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journal or publication title	Science reports of the Tohoku University. 2nd series, Geology. Special volume = 東北大学理科報告. 地質学
volume	4
page range	127-153
year	1960-05-05
URL	http://hdl.handle.net/10097/28890

Science Reports, Tohoku University, Sendai, Japan, 2nd Ser. (Geol.), Spec. Vol., No. 4, pp. 127-153, 1960

Japanese Miocene Reconsidered

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INTRODUCTION

That opinions diverge concerning the position of the boundary between the Pliocene and Pleistocene is well known. Likewise the boundaries between other divisions of the Cenozoic rocks have also been subjected to diverse views and various classifications have been proposed for them. Geological ages ascribed to the different stratigraphic units based upon paleontological evidence has lead to the establishment of different methods of classification of the Cenozoic rocks. However, owing to many reasons opinions diverge rather widely, and it is thought that this gap may be narrowed through a reconsideration of problems relating to the lack of uniformity in stratigraphic nomenclature, interpretation of the geology from a broader view, paleontological treatment of different kinds of fossils as related with paleoecolgy, stratigraphic ranges, geological distributions and others.

Owing to that numerous important articles on the geological sciences of Japan have been published during the past some ten years, it is evident that the progress has been great. It does not seem to be too early to briefly outline the present status concerning the aforementioned problems, and also to show that in the Neogene deposits of Japan there exists a characteristic cycle, sedimentological and paleontological in its character, which shows good correlation with the change in climatic pattern since the early Miocene, among which those of the Pleistocene have already been reported (K. Hatai, 1958) in part.

PREVIOUS CLASSIFICATION AND PROBLEMS

The geology and paleontology of the Cenozoic rocks of Japan commenced at an early date, but it is Yabe and Aoki (1923), who first subdivided them into time-stratigraphic units independent of the European standard chronology. They recognized four grand units of Akitsu, Takachiho, Mizuho and Shikishima. The Akitsu is a period of submergence and includes minor stratigraphic breaks; the period being represented by the Akitsu series. The Takachiho is a period of emergence and is represented by the Takachiho series. The Mizuho period is one of submergence, includes smaller stratigraphical breaks and is characterized by the Mizuho series, and the Shikishima period of emergence which is most typically represented by terrace deposits and marine sediments is typical of the Shikishima series. Those authors hold, from paleontological evidence, that the Akitsu is the Japanese Paleogene (Eocene to early Oligocene), the Takachiho represents the Middle and Late Oligocene, the Mizuho is the Japanese Neogene and the Shikishima corresponds to the

Pleistocene. This important contribution is based largely upon the significant stratigraphical breaks supported by paleontological evidence.

During the same year Matsumoto (1923) recognized several important stratigraphical breaks in the Cenozoic rocks of Japan, and from them and the fossils derived from the different formations proposed the following classification. Sub-Paleogene break, dividing the Paleogene from the late Cretaceous, the Sub-Miocene break which separates the older Miocene from the Paleogene, the Mid-Miocene break which distinguishes the older Miocene from the younger, and the Sub-Pontian break which separates the Post-Pontian including older Pleistocene from the Pontian. The principal crustal movements according to Matsumoto are, 1-Uppermost Cretaceous emergence (Sub-Paleogene break), 2–Lowest Paleogene submergence, 3-Lower Paleogene emergence, 4-Middle Paleogene submergence, 5-Middle Paleogene emergence, 6-Upper Paleogene submergence, 7-Uppermost Paleogene emergence (Sub-Miocene break), 8-Lower Miocene submergence, 9-Mid-Miocene emergence (Mid-Miocene break), 10-Upper Miocene submergence, 11-Pontian emergence (Sub-Pontian break), and then, 12-Post-Pontian submergence. He has also recognized some fossil zones such as lower, middle and upper *Thyasira* zones, *Vicarya* zone, lower and upper *Desmostylus* zone. Among these he states that the middle *Thyasira*, *Vicarya* and lower *Desmostylus* zones are representative of the upper half of the older Miocene, while its lower half by the zone of the *Anchitherium* faunas (lower), and the zone of the lower *Thyasira*, *Euhinodelphis* and *Idiocetus*. The upper *Desmostylus*, upper *Thyasira* and lower *Carcharodon megalodon* zones occur in the lower half of the younger Miocene including Pontian. The upper half is characterized by the upper *Carcharodon megalodon* and *Mastodon latidens* zones and is referable to the Pontian. Thus stating that Pontian is upper Miocene in age.

The views expressed by the above mentioned authors are very interesting and valuable because they have stimulated subsequent writers in progressing the methods of classification of the Cenozoic rocks of Japan. Although the two papers are not in agreement their basic standpoints are valid and provide the foundation for subsequently published works.

Grabau (1927) proposed for Asia a new subdivision of the Cenozoic deposits and correlated them with the standard chronology of Europe. For Asia he proposed, from the older to the younger, Libyan for Paleocene, Sindian for Eocene, Narian for Oligocene, Sumatran for Aquitanian, Javan for Burdigalian, Iranian for Vinobonian, Malaysian for late Miocene, and Nipponian for Pliocene. However, with regard to the stage name of Nipponian, it must be added that he based his works on the numerous papers published by Yokoyama on the molluscan fossils of Japan. Yokoyama's Pliocene in his works are now distributed from early Miocene to late Pliocene, and therefore, Grabau's proposal of that name should be rejected.

Otuka (1932) in his work on the sedimentary cycles in the Japanese Neogene proposed three cycles of sedimentation for the upper Neogene, namely, 1-mm∼mu (upper Miocene) cycle, 2-mu∼pm (uppermost Miocene∼Middle Pliocene) cycle, 3-pu (upper Pliocene) cycle. Transgression takes place in mm, regression in mu, transgression in pl, regression in pm, transgression in pu, and another regression in d.

In his work on the Tertiary structure of the western Kanto district, Watanabe (1954) proposed four stage names, namely Akahirian, Chichibumachian, Matsuyamian and Itanhanian in upward sequence, these are considered by him to correspond to Oligo-Miocene (or late Oligocene), early Miocene, early middle Miocene, and later middle Miocene respectively. His correlation table gives for the standard of the stage names, the Akahira group, Chichibumachi group, Matsuyama group and Takasaki group respectively for the four stages. Each of the stages is characterized by many fossils, for example, the Akahirian by *Yoldia asagaiensis* Makiyama, *Cardium asagaiensis* Makiyama, *C. iwakiensis* Makiyama, *Venericardia laxata* Yokoyama, *Liocyma furtiva* (Yokoyama), *Macoma asagaiensis* Makiyama, *Mya grewingki* Makiyama, *Colus asagaiensis* Makiyama, and others. The Chichibumachi stage is characterized with *Lepidocyclina nipponica* Hanzawa, *L. japonica* Yabe, *Miogypsina kotoi* Hanzawa, and *Cornwallius*. The lower part of the Matsuyamian by *Miogypsina kotoi*, *Vicarya yokoyamai* Takeyama, *Vicaryella ishiana* (Yokoyama),*Sanguinolaria minoensis* (Yokoyama), and the upper part of the same with *Desmostylus japonicus* Tokunaga and Iwasaki, *Turritella s–hataii sagai* Kotaka, *Cultellus izumoensis* Yokoyama, and the Itahanian is characterized by *Cornwallius* ? sp., *Dosinia kaneharai* Yokoyama, *Chlamys kaneharai* (Yokoyama), *Turritella kadonosawaensis* Otuka, and others.

Makiyama (1931) on the other hand proposed the following stage names based upon the Tertiary deposits of the Kakegawa district in Shizuoka Prefecture. The stages recognized by him are the Ketienzian (Middle Pliocene), Dainitian (Lower Pliocene), and Infra-Dainitian (Upper Miocene), all three being referred to the Kakegawa series, which is stated to be separated from the older deposits by orogenic movement and from superjacent sediments by epirogenic movement. Each of the stages are described in detail and their paleontological features indicated.

Otuka (1939) subsequent to his work of 1932, subdivided the Tertiary deposits of Japan using letters, into the following way, e–Eocene, ol–lower Oligocene, ou–upper Oligocene, ml–lower Miocene, mm–middle Miocene, mu–upper Miocene, p–Pliocene, pd–Plio-Pleistocene, and d–Pleistocene.

Ikebe (1948) in his first proposal of subdividing the Japanese Cenozoic deposits by letter nomination, published contradicting remarks, as may be noticed from the descriptions in the text and his tables appended to the article. However, again in 1954, he published the following definitions of his previously established letter nomination units, as :

A (Lower Eocene). Type formation–Kamishima group (Ariake stage) in western Kyushu. *Nummulites amakusensis*, *Discocyclina* af. *protti*, *Turritella okadai*, *Orthaulax japonicus*, *Turritella* cf. *merriami*.

