A Historical Sketch of Foraminiferology in Japan : Centered Upon Studies on Post-Paleozoic Foraminifera

genus *Pseudocyclammina* by his followers (Yabe and Hanzawa, 1926). With due respect of his pioneering works amongst the Japanese, the year 1890 may be chosen as the dawn of foraminiferology in Japan.

A HISTORICAL SKETCH OF FORAMINIFEROLOGY IN JAPAN
—— Centered Upon Studies on Post-Paleozoic Foraminifera ——

Period from 1901 to 1944

During the transitional phase beteween the 19th and 20th centuries, studies on foraminifera were chiefly pursued by Hisakatsu Yabe, an active paleontologist. He published several papers which dealt with larger foraminifera of Paleozoic to Cenozoic ages and also described late Cenozoic smaller foraminifera. In 1912, he was appointed professor of Tohoku Imperial University which was founded in Sendai in 1907. Since then he endeavored to develop active research on geology and paleontology. During nearly a decade since 1921 he published more than 20 papers on larger foraminifera under the joint authorship with Shoshiro Hanzawa, who was Yabe's first student in foraminiferology. In a historical sense, we may call these days "the age of Yabe and Hanzawa". They covered, independently or in close collaboration, fossils from such wide regions as the northwestern Pacific, Indonesia, the Philippines and Taiwan in addition to the Japanese Islands. Their scientific activities motivated a number of people to study foraminifera of southeastern Asia and Pacific regions. Among the scientists directly influenced by Yabe, Shosiro Hanzawa and Yoshiaki Ozawa are the most distinguished. Their subject of activities extended from late Cenozoic smaller foraminifera to Paleozoic fusulines. Hanzawa bent his study mainly to Tertiary larger foraminifera and brought to light the characteristics of Pacific faunas during his long academic life. On the other hand, Ozawa devoted himself to studies both of smaller and larger foraminifera during his short lifetime. After his epoch-making study of the geologic structure of the Akiyoshi Limestone based on a fusulinid biostratigraphy (1925), he undertook systmatic analyses of the Polymorphinidae in collaboration with J.A. Cushman, the foremost authority of foraminiferal research at that time. Their joint work on this group, which appeared in 1930 after the premature demise of Ozawa, may be regarded as one of the classical works in the foramininiferal classification. It seems to be remarkable that both Hanzawa and Ozawa were able to work with Cushman at the then renowned Cushman Laboratory for Foraminiferal Research.

From the 1920's to 1930's, some events occurred in the U.S.A., as if they signal a bright future in foraminiferology. In 1924, the journal *Contributions from Cushman Laboratory for Foraminiferal Research*, the predecessor of the *Journal of Foraminiferal Research*, was founded. Cushman (1928) set forth the first edition of "Foraminifera: Their Classification and Economic Use". Five years later in 1933, Galloway published "A Manual of Foraminifera". The *Journal of Paleontology*, which started in 1926, was also an important medium for foraminiferal researchers to disseminate results of their work especially in those days. Such academic movements were apparently linked to economic demand for the exploration of oil and gas resources.

In the history of fusulinacean studies, Japan saw florescence during the years from 1930 to 1942 and again a similar period from 1946 to 1960. Since then a remarkable reduction occurred in the number of researchers, especially among

younger generations. Such a trend is not limited to this country, and it may imply that various factors are involved. In Japan, stratigraphical aspects of paleontology have become much emphasized; while research activity on fusulinacean biostratigraphy appears to have nearly reached a plateau, most other Paleozoic workers have become interested lately in other microfossil groups such as radiolarians which have a finer stratigraphic resolving power and wider geographical applicability. Furthermore, such a traditional method of studying fusulinacean paleontology as thin-sectioning has its limitations. It appears that a novel innovation of research techniques is needed to relieve the present state of fusulinacean paleontology.

From the early stage of foraminiferal research in Japan, contributions by biologists have been limited to a very small numbers. With the exception of Ikari (1927) who made a short note on Recent fauna, Yoshine Hada was the only one who worked on Recent faunas from various shallow water environments, somewhat intermittently since 1929. His paper on the Mutsu Bay fauna (1931) is still an important reference to the Japanese fauna. However, these contributions by biologists are mostly concerned with taxonomic problems and no paper on the subject of either physiology or autoecology has been published by Japanese workers until very recently. Such deficiency in research activities in the field of biology has hampered to a certain degree to improve the standard of foraminiferal studies in Japan.

In the early 1930's, Cenozoic foraminifera were reported by various workers such as T. Nagao, M. Nakamura, S. Imamura, J. Makiyama, K. Tan, K. Mochizuki, Y. Otuka, I. Hayasaka, and H. Fujimoto. Their contributions were sporadic and mostly limited to the description of local faunas and listing of species. It seems notable, however, that all of them later became leaders in paleontology or stratigraphy, or both, at their respective universities, with the exception of Nakamura who died in the field during World War II.

In 1935, a young micropaleontologist who specialized in smaller foraminifera appeared in this country. Immediately after his graduation from Tohoku Imperial University, Kiyoshi