported assemblage of pebble types.* The evidence therefore indicates that the Pliocene shallow marine deposits are present in various locations which range in elevation from 200 m to 500 m on land and from 300 m to 2000 m in depth the submerged continental slope. Yet in all areas these deposits must have originated at approximately the same depth below sea-level. This strongly suggests that the geomorphology of this Pliocene depositional surface, including some areas now exposed as land, must have been much a much broader and gently inclined surface than the present continental slope. If this were the case, a small amount of upwarping of this surface would have produced a widespread and extensive retreat of sea. IIZIMA and KAGAMI's record indicates that the post-Pliocene shoreline was indeed displaced to near the outer edge of the present continental slope.

Pliocene fossils frequently have been dredged from the floor of the Japan Sea off the coasts near Nagasaki, Yamaguchi, Shimane, Niigata, Yamagata and Akita, as well as from Korea and the Tsushima Strait. These fossils previously have been considerated to be reworked specimens transported great distances from the land or from unknown localities on the sea bottom. However, from the standpoint of the outline of Pliocene geomorphology presented above, it appears rather more probable that these fossils originated *in situ* from each sampling localities or from its immediate vicinity and were derived from Pliocene sediments originally deposited in these areas. In this connection, HOSHINO (1965) reported Plio-Miocene fossils from a depth of 1500 m on the continental slope to the west of the Izu Peninsula, southwest Honshu. All of these fossils, regardless location and depth, indicate a shallow sea envinonment, which tends to support the thesis advanced above.

FUJITA has estimated in 1962 the post-Pliocene seashore at a depth of 2000–3000 m on the present continental slope in the Japan Sea in his consideration of the origin of this Sea. He emphazed the significance of the submarine canyons which

* The Takikawa Formation consists of boulder-pebble conglomerate, supplied by the uplift and erosion of Hidaka Alpine orogenic belt and distributed rather widely and narrowly with a N-S trend along the western wing of the Hidaka Mountain Range. This formation may extend southward far beyond the present shoreline of Hokkaido. Moreover, from our knowledge concerning Neogene conglomerates in Hokkaido, the assemblage of the gravel, reported by IIZIMA and KAGAMI, is very similar to that of the Takikawa Formation and not that of other conglomerates.

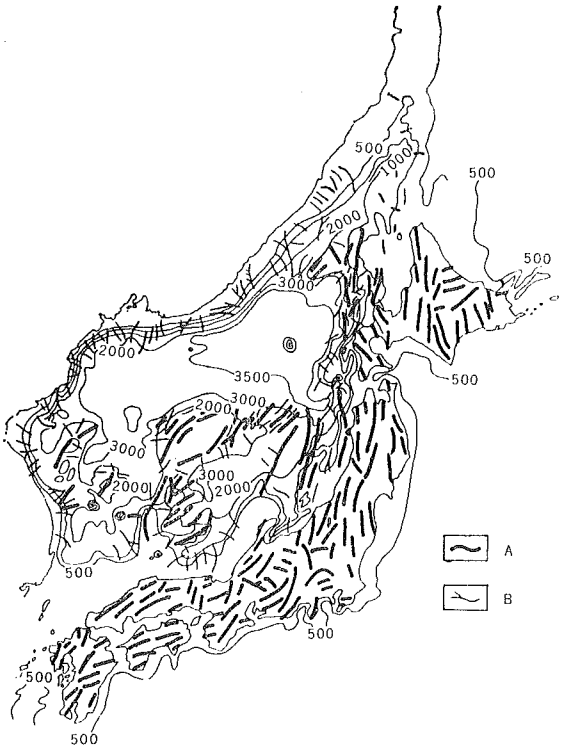

Fig. 4
Topography of Japanese Islands and Japan Sea.
A: Highland and submarine ridge; B: Submarine canyon (After N. FUJITA, 1962).

range from 200 m~2000 m in depth on the continental slope, especially off southwest Hokkaido, northeast Honshu and the Noto Peninsula, as well as evidence concerning the geological structure of the deep basins of the Japan Sea.

The submarine canyons off Japan cannot be older than Pliocene or late Miocene depoists, since they are cut into them. They may well have been formed by subareal erosion by rivers, which is consistant with the upwarping of the continental slope. The longitudinal profiles of these canyons are rather steep for river valleys, as has been pointed by some geologists; however, the present profiles would have been steepened during post-Pliocene periodic upwarping. These canyons would, in fact, be polycyclic. Such an interpretation is easy to accept in Japan, where large scale crustal movements are known to have occured in the late Tertiary and Quaternary periods. That have produced many canyons of recent origin. Accordingly, similar canyons could have been excavated in the flat Pliocene depositional surface and subsequently modified by upwarping movement that continued into

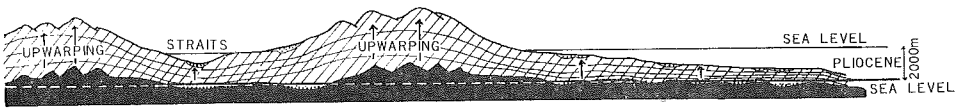

Fig. 5
Generalized geomorphologic profile showing the upwarping of the crust and changing level of sea, since Pliocene time. The Pliocene geomorphology is shown in solid black; uplift of crust is in hatch and the Pliocene deposits are in stipple.

the Pleistocene.

The writer therefore has arrived at the following general conclusion concerning the geomorphology of the continental slope off Japan.

1) During the Pliocene, the continental slope, which included some parts of the present land, consisted of a very broad and flattish epicontinental floor which contained several shallow depositional basins. The present area of the Tsugaru Strait and adjointing lowlands constituted part of this surface upon which fossiliferous Pliocene shallow marine sediments were deposited.

2) With the beginning of upwarping of this slope, the Pliocene sea began a retreat to a position which approximately coincided with the 2000 m depth line near the present outer edge of the continental slope.

3) " Submarine canyons " were excavated subareally on this slope during the gradual retreat of the sea. Furthermore, variations in the degree of uplift of this region produced variable geomorphologic relief; this relief tends to be greater on the present land and more subdued in submerged areas.

4) It seems probable that the subsequent net increase in sea level was caused by a comparatively greater rise of the ocean floors. Thus, the cumulative incursion of the sea which subsequently flooded the rising continental slopes were the result of the sea level rises which more than compensated for upwarping.

5) The fact that most submarine canyons do not connect with present continental river systems and are not found on the submarine plane at depths of less the 200 m is a disturbing fact that requires explanation. With some reservation, the writer suggests that this flate surface, which ranges from 100 m to 200 m in depth, may be newly eroded surface underlain [by Pliocene deposits which has been modfies by the periodic occilations of the sea since the early Pleistocene. The many submarine terraces between 0–100 m may represent temporary sea level stands from the late Pleistocene to recent.

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(Manuscript received January 31, 1967)