B (Upper Eocene). Type formation–Nogata group (Nogata stage) in northern Kyushu. *Crassatellites nipponicus*, *Athleta nishimurai*, *Venericardia nipponica*, *Desmatotherium grangeri*, *Amynodon watanabei*.

C (Upper Eocene or Lower Oligocene). Type formation–Otsuji group (Otsuji stage) in north Kyushu, *Chlamys sakitoensis*, *Venericardia subnipponica*.

D (Oligocene). Type formation–Ashiya group (Tsukushi stage) in north Kyushu.

Glycymeris "cisshuensis", Venericardia subnipponica, Crassatellites yabei, Chlamys ashiyaensis.

E (Upper Oligocene or Lowest Miocene). Type formation–Asagai formation (Asagaian stage), upper part of the Shiramizu group, in the Joban coal-field, East Japan. *Periploma besshoensis, Cardium harrimani, Cardium asagaiensis, Mya grewingki, Turritella importuna, T. tokunagai, Trochocerithium wadanum.*

F_1 (Lower Miocene). Type formation–Megami group (Oigawan stage) in Shizuoka Prefecture. *Lepidocyclina (Nephrolepidina) nipponica, L. (N). ferreroi, L. (N.) angulosa, Miogypsina kotoi, Operculina complanata japonica.*

F_2–F_3 (Middle Miocene). Type formation–Kurami group (F2) and Saigo group (Tozawan stage, F3) in Shizuoka Prefecture. *Lepidocyclina (Nephrolepidina) japonica, L. (N.) makiyamai, Miogypsina kotoi, Operculina complanata japonica, Anadara abdita, A. daitokudoensis, Pecten kanbaraensis, Chlamys kaneharai, Dosinia kaneharai, Katelysia nakamurai, Sanguinolaria minoensis, Vicarya callosa, V. yokoyamai, Vicaryella ishiiana, Batillaria tateiwai, Protorotella yuantaniensis, Turritella s-hataii, T. kadonosawaensis, Bunolophodon annectens, Prostegodon latidens, Desmostylus japonicus, Comptoniphyllum naumanni.*

G (Upper Miocene or Lower Pliocene). Type formation–Sagara group (Yuian stage) in Shizuoka Prefecture. Epibole of *Sagarites chitanii, Pecten kagamianus, Chlamys crassivenia, Pecten kimurai, Phos iwakiana.*

H_1 (Lower Pliocene). Type formation–Dainichi formation of the Kakegawa group (Suchian stage) in Shizuoka Prefecture. *Umbonium suchiense, U. subsuchiense, U. obsoletum, Chlamys miurensis, Ammusiopecten praesignis, Glycymeris nakamurai, Venericardia panda, Turritella perterebra, Siphonalia declivis, Turritella saishuensis motizukii.*

H_2 (Upper Pliocene). Type formation–Hijikata formation of the Kakegawa group (Ketienjian stage) in Shizuoka Prefecture. *Umbonium subsuchiense, U. akitanum, Turritella saishuensis, Pecten kurosawaensis, Pecten tokyoensis, Pecten takahashii.*

I_1 (Plio-Pleistocene). Type formation–Kanozan formation of the Miura group (Kanozanian stage) in the Boso Peninsula near Tokyo. *Stegodon akashiensis,* S. *aurorae, Metasequoia, Sequoia, Glyptostrobus, Liquidambar formosana, Juglans cinerea.*

I_2 (Lower Pleistocene). Type formation-Sanuki formation of the Narita group (Sanukian stage) in the Boso Peninsula. *Elephas naumanni, Stegodon orientalis, Pecten tokyoensis.*

J (Pleistocene). The stage in the type area may be divided into the following subdivisions. Types of these substages are: Jizodo (Makutian, J_{1a}), Semata (Sematian, J_{1b}), and Yatomi (Naritian, J_{1b}), Manzaki (Manzakian, J_2) formations of the Narita group, and Tachikawa (Kwanto Loam, Tachikawan, J_2) formation, all near Tokyo. *Elephas namadicus naumanni* (J_1, J_2), *Elephas namadicus* (J_2), P*ecten tokyoensis* (J_{1-2}), *Cardium braunsi* (J_{1-2}).

From his range chart it appears that *Lepidocyclina nipponica* and *L. japonica* occur from two distinct horizons, *Miogypsina kotoi* from three distinct horizons ranging from F_1 to F_3, that *Mya grewingki* and *Cardium asagaiensis* occur both in late Oligocene and early Miocene, that *Solemya tokunagai* extends its range up to the Plio-Pleistocene Kanozanian stage. Remarks as to Ikebe's procedure concerning the Pleistocene of the Kwanto District, have been given elsewhere (K. Hatai, 1958), and will not be repeated here.

Although Ikebe's article is an interesting one and very valuable from the reason that such a kind of classification is needed for the Tertiary deposits of Japan, it is to be added that since his explanations, range-chart of the various genera and species and correlation table of the typical Cenozoic formations do not show correspondance, the writer refrains from its usage and therefore omits further remarks.

Other methods of classification have been proposed for the Cenozoic rocks of Japan by Hatai (1937), Kitamura (1959), and Makiyama (1931, 1940), and among them, the one of Makiyama (1940) is of considerable interest in that it classifies stages for the Cenozoic rocks ranging from late Oligocene to late Pliocene. He recognized the following in ascending order, namely, Asagaian, Ooigawan, Togarian, Yuian, Dainichian, Ketienjian, and Transition. Although there remain problems as to his correlation and the inclusion of terrestrial facies (Hiramaki formation) with marine sediments (Togari) and the neglecting of the Tsukiyoshi which is continuous downwards from the Togari, and the terrestrial Nakamura which is continuous upwards with the Hiramaki formation. However, his idea is a good one.

For the Pleistocene, Makiyama (1931) proposed the following stages, in upward succession as follows, Kanozanian, Sematian, Naritian and Tatikawan. Although there remain some problems as to the stratigraphic units included into these stages, discussions will here be omitted because they have been presented elsewhere (K. Hatai, 1958).

Various problems remain concerning each of the different classifications hitherto proposed in Japan. So far as literature is concerned none of the previously defined stages have been designated upon both stratigraphic and paleontologic grounds, (except for J. Makiyama, 1940) and generally only the fossils from a given formation or lithological unit are listed and the name of the unit taken as the time-rock name without reference to the kind of lithology making that unit. Also the stratigraphic sequence of the sediments making the stratigraphic unit and the position of the fossils occurring in the sequence have generally been not treated. This procedure leads one to doubt as to whether the original author had taken into consideration only the horizon in which the fossils occurred, the entire stratigraphic unit regardless of lithology, the paleoecological phenomena influencing the fauna or flora buried in the unit, neglected the whole stratigraphic sequence of the different rock units, and many others.

From the foregoing lines it becomes clear that there are many problems incorporated in the classifications previously proposed in Japan and that, if the classifications were well founded, and subjected to trial and even modification by subsequent workers, the problems of correlation of the deposits developed in separated sedimentary basins with one another or even within a single sedimentary basin would have been much progressed.

In the present article, the writer attempts to make a more natural classification of the Cenozoic rocks of Japan, particularly of the so-called Miocene of Japan, and details of the deposits younger and older than the Japanese Miocene will be reserved for another opportunity.

RECONSIDERATION OF CERTAIN PALEONTOLOGICAL DATA

Before entering the discussions upon which the present work is focussed, and preliminary to one expected to be published, it may be best to reconsider some of the paleontological data that have hitherto been regarded to be of importance in age determination and correlation. This seems to be necessary in order that a general view may be gained of the role played by certain fossils in their value of both stratigraphic and paleontologic problems as related to correlation and age determination. For this purpose the fossils will be treated in a general way.

DESMOSTYLID AND VICARYID SEQUENCE

Among the fossils occurring from the Cenozoic rocks of Japan, the desmostylids and vicaryids are of interest because they have been regarded as having intimate relation with geological age determination, indications of paleoecological conditions and since they are specialized in their development and extinct, their value in stratigraphy can not be neglected. The problem concerning them is their exact stratigraphic ranges, geological distributions, their interrelation from a stratigraphical standpoint, and causes for their extinction. These two different specialized fossils will be treated in the following lines.

According to Nagao (1937, pp. 46–49), there are at least two distinct horizons of *Desmostylus* in Saghalen (T. Iki 1938, p. 3), namely, *D. mirabilis* Nagao (1935, pp. 822–824) and *D. minor* Nagao (1937, pp. 46–49). The stratigraphic positions of them in the stratigraphic sequence of South Saghalien are *D. minor* from the basal part of the Hatchorei formation and *D. mirabilis* from the Naihoro formation. These two formations are included into the Honto group, which lies unconformably below the Pliocene Shiritoru and above the Maoka group which contains Oligocene fossils.

With regard to the geological ages and correlatives of the Maoka and Naibuchi groups, Hatai and Kamada (1950, pp. 72–73) expressed the view that these two groups are referable to the Oligocene upon fossil evidence. Their correlatives are the Shirasaka and Asagai formations in the Joban coalfield of Fukushima and Ibaraki Prefectures, the Momijiyama and Poronai formations of Hokkaido, the Aragai and Nishisakutan formations of South Saghalien, and corresponding deposits also occur in the Chichibu Basin in Saitama Prefecture and rather extensively in Kyushu. The age of the Shiritoru group is Pliocene (H. Yabe and K. Hatai, 1940, p. 158), and the Maruyama sandy shale in the lower part of the group is early Pliocene from the occurrence of *Fortipecten takahashii* (Yokoyama). Therefore, the Honto group is inserted between the late Oligocene Maoka and the early Pliocene Shiritoru groups, and from stratigraphic position and paleontologic evidence is of Miocene age, and since desmostylids are unknown from deposits other than the Honto, its stratigraphic range is restricted to that age.

Desmostylid teeth have been reported from Hokkaido (T. Nagao, 1937, pp. 110–113), especially from the Pirika formation of the Kunnui group. This formation occupies the middle upper part of the Kunnui group, which is overlain conformably with the Yakumo and

Kuromatsunai groups in upward order. The latter mentioned group is unconformably covered by the Nigorikawa group, which is unconformable with the next younger Setana group of late Pliocene age. The Kunnui is subdivided into the Kamikunnui, Chayagawa, Pirika and Niseibetsu formations in upward succession, and is generally accepted as a correlative of the Kawabata group from paleontological and stratigraphical evidence. Nagao (1937, p. 113) pointed out that the Kunnui group is nearly equivalent to the Kawabata and almost contemporaneous with the Honto, judged from the similarity of their molluscan faunae.

The occurrences of desmostylid fossils from Honshu have been reviewed by Watanabe (1953, pp. 43–60), who recognized three distinct horizons; these are quoted below:

A) Desmostylids belonging to the lower horizon (the Lower Miocene, the Burdigalian stage).

1. Chichibu specimens, *Cornwallius* ? sp. (1951); the Chichibumachi formation (upper part of the Chichibumachi group) of the Chichibu Basin, Saitama Prefecture.

2. Yumoto specimen, *Desmostylus* cf. *mirabilis* Nagao (1936); the Kameno-o formation (middle part of the Yunagaya group) of the Joban Coalfield, Fukushima Prefecture.

B) Desmostylids belonging to the middle horizon (lower part of the middle Miocene, the Helvetian or Vindobonian stage).

3. Togari specimen, *Desmosytlus japonicus* Tokunaga and Iwasaki (1902); the Togari formation of the Toki Basin, Gifu Prefecture.

4. Sawane specimen, *Cornwallius tabatai* Tokunaga (1939); the Tsurushi formation of Sado Island, Niigata Prefecture.

5. Yuda specimen, *Desmostylus japonicus* Tokunaga and Iwasaki (1923) and *Desmostylella typica* Nagao (1937); lower part of the Kadonosawa group of Iwate Prefecture.

6. Shikonai specimen, *Desmostylus japonicus* Tokunaga and Iwasaki (1923); lower part of the Kadonosawa group of Iwate Prefecture.

7. Nanami specimen, *Desmostylus japonicus* Tokunaga and Iwasaki (1943); the Anamizu formation of Noto Peninsula, Ishikawa Prefecture.

8. Tashiro specimen, *Desmostylus japonicus* Tokunaga and Iwasaki (1951); the Yuzawa formation of the south marginal region of the Yokote Basin, Akita Prefecture.

C) Desmostylids belonging to the upper horizon (upper part of the middle Miocene, the Tortonian or Sarmatian stage).

9. Izumi specimen, *Cornwallius* ? sp. (1951); the Yamanouchi formation of the Toki Basin, Gifu Prefecture.

10. Yumachi specimen, *Desmostylus* sp. (1918); the Fujina formation of Shimane Prefecture.

11. Shiogama specimens, *Desmostylus* sp. (1935); the Shiogama formation of Miyagi Prefecture.

From the molluscan fossils occurring in association with the desmostylids, Watanabe concluded that the horizons in the lower Miocene and lower part of the Middle Miocene indicate warm thermal conditions, while that of the upper part of the Middle

Miocene yielded molluscs pointing to a cold water current. From such evidence he stated that the desmostylids "may have been animals of the so-called boreal type, but were not dwellers in the cold sea only". The cold water environment of the mammalian was also noticed by Hanzawa (1950, p. 80), who stated "the occurrence of Desmostylids just mentioned indicates that the Japanese Islands where becoming influenced by a colder climate which seems to have commenced during the upper Middle Miocene (Tsunaki formation in the Sendai Area, Kameno-o formation of the Joban coalfield, etc.) than the Lower Miocene and the Lower Middle Miocene".

Problems still remain concerning the stratigraphic positions, thermal conditions and geological significance of the desmostylids distributed widely but sporadically in the Miocene rocks of the North Pacific borderland, and it may be mentioned here that the discovery of a desmostylid from the late Oligocene rocks of Hokkaido (H. Yabe, 1959, pp. 44–51) is of deep interest. These problems will be treated in the following lines.

The stratigraphic name of Shiogama formation mentioned in earlier pages is not recognized by Hanzawa et al. (1953, pp. 1–50) because it has not been designated, its distribution not known, its relation with other units in the same area not worked out and also because it includes the Ajiri, Hamada, Sauramachi and Nobiru formations which have been designated formally and treated geologically. Therefore the stratigraphic position of the Shiogama desmostylid should be reconsidered. It was derived from the hills near the Shiogama Fish-market (uppermost part of Ajiri formation) and from the vicinity of Nojiri (Hamada formation). These two formations of different lithological characters but of the same stratigraphic position yield abundant molluscan fossils.

The molluscan fossils from the uppermost part of the Ajiri formation to be mentioned are, *Trachycardium shiobarense* (Yokoyama), *Lutraria sieboldtii* Deshayes, *Cultellus izumoensis* Yokoyama, *Proclava atukoae* (Otuka), *Sinum yabei* Otuka, *Phos* (*Coraephos*) *iwakiana* (Yokoyama), *Murex tiganourana* Nomura, *Fulgoraria striata* (Yokoyama), *Conus* and other genera. These typical Ajiri genera and species occur in an area far north of the present limits in distribution, thus advocating that there is no evidence for claiming a cool water condition. In the middle part of the Ajiri formation, *Nanaochlamys notoensis* (Yokoyama), *Siratoria siratoriensis* (Otuka), *Vicarya yokoyamai* Takeyama and other warm water molluscs occur. These have wide distribution in the Miocene deposits of Japan and occur stratigraphically in a position higher than the strata which have yielded *Eostegodon pseudolatidens* (Yabe) and the well-known and extensively distributed *Comptoniphyllum-Liquidambar* flora. The fauna and flora both indicate warm conditions.

The Yamanouchi formation aforementioned is stated to contain a cold water molluscan fauna and to correspond to the Ajiri and Hamada formations (the Shiogama in part). This formation is reported to have yielded *Cultellus izumoensis, Fulgoraria megaspira* (Sowerby), *Ancistrolepis* and *Lunetia*, and therefore to indicate cold water (Watanabe, 1953, p. 47). The Yamanouchi is said to be overlain with the almost fossil-bare Ichihara formation and to be superposed conformably upon the Togari, which lies conformably on the Tsukiyoshi formation. All are conformable with one another, and lithologically the Tsukiyoshi can hardly be distinguished from the Togari, exhibiting the same color, same kind of sediments, similar degree of induration, but have previously been distinguished from one another by the *Felaniella*-bearing concretions occurring in the middle part of a massive, coarse-grained sandstone. The desmostylid was said to be from the Yamanouchi formation, but is listed as occurring from the Togari (K. Watanabe and S. Iwahori, 1952, p. 437). Therefore, if the Togari formation is correct, the associated molluscs comprise such as *Dosinia* cf. *kaneharai* Yokoyama, *Turritella s-hataii sagai* Kotaka, and *Turritella kadonosawaensis* Otuka, all which fail to indicate cold water and have warm water relatives. From lithofacies, I consider that there is no sound basis for accepting the lithological names of Tsukiyoshi and Togari, and although the Yamanouchi can, with difficulty, be distinguished from them, all three may better be included into the single rock-unit known as the Akeyo formation.

Concerning the problem of superposition and interstratigraphic relation between the Nakamura-, Hiramaki- (=Hongo formation), Tsukiyoshi-, Togari-, Yamanouchi-, and Oidawara formations, several remarks are here added from a viewpoint different from those hitherto presented. First it known that the marine Oidawara formation has in its lower part a sandstone and conglomeratic facies. This facies comprises several layers of conglomerate and sandstone, the lowest of which is unconformably superposed upon the Nakamura formation without the development of the Hiramaki. Above this lowest thin conglomerate layer is the Shukunohora *Miogypsina*-bearing sandstone which yields abundant molluscan remains. This sandstone is overlain with a conglomerate layer which is covered with a sandstone layer and another conglomerate layer. Traced laterally both conglomerate layers and sandstone layers seem to decrease in their thickness and degree of development, and at some places there can be seen apparent fusion of the two conglomerate layers with a lenticular intercalation of the fossil-bearing sandstone, and in such places the fossil-barren sandstone situated above the conglomerate layer overlying the *Miogypsina*-bearing one thins out to disappear. The lithological features of the sandstone which thins out is materially similar to the sediments building the Hiramaki formation. The unconformity between the Nakamura formation below and the Shukunohora *Miogypsina*-bearing sandstone above is pierced at places with abundant holes of the boring shell (*Pholadide*) and covered with a thin layer of sporadically distributed gravels whose interspaces are filled with the Shukunohora sandstone.

Here the problems for consideration are, 1–because the Hiramaki formation is lacking here, does the unconformity represent the time necessary for the eroding away of that stratigraphic unit ?, 2–the sandstone layers lying above the Shukunohora sandstone and below the massive siltstone comprising the main part of the Oidawara formation comprises materials differing from the Shukunohora and similar to the Hiramaki, does this imply that its source is the Hiramaki ?, 3–the geological ages of the Akeyo formation and the Hiramaki formation have been considered to be the same, and the former and the latter to represent merely different lithological facies, if so, then how should their interrelation be explained ? 4–that both the terrestrial sediments classified into Nakamura and Hiramaki formations in upward sequence and the marine Akeyo formation are unconformable with the basement suggests their contemporeinity, but what do the observed unconformity separating the terrestrial from the marine sediments imply ?, and, 5–is there some adequate means for interpreting the geological phenomena ? such problems seem to be important for clearing the geo-history of the area and satisfactory explanations are difficult.

With regard to the above stated problems, the writer would like to express the following view. That the Hiramaki formation is missing in only certain areas (in the Gifu district) and is there overlapped with marine sediments to exhibit an unconformable relation, is evidence of the transgressive nature of the early Miocene seas. Because a land must have existed at the time of marine transgression, and the land surface would thus everywhere correspond in time to the advancing sea even though the strand line would be retreating, by which reason its surface sediments would be stripped away in part to be incorporate into the transgressing seas to be deposited. From this view the stripping away of the Hiramaki sediments (then the land surface) to be incorporated into the advancing seas is not representative of an unconformity in the true geological sense. The sandstone forming the Shukunohora *Miogypsina*-beds lithologically suggests its derivation from the Nakamura formation, while the sandstone lying above it but separated with a conglomerate layer, makes one to find its source in the Hiramaki sediments. If such can be accepted then we may interpret the relief of the land at the time of marine transgression, the nature of the advancing sea, and their respective positions of deposition as related with the rising sea-level. Since the mammalogoists agree that the Hiramaki formation is Burdigalian from the occurrence of numerous genera and species already mentioned in earlier lines, and the marine invertebrate paleontologists consider the Akeyo in its lower part to be of the same age, although the facies of the two are contrasting, the view that the land surface and the advancing seas were of the same age does not conflict, but show remarkable good correspondence. The only evidence that has hitherto been responsible for continued divergence of opinions, is the stratigraphic sequence of the sediments from the Nakamura up to the Akeyo formations. Also to the present there has always been the problem as how to correlate terrestrial sediments with marine deposits when no evidence of interfingering of the deposits can be observed in the field. It is well known that a land must have existed if there was a sea, and naturally an unconformable relation would be produced by transgressing sea water upon the then land surface, even though the time would be the same.

Problems relating to the source of sediments making a stratigraphic unit and the relation of them to the migration or development of sedimentary basins are interesting but often neglected in the interpretation of the recognized geological sequence. This is particularly interesting because it is from this view that interpretation and development of deposits may be worked out. As an example if a silty sandstone is considered the source of a superjacent deposit, that deposit would be lacking in silty facies and the resulting rock would be more sandy and incorporate sediments other than contained in the major source rock, even though there be retained considerable resemblance between the two. Reworking of sediments causes sorting and the removal of finer fractions by suspension-currents, the deposition of the coarser fractions and the possible incorporation of other sediments transported at the time. Also another point is the migration or development of sedimentary basins which may be interpreted from various evidences, among which the structural conditions of the strata, being of primary and secondary nature, may be mentioned. Also related is the relief of the subjacent deposits upon which transgression takes place and the rocks building them, because they are subjected to become incorporated in the newly deposited sediments.

The number of lithological units developed in a sedimentary basin reflects the depositional history and suggests the nature of the hinterland, but do not represent different ages of the Miocene and are not the basis for inter-basin correlation.

The Fujina formation in Shimane Prefecture has yielded *Cultellus izumoensis*, *Lyropecten kagamianus* (Yokoyama), *Shichiheia yokoyamai* (Nomura and Hatai) and others (T. Tomita and E. Sakai, 1938), stratigraphically it is superposed conformably upon the Kimachi formation which contains *Fulgoraria prevostiana* (Crosse), *Protorotella depressa* Makiyama and others, all of which show that the rather uniform thermal conditions represent a transgressive phase during a warm period.

So far as the molluscan fossils occurring from the sediments known to have supplied or to have intimate stratigraphic relation with the desmostylid specimens reported in literature are considered, there is evidence pointing to a transgressive phase succeeded by gradual deepening, a tranquil phase, uniformity in thermal conditions, remarkable mutuality among faunas of remote areas, and also suggest strongly that every fossil animal had a certain time span during the Miocene. From the evidence it is considered that the desmostylids aside from the one from the late Oligocene (H. Yabe, 1959) were delimited in their span governed by warm thermal and other physical conditions and therefore, within that time of warm temperate and possibly to subtropical time the desmostylids were buried by chance in different sediments which generally determine the molluscan fauna living there by bottom control. For such reasons, without knowledge of the relationship between molluscan fauna and bottom sediment control, judgement of thermal conditions may be contrary to the actual one.

In literature there is often found remarks that fragmentary or broken marine shells indicate strong wave action or agitation, or indicate that they have been derived from an older formation. Also stated is that fragmentary molluscan shells may indicate transportions from a foreign locality and that water worn shells also suggest the same phenomenon. However, whether such simple treatment of the fossil shells is permissible is subjected to debate for several reasons as to be stated.

It is known to persons familiar with the sea-side and marine life in shallow waters that crabs frequently crush molluscan shells to devour their soft contents. Star-fishes also increase in so great numbers that they even destroy culture grounds as in the case of Tokyo Bay. Gastropods have been reported to destroy oyster reefs, culture grounds and other bivalves in nature, by which procedure the dead shells are subjected to further disintegration and destruction. Sea mammals have also been reported to devour large quantities of bivalves, crush them with their strong teeth and digest only the soft animal meat. Bottom fish as flounders prey (K. Hatai, 1937) upon shallowly buried bivalves and brachiopods to destroy their shells. Land animals have been reported (A. H. Cook, 1927) to break oyster and other molluscan shells with the aid of stones and other materials to increase the accumulation of shell fragments. In fact there seems to be almost an endless list of animals capable and actually breaking molluscan shells for food. From such known facts, the occurrence of fragmentary or broken shells in fossil state may not so frequently be ascribed to the mere idea of being derived from some other sedimentary formation.

In some regions there can be found in fossil state abundant remains of the operculum without any trace of the original shells, and such mode of occurrence has been considered evidence for secondary deposition. However, gastropods with operculums are often killed by various reasons, and their shells occupied by hermit-crabs. Thus the operculum will be incorportated into the deposits as part of the sediments, while the original gastropod shell occupied by hermit-crabs will be subjected to rapid migration according to the changing of the physical environment. Here also is a case where the find of only the operculum has no relation with secondary deposition. Also the gastropod after death can be bouyed by the decaying animal matter to be floated elsewhere, while the operculum, which is attached to the animal flesh will thus be detached to accumulate at or possibly near the place where the gastropod originally thrived.

Another interesting case is the mass death-migration of *Mactra sulcataria*. Due to heavy floods and the resulting muds accumulated near the mouth of rivers emptying into the bay where that bivalve was being cultured, the mollusc was subjected to mass death probably because of the lack of oxygen owing to the cover of muds. These shells after death were bouyed up some centimeters above the sea-bottom by the decaying animal flesh to be transported by bottom currents for considerable distances to become deposited in areas where the bottom control would not permit their living. This mass death-migration as it may be called, resulted in the accumulation of an enormous number of closed bivalve shells in perfect condition, even though they had been transported considerable distances. This goes to show that even well preserved molluscs can be transported for considerable distances without evidence of wear, and therefore, well preserved shells in fossil state do not always indicate the original habitat.

Along the coasts of the Boso Peninsula, Chiba Prefecture and other beaches of Japan, the writer has observed numerous detached bivalve shells buried in the sand near the strand line and showing no evidence of wear. This suggests that normal waves may not always produce wear of the molluscan shells but may preserve them by rapid burial. Also in the dead shell-bed off the southern tip of the Izu Peninsula, Shizuoka Prefecture at a depth of about 150 meters, there have been dredged numerous kinds of molluscan shells and brachiopods, all dead, not water worn, well preserved even as to coloration. The original locality of these dead shells is thought to be more than several kilometers distant. This shows that even transportation after death for considerable distances does not always result in the production of water worn shells. However, besides all being dead shells, there occurred in association intact-, isolated-, and broken-shells. From the depth, it can be considered that wave action had no or very little influence upon them.

For the above reasons it is strongly emphasized that treatment of isolated, intact, or broken shells in sedimentary formations should be given more attention than hitherto

(W. H. Twenhofel, 1931). This saying also applies to the mammalian fossils found in sedimentary formations of marine or freshwater origin.

It is well known that different areas have different histories in their sedimentological, lithological, paleontological and geological backgrounds, even though under the influence of identical or similar oceanographical-physical conditions. Thus the number of lithological units in one area need not be the same in other areas, and likewise the sedimentological and geological histories may also differ. The paleontological side of the problem which determines time will remain uniform so long as the physical conditions permit. Therefore, in one region there may be many rock units and in another area only few, yet they may possess a similar paleontological construction because of being under the influence of physical conditions which permit such a building. Regional paleontological dissimilarities frequently fail to reflect the similarity in physical conditions particularly due to misinterpretation in faunal analysis resulting from the restricted knowledge of the relation existing between fauna, latitude, depth and sediment control. Under the influence of similar thermal conditions, one might expect a similar faunal construction, but this is not always the case; oceanic currents, geographical position, direction of bay-mouths and other regional factors assist in controlling the kind of fauna inhabiting the area. Thus, correlation of strata becomes difficult and the delimiting of the desmostylid horizons by data not throughly worked out or dificient, and with other views remaining to be considered, there still exist room for debate, as will be explained.

From the view that the known desmostylids are restricted in their distribution to the borderland of the North Pacific north of 33° North latitude, lead some authors (F. Takai, 1939; K. Watanabe, 1953) to claim that it must represent a northern type of animal, and that its migration into southern areas is indicative of the southward extension of cold thermal waters (S. Hanzawa, 1950). However, from the fossils occurring in association with it, in strata conformably above or below and from the general acceptance that all mammals originated in tropical regions but later became adopted to the conditions gradually changing with time to be separated at present into aquatic mammals of different distributions, there seems to be no conclusive evidence for considering the desmostylids to be a northern habitant in thermal sense. The conditions in the North Pacific area during the Miocene are deemed to have been uniform and warm from paleontological evidence.

Its distribution in regions north of lat. 33°, which marks its present southern limit of occurrence, may probably be explained in the case of Japan, by barriers or possibly by subsequent eroding away of strata in which it may have been buried, rather than by thermal restrictions. Since the sluggish aspect of the desmostylids, that is to say, its short and sturdy limbs, heavy body and other characteristics suggest that it was not a swimming animal nor one with the ability of rapid travel on land or in water, but one which probably lived in an environment of shallow coastal areas. A deep water strait or channel, narrow or broad, could probably serve as a barrier to its migration. Even the presence of cliffed areas befronted with deep water possibly could act as a barrier. Such barriers as well as other phenomena have probably resulted in determining the limited distribution of the animal because the thermal conditions so far as can be proved by the fossils occurring in association or in the same strata, all point to warm water conditions.

Since the migration of the ancestor of the desmostylids to the Pacific (Vander Hoof, 1937) and its being unable to return owing to the changing paleogeographical conditions, the animal may have become by adaptation, specialized owing to geographical isolation from its original habitat. If this is accepted, it is suggested that specialization may be one form of evolution, which also incorporates the view that the animal was thus doomed to become extinct. This may have been accelerated by the changing physical conditions, both oceanic and terrestrial.

Since desmostylids occur in the lower and upper parts of the Honto group (T. Nagao, 1937), which is siltstone in its larger part and measures from 1,350–5,700 meters in total thickness in the east and west coasts of South Saghalien respectively, its life span during the Miocene is equal to the time required for the deposition of that thickness of sediment. Thus its life span in the late Oligocene (H. Yabe, 1959) is to be added to that of the Miocene. For such reasons, during its life span its occurrence may be in any lithological unit which was deposited during that time, and the necessity of referring it to a single or several distinct horizons which can be correlated throughout the Japanese Islands seems inadequate. If there were considerable differences in the morphology of the desmostylids from the different horizons or lithological units built during the life span of the animal, then there may be concrete evidence for separation and correlation of the various horizons.

Similarly the vicaryids in Japan have been referred to a single horizon by some authors and to more than one by others. The specialized gastropod is here taken into consideration because it has been thought among geologists that, 1–there is only one desmostylid horizon and two of the vicaryids, one above and the other below the desmostylid, 2–there is only one vicaryid horizon and two of desmostylids, one above and the other below the vicaryid, and 3–the two specialized animals are intimately related geologically, but their stratigraphic relations are not clear. *Vicarya* is a genus (H. Yabe and K. Hatai, 1938) ranging from the Eocene to Miocene and has its origin in India, from where it migrated northwards to the Philippine Islands, Ryukyu Islands and Japan. Thus it is a typical tropical genus, while *Desmostylus* on the other hand has been considered by some authors to be a northern genus. From this view it is interesting that both occur in association from the same stratigraphic unit, locality and horizon as in the case of the Shiratori formation at Yuda, Ninohe-gun, Iwate Prefecture, in association with such molluscan genera as *Vicaryella*, *Conus*, *Sinum* and others.

Although it has been stated that *Vicarya* is a brackish water genus (H. Yabe and K. Hatai, 1938), there remains room for further discussions concerning its ecological features. It seems quite evident that the genus is associated with the transgressive phase and therefore, a shallow water, near shore and possibly even a genus that could inhabit the tidal flat, like the genera *Batillaria* and *Cerithidea*. However, the latter two genera wherever found along the coastal region of present day Japan, generally occur in large populations, and when found in fossil state as in certain Pleistocene deposits of the Boso Peninsula, Chiba Prefecture, also occur in large numbers. In the case of *Vicarya*, it is very abundant in the rocks of Tsuyama, Okayama Prefecture, very rare in the early Miocene rocks of the Ninohe

District of Iwate Prefecture, more or less common in the early Miocene rocks of the Mizunami District, Gifu Prefecture, but elsewhere it is not commonly abundant nor to be considered common, although it occurs.

So far as known the genus occurs in association with molluscs generally taking to shallow but clear marine environment, among which sometimes there occur species of bivalves which can also live in a very brackish water condition. From this evidence it may be inferred that most of the vicaryids in fossil state have been removed from their original environment to be buried in that of another, that is to say, in an environment in which it did not favor. If this is the case then we may be able to gather data with regard to the nearness of the strand line, and from its associated fossils to estimate roughly the water depth in which it was buried and the conditions under which transportation or burial took place. However, further data is needed before conclusive remarks may be drawn.

The above remarks are here added as a supplementary note to the writer's previous work on the genus in collaboration with Professor H. Yabe (1938) and to provide information as to the nature of the genus.

The said gastropod genus may have many different horizons in the southern areas of its distribution, but northwards the number of horizons may decrease owing to the rise in latitude and increased distance from its home, contrary to the case of the desmostylids, which may have many horizons in the northern areas of distribution but only one or a few in its southern area of distribution. In other words, the two characteristic animals may form some kind of a triangle with their apexes crossing, and their long axis occupying the opposite sides. Thus, in the extremes of either group, where their actual ranges are longest, many horizons may occur, while in the other extremes where their ranges are shortest, only a single horizon may exist, providing that the deposits favor their burial and preservation.

The time span of the two specialized forms may be about the same, so far as the Miocene rocks of Japan are concerned, but should their lower limits be included, the vicaryids extend back to the Eocene and the desmostylids to the late Oligocene. From such considerations the respective horizons of the desmostylids and vicaryids may conflict, be the same or about so, overlap and even offlap (K. Hatai, 1940) during the Miocene, even though their span be the same.

Wherever the two forms have been reported from the Miocene rocks of Japan they are found to occur in a stratigraphic sequence comprising in general, more than a single stratigraphic unit continuous from one to the other. When the stratigraphic units consist of more than one or two formations conformably related with one another and marine in origin, generally the lower of the units commence from a transgressive phase and terminate with a regressive one. In such cases the faunal sequence, conditions indicated therefrom and the more important faunal elements show remarkable similarity, the chief differences recognized being explainable by bottom control and latitude, depth considerations, and physical background.

Among the fossils others than those of the vicaryids and their related vicaryellids and the desmostylids, there occur numerous others which have important bearing on the determination of the geological ages of the respective formations, paleogeographic considerations and intimate relation with those of the above described ones. Among such kinds of fossils are to be included the lepidocyclines, miogypsines, some echnioids as the echinolampids, astriclypeds, and numerous kinds of marine molluscs, all of which have wide distribution and rather limited time span.

In the early Miocene deposits of the Boso Peninsula, Chiba Prefecture, *Lepidocyclina*, *Miogypsina* and *Operculina* occur in association, and thus whether the first mentioned fossil ranges up into the zone of *Miogypsina* and *Operculina*, or the first two range into that of the last mentioned, or whether the last two extend their range down to that of the first mentioned is problematical. Along the borderland of the Japan Sea *Miogypsina* occurs with *Operculina* in western Aomori Prefecture, and in western Yamagata Prefecture, while in the Sendai area *Lepidocylina* is found but not in association with the first two mentioned ones. In Fukushima Prefecture, *Miogypsina* and *Amphistegina* have been reported by Fujita and Ito, the latter genus often accompanies *Lepidocyclina* in the Boso Peninsula, above mentioned. In the Ooigawa area of Shizuoka, Makiyama (1941) mentioned the occurrence of *Lepidocyclina nipponica* and *Miogypsina kotoi* from the Megami limestone. Other relationships have been mentioned by Hanzawa (1935, 1953). Thus whether *Lepidocylina* and *Miogypsina* really occur one superposed above the other in a continuous stratigraphic sequence and both represent two different ages, or whether they can be taken to represent the same age but indicate different ecological conditions, seems to be subjected to debate. So far as literature and occurrences known to the writer are concerned, they seem to occur in association, and to represent the same age, although there may or may not be some differences in their horizons in the same stratigraphic unit. Evidence is needed to prove that they (*Lepidocyclina* and *Miogypsina*) occur in succession, that is, superposed one upon the other in a continuous stratigraphic sequence and actually indicate two different ages, the latter younger than the former. The mentioned kinds of fossils are intimately related with one another so far as concerns the time span, distribution, geological significances and stratigraphic importance. Some of others are mentioned in the following lines, together with remarks on the geological ages of the formations yielding them.

In the earlier lines of this article the term Miocene has been used but without definition of its basal part, the relation with the underlying pre-Miocene deposits, and its upper part has also not been mentioned, for this reason remarks will be given before advancing the discussion.

SEDIMENTARY CYCLE

Cenozoic deposits of Japan are by no means uniform in their distribution regardless of their large coverage. These may be subdivided into epicontinental and geosynclinal facies with or without the intercalation of terrestrial sediments. The geosynclinal facies of the Japan Sea, Kazusa-, and Sagara geosynclines (S. Hanzawa, 1950) are distributed in the present oil-field regions of along the borderland of the Japan Sea, eastern-central Japan and southwest Japan, respectively. The epicontinental facies are distributed in areas other than those just mentioned and in ones covered with marine sediments with or without intercalated terrestrial ones. The intercalated terrestrial sediments are found sporadically along the marginal portions of the epicontinental and geosynclinal facies or of the foundation rocks. Of these deposits, late Miocene marine sediments are generally lacking or only poorly developed in the area of distribution of the epicontinental facies, but are more or less well developed in the geosynclinal areas mentioned. Exceptions may be found in southwest Japan where terrestrial facies are rather well developed, such as in the Gifu area. Terrestrial sediments of early and late Miocene and Pliocene ages vary in their degree of development and more so in their area of distribution.

Although of different nature, both types, epicontinental and geosynclinal, contain in their lower parts a cycle of sediments commencing with transgression (H. Yabe, 1927) over the eroded basement or upon terrestrial deposits, and closing with regression; these are referable to early Miocene in age, and of a paleontological sequence comprising warm water marine invertebraes and land plants of mild climate, both of which show a gradual change in their upward succession, thereby facilitating correlation of strata of remote areas as can also be interpreted from the physical conditions indicated by the fauna and stratigraphical structures.

The climatic changes indicated by the respective fauna in the Neogene deposits of northern Japan is rather contrasting compared with that of southwest Japan, resulting in the construction of thermal gradient curves of different aspect, as would be expected from the oceanographical conditions then thought to have prevailed and as also inferred from the present ones. Prevailing conditions in the northern Pacific area during progression of Cenozoic time and correlation with the evolution of climatic patterns are reflected in the fossil faunas of the different areas and geological ages.

For the reasons above described it becomes possible to classify the respective fossiliferous and non-fossil-bearing stratigraphic units and to correlate them with geological age. However, whether the ages ascribed to the rock units will be equivalent with the standard European chronology is a matter left for the future. For the sake of convenience, the respective terms of European chronology, if applied to the fossil-bearing strata of the Japanese Neogene deposits, may be characterized as to be mentioned.

As one example of epicontinental sedimentary cycle the Natori group in the Sendai area (Hanzawa, *et al.* 1953) may be briefly outlined. The Cenozoic deposits in the Sendai area consist of marine and terrestrial sediments of Miocene and Pliocene age, the latter in the early part of the former age are restricted in distribution and interfinger with marine sediments as well as with volcanic products, while those of the latter part of the same age have wider distribution, being known as the Paleo-Sendai Lake (S. Hanzawa, 1950). The terrestrial facies of the Pliocene are more extensive compared with those of the early Miocene in the Sendai area in distribution and have at their lower (Tatsunokuchi formation) and upper (Dainenji formation) parts marine sediments, rather extensively distributed in the lower but restricted in the upper. The marine sediments are typically epicontinental and represent a cycle of sedimentation (Miocene) of extensive distribution in the Japanese Islands (S. Hanzawa, 1950). This cycle commences with transgression over the eroded land surface and closes with gradual regression of the seas and uplift of the land, and can be classified broadly into three phases of transgression with gradual submergence of the land, rather rapid or gradual downsinking of the area being flooded, then gradual regression and relative uplift of the land. These three facies are represented by stratigraphic units here treated as the Moniwa conglomerate member of the Hatatate formation, the Hatatate formation and the next younger Tsunaki formation which also includes the Hayama green tuff member and Yumoto tuff member. These marine sediments are unconformably overlain with the Shirasawa formation, which is a terrestrial deposit of considerable extension and comprises the Paleo-Sendai Lake of Hanzawa (1950). The said marine deposits are included into the Natori group and form the lowest division of the Neogene rocks developed in the Sendai area. Within this group, there can be recognized gradual change in both rock facies and faunal elements both vertically and laterally. The vertical change in the fauna and rocks are related with the physical conditions and that of the fauna both by bottom control, depth and the replacement of new elements.

In the Moniwa conglomerate member which has sandy, silty and calcareous facies of restricted distribution and development, the characteristic fossils as *Lepidocyclina* (*Nephrolepidina*) *japonica* Yabe, *Echinolampas yoshiwarai* P. de Loriol, *Echinanthus* n. sp. (Nisiyama, MS), and abundant molluscs of *Morum*, *Conus*, *Ranella*, *Babylonia*, *Xenophora*, *Venus* (S. Nomura, 1940) besides others occur. In the marginal facies of the Hatatate formation there occur *Trochus*, *Dentalium*, *Shichiheia* and others, while in its deeper facies *Lima*, *Lucinoma*, *Venus*, *Nuculana*, *Ancistrolepis*, and others occur. The Tsunaki formation is characteristic in its shallow near shore molluscs as *Glycymeris*, *Macoma*, *Lucinoma* and some pectinids. Pectinids are also abundant in individual and specific number and show a wide variety of sculpture and remarkable development. Thus, from the invertebrate fauna it is evident that the paleontological cycle corresponds well with the lithological one.

The terrestrial facies (Tsukinoki formation) interfingering with the lower part of the Hatatate formation is characteristic in having yielded the well known *Comptoniphyllum-Liquidambar* flora (S. Endo and H. Morita, 1932), *Eostegodon pseudolatidens* Yabe and *Stegolophodon miyokoae* Hatai. It should also be added that *Desmostylus* occurs in a stratigraphic position corresponding to the main part of the Hatatate formation, thus occupying a position above that of the Moniwa conglomerate member which has yielded *Lepidocyclina* and abundant warm thermal molluscs and echinoids in association.

This subtropical to subtemperate marine invertebrate assemblage and terrestrial plant and mammalian members are widespread in the Japanese Islands (H. Yabe and K. Hatai, 1941), and where the correlatives occur they are almost always unconformable with the older rocks.

The sedimentary and paleontological cycle just referred to is considered to be of Miocene age and concerning the first transgressive phase which brought into the Japanese Islands a marine fauna comprising such forms as found in the Moniwa conglomerate member of the Hatatate formation, further remarks are given below.

Accepting that the geological age indicated by such fossils as *Lepidocyclina* (*Nephrolepidina*) *japonica* Yabe, *Eostegodon pseudolatidens* Yabe, *Bunolophodon annectens*

(Matsumoto), *Anchitherium hypohippoides* Matsumoto, *Rhinoceros pugnator* (Matsumoto), *Brachyodus japonicus* Matsumoto, *Amphitragulus minoensis* (Matsumoto), the marine shells as *Cryptopecten yanagawaensis* (Nomura and Zinbo), *Pitar itoi* (Makiyama), *Siratoria siratoriensis* (Otuka), *Turcica preimperialis* Nomura, *Turbo parvuloides* Nomura, *Fusitriton nipponensis natorianus* (Nomura), *Siphonalia prespadicea* Nomura and Zinbo, *Babylonia kozaiensis* Nomura, *Phos* (*Coraephos*) *nakamurai* (Kuroda), and echinoids as *Echinanthus* n. sp. (Nisiyama, MS), *Echinolampas yoshiwarai* P. de Loriol, besides others, corresponds to the Burdigalian stage of the standard European chronology, then from paleontological evidence and stratigraphical position the early Miocene of Japan may be defined. From this view, the Aquitanian can be taken as representative of the late Oligocene as originally defined by Beyrich and discussed in detail by Schenck and Rheinhart (1938). However, whether such stage names as Burdigalian and Aquitanian as well as others of the European standard chronology should be used in Japan is a matter open to question, and the writer is in the opinion that until definite conclusions can be made, it may be better to define our own stage.

For this purpose the term of Mizuho introduced by Yabe and Aoki (1923), and Malaysian, Iranian and Javan proposed by Grabau (1927) are available for consideration, the former stated to correspond to the Neogene and the latter three to the Miocene with the Tertiary deposits of Malay, Iran and Java being taken as type localities in Asia. However, the Mizuho is too broad a name because it includes the whole Neogene and the terms Malaysian, Iranian and Javan are not suitable for use in Japan because their type localities are remote and interrelationship not clear. Also it may be added that since Grabau (1927) at the time of proposing the many terms for the Tertiary deposits of Asia definitely correlated each of them with the standard chronology of Europe, but the problems related therewith make it advisable to refrain from using the names. The name of Hiramakian (F. Takai, 1939) was introduced to include the Moniwa formation in Miyagi Prefecture, Domi formation in Ishikawa Prefecture, Hiramaki formation in Gifu Prefecture, Ube coal-bearing formation in Yamaguchi Prefecture, and the Nakasato formation in Nagasaki Prefecture, all of which were taken to correspond to the Burdigalian of Europe. He also proposed the Togarian stage to include the Naihoro, Naikawa and Hachorei formations in South Saghalien, the Kawabata, Kunnui and Onbetsu formations in Hokkaido, Oirase formation in Aomori Prefecture, Kadonoswa formation in Iwate Prefecture, Saboyama formation in Miyagi Prefecture, Tsurushi formation in Niigata Prefecture, Kamenoo formation in Fukushima Prefecture, Bessho formation in Nagano Prefecture, Togari formation in Gifu Prefecture and the Fujina formation in Shimane Prefecture. The Togarian is characterized with such mammals as *Desmostylus japonicus* Tokunaga and Iwasaki, *Sinanodelphis izumoensis* Makiyama, *Ontocetus oxymycterus* Kellogg, *Idiocetus tsugarensis* Matsumoto, and said to correspond broadly to the Vindobonian stage of Europe.

In the area where the types of the Hiramakian and Togarian occur, the marine deposits called Tsukiyoshi is inserted between the Hiramakian and Togarian, and the marine Yamanouchi and Oidawara formations lying above the Togarian have not been named, nor mentioned by Takai (1939, 1954). Thus, whether Takai expected to include the Tsukiyoshi in his Togarian and to leave the Yamanouchi and Oidawara formations unnamed as a stage, or had doubt as to their position is unknown to the writer. However, from field observation in that area, the writer believes that the Tsukiyoshi, Togari, and next younger Yamanouchi formations, which are conformable with one another and hardly distinguishable from each other lithologically, should be referred to the Akeyo formation as done by Yabe (1935). Thus the name of Togarian if accepted, should be revised to include the Tsukiyoshi and Yamanouchi, the former below and the latter above the Togari, and the name of Togarian to be redefined to include all of the three so-called formations which are not strict lithological units, from a stratigraphic point of view. Retaining Takai's stage names (but including the Tsukiyoshi and Yamanouchi), it can be said that the Moniwa conglomerate member and the Tsukinoki formation of terrestrial nature both correspond to the Hiramakian, and the main part of the Hatatate to the Togarian, and the Tsunaki formation (marine) to an unnamed stage. Occurring above the Togarian is the Oidawara formation of marine origin, and if the name of Oidawara could be introduced the early Miocene of Japan may show a natural cycle of sedimentation and paleontological sequence, particularly when the corresponding sediments in the Sendai area are incorporated. The chief differences would be in that in the Gifu area, the Nakamura formation which is terrestrial and coal-bearing and conformably subjacent to the Hiramaki, is not represented in the Sendai area unless its equivalent is considered to be the Kanayama formation which is a lateral facies of the Tsukinoki formation already mentioned, and also coal-bearing (lignite).

With regard to the stratigraphic units and paleontology of the Neogene deposits sporadically developed in southwest and western Japan, Y. Tai (1959) has published a comprehensive work. From this work it may be noticed that the sedimentary cycles described in this article also occur in those areas, and from the micropaleontological work of Tai (1959) and his correlation chart of the formations treated by him, evidence for the above stated is upheld.

The relation above mentioned can be recognized also in many other areas of Japan, thus indicating that the cycle seen in the Sendai area is also developed extensively in the Japanese Islands. The respective minor units and local unconformities or ones thought to be as developed in different sedimentary basins can not be correlated with one another owing to the differences in the physical conditions as well as geological background during deposition of those stratal units, and such factors would be expected in regions strongly influenced by earthquakes, volcanisms, and other regional and local movements. However, broadly speaking, remarkable similarity can be recognized among the deposits of each of the different sedimentary basins distributed in Japan. Thickness of the deposits and the number of lithological units recognized in any area is strongly related with and frequently are a reflection of the physical background of phenomena of the sedimentary basins and both the duration of time required for their making because of not incorporating paleontologic evidence, and therefore, do not serve for interbasin correlation purposes. For such reasons, the recognition of stages and based upon them interbasin correlation becomes simplified and forms a working basis for finer cut classifications.

The cyle or three divisions of its classification are thought to be representative of the Japanese early Miocene, while the late Miocene which has no named stage name is represented in the Sendai area by the Shirasawa formation, a terrestrial deposit called the Paleo-Sendai Lake (S. Hanzawa, 1950) and stated to have been about 200 km in length in north to south direction and of considerable breadth because it is known from both sides of the Ou backbone range of northern Japan. If this deposit should be called the Shirasawaian, although not advisable, and to be included as the fourth of the Miocene subdivisions, regardless of whether its further subdivision becomes possible, treatment of the Japanese Miocene becomes simplified. This fourth division may be given the name of Kitauraian, although not designated here.

Related with the cycles so far mentioned is volcanism. Stratigraphic evidence shows that prior to the first marine transgression which encroached upon the eroded land surface, rather intense volcanicity took place in various parts of Japan, being represented by green tuffs, agglomerates, andesites, basalts and other volcanics. The volcanicity also accompanied the first marine transgression and in the Sendai area the Takadate andesite is observed to interfinger with the Moniwa conglomerate of the Hatatate formation and also with the terrestrial Tsukinoki formation. Such relationships can also be observed at various places along the Japan Sea geosyncline, along the epicontinental borderland of the Pacific side of northern Japan, the marginal portions of the Kazusa geosyncline, and in other parts of Japan. Also during regression and immediately after it there occurred another period of volcanism associated with uplift of the land. This volcanism in the form of dacite tuffs, its flows, andesite flows and its agglomerates and tuffs can also be observed along the interior portions of the Pacific and Japan Sea sides of northern Japan and elsewhere in Japan. This period of volcanism marks the beginning of the fourth cycle noticed in Northern' Japan, and is thought to have rather extensive distribution in the Japanese Islands. At places there are developed terrestrial deposits, such as the Shirasawa formation in the Sendai area while in the oil-field regions of northwest Japan there are found marine sediments associated with volcanism, slight uplift and again deepening before the next uplift, which is though to mark the end of the fourth stage or cycle.

Thus, from stratigraphical, paleontological and with the inclusions of minor stratigraphical breaks, it is considered that there are developed four rather definite cycles within the so-called Miocene deposits of Japan. Here the base of the Miocene, as already stated in earlier pages is marked by the widespread hiatus and violent volcanisms recorded in nearly all parts of Japan where either terrestrial or marine sediments containing a fauna or flora comprising such elements as, the mammalina fauna of the Hiramaki-, Tsukinoki-, Ajiri-, Sasebo formations, the flora well known under the name of *Comptoniphyllum-Liquidambar*, and the marine invertebrates of the so-called *Lepidocyclina-Miogypsina-Astriclypeus-Echinolampas* fauna. The deposits subjacent to the widespread unconformity are entirely lacking in such above stated elements and the paleontological change from the latter to the former is abrupt, distinct and recognizable over wide areas. It is quite evident that during the cited phases the differences in latitude, bathymetrical environment and bottom control play a role in changing the faunal elements. The replacement can be recognized when the said items are taken into account.

MIOCENE-PLIOCENE PROBLEM

As in the case of the boundaries between the Tertiary and Quaternary or between the former and the Cretaceous, the problem also prevails within the Cenozoic rocks. Among problems there related one may be in the usage of terms, for example the effort to compare a sedimentary deposit with the standard chronology regardless of the remoteness of the areas treated may result in drastic conclusions because of the non-similarity of the compared elements of the separated regions. Although such may be the case there is always the strong tendency to apply the standard chronology of Europe for remote local sedimentaries.

To overcome the difficulty existing in such a procedure, different authors have proposed time-rock terms for the local sequences, which in cases frequently causes confusion rather than simplification of the problem. As mentioned in the section of the previous classifications and the problems embodied, such has been the case for Japan.

The Japanese Miocene has been considered to be equivalent to the European standard but there remains doubt as to whether they are equivalent and their boundaries correspondent. Therefore, holding the view that even though the two may be broadly equivalent in age, the writer believes that there is no evidence for considering the standard Miocene stages of Europe to have approximate correlatives in Japan based upon concrete paleontological data. This probability, however, may be justified by future research on the problem.

The Japanese Miocene can be distinguished from the early Pliocene by several important features. Almost everywhere as known at present there exists a stratigraphical break between the two or evidence for diastrophism when the relation is conformable. Frequently volcanic activity accompanies the sediments superposed upon the unconformity or associated with eustatic movement, whether the sediments are terrestrial, brackish or marine, while immediately below it or the uppermost limit of the late Miocene evidences for regression can be often recognized but without intense volcanism. Immediately above the break there is found the first occurrence of *Fortipecten takahashii* (Yokoyama) (H. Yabe and K. Hatai, 1940), and *Linthia nipponica* Yoshiwara while below it the buccinids, neptunids and serripeds are common and certain turritellids and *L. yoshiwarai* are important. Abundant brachiopods are generally found above the unconformity separating the late Miocene from the middle part, at least in the sense employed in this article, and their assemblages differ from those appearing in early Pliocene in the larger number of species, among which important extinct forms have been reported (K. Hatai, 1940).

Along the Pacific borderland of northern Japan the sediments superposed on the break generally commence with brackish or lagoonal deposits associated with volcanic activity, and this marks the first transgression or gradual submergence of the land since the late Miocene. Along the borderland of the Japan Sea the sediments referable to the same age either commence with shallow marine to more or less brackish water sediments followed with gradual deepening of the sedimentary basin but migration of it more or less westwards. In central Japan, particularly the Boso Peninsula (K. Hatai, 1958), there is a distinct unconformity separating the late Miocene from the early Pliocene, and instability of the conditions can be recognized in the sediments of the latter age, there being incorporated abundant material from the former. Here also the Pliocene commences with a shallow water fauna including members of the rocky shore, but upwards gradually changing to deeper water elements, particularly of both the foraminifers and molluscs. This same relationship may also be noticed in the Hokuriku region, which is similar to that of the area along the west side of northeastern Japan.

Faunal differentiation of the late Miocene and early Pliocene is not always easy because the problem is both vertical and lateral; the Japanese Islands being influenced by oceanic currents probably more complex than at present. It is lateral because a postulated barrier (J. Makiyama, 1927) situated approximately at the present day Izu Peninsula, Shizuoka Prefecture, serves in distinguishing the faunal elements north and south of it. Therefore, the postulated barrier aids in explaining the mixed early Pliocene marine invertebrate fauna in its adjacent northern region, and the oceanographic conditions bringing the cool water fauna present in its more northern areas. On the southern side of the barrier, however, there existed a warm water marine fauna, well represented in the Pliocene Kakegawa series and distributed southwards or southwestwards to the eastern side of Shikoku, northern Kyushu and also in the southern part of the borderland of the Japan Sea, showing that a water-route tied the paleo-Japan Sea with that of the Pacific via the present Chubu District. The cool water fauna distributed northwards of the said barrier extends along the Pacific coast of northern Japan to Hokkaido and farther northwards, and also along the Japan Sea foreland from Hokkaido southwards to the Hokuriku region although considerable displacement in its elements occur.

The just stated lateral distribution of the early Pliocene marine fauna of Japan is well indicated and must be incorporated in a consideration of the position of the time-line between the early Pliocene and late Miocene. Vertically the lateral distribution become important because, in areas south of the above mentioned barrier the differences in faunal components between the two divisions as inferred from thermal conditions becomes less than in the areas north of the said obstacle, where more or less distinctive features prevail. Therefore, both vertical and lateral distributions of the marine fauna enclosed in the strata of late Miocene and early Pliocene vary according to the geographic position. Thus, geographic position inclusive of vertical and lateral distributions must be considered for determination of the boundary to be drawn.

It is thought that the different distributions of the marine invertebrates used in correlation and age determination of sedimentary deposits of geographically isolated sedimentary basins has been one of the causes for misinterpretation of the said features. Here it is to be mentioned that the boundary between the late Miocene and early Pliocene also varies according to what the author considers as belonging to those ages. But whatever be the case, it is evident that at certain times there occur widespread volcanism, instability of the land, differences in the respective ranges of numerous kinds of fossils, and that the younger the geological age is, the more moderate is the geomorphological features and somewhat more migrated is the sedimentary basin. From such considerations, it seems that the said time-line may fall within the boundary mentioned in earlier pages.

The limits of the Japanese Miocene, whether marine or terrestrial, geosynclinal or epicontinental, and widespread or narrowly distributed, can be delimited downwards by the extensive unconformity under the *Lepidocyclina-Echinolampas* representing marine fauna and *Eostegodon* indicating terrestrial fauna and *Comptoniphyllum-Liquidambar* flora, and upwards by the period of instability represented by marine transgression bearing a marine fauna having *Fortipecten-Linthia*, a terrestrial fauna with *Trilophodon*, and superjacent to one with a rich buccinid-neptunid serriped fauna in northern Japan, and with one comprising numerous bivalves against the subtropic large gastropod fauna in southern or southwestern Japan.

CLOSING REMARKS

Delimited in the way above mentioned, there is found in the Japanese Miocene a characteristic sedimentary cycle in good correspondence with the paleontological one and is represented by three phases of transgression, gradual deepening and stable conditions and a regressive phase. These three phases are generally overlain, where the deposits are developed, by another less distinct cycle, which is the fourth and last one of the Miocene. As already mentioned all Miocene deposits in Japan so far as reported in literature and aware to the writer can be incorporated without difficulty. But the correlation or age determination of each respective strata or stratum developed in separated sedimentary basin with one another is impossible at the present status of knowledge on the Miocene rocks of Japan. This is because sediments barren of fossils or only very poorly represented are commonly found in nearly all of the sedimentary basins in Japan, the fossils do not occur continuously throughout any marine sequence of great magnitude, knowledge concerning respective ranges of different kinds of fossils, marine and terrestrial is yet literature-premature, and any attempt for fine-cut intercorrelation of sedimentary basins has caused confusion and the misinterpretation of age-value of certain fossils, their restriction to limits which they actually cross, the combining of deposits actually intervened by thick sediments or the incorporation of isolated recurrent faunas into a single horizon, and the construction of a misleading correlation chart. Further, to date little if any attention has been given to the presence of relic and recurrent faunas, the significance of their mode of occurrence, relation with latitude-, depth-, and bottom control, and therefore, the conclusions reached may be said to be not only premature but also misleading.

For the reasons stated in earlier lines of this article it is proposed that the cycle-phase introduced be used for widespread correlation of the Japanese Miocene rocks before an attempt be made to cause further confusion by the combining of faunal units of different stratigraphic position or the assumed relation between the terrestrial and marine faunas. It is thought that by the proposed method there may be established a rather concrete correlation among the isolated sedimentary basins developed in various parts of

Japan, and that from their respective histories reflected from the various backgrounds previously mentioned, handling will become simplified and based upon a more natural basis so far as concerns the complicated marine geology of Japan.

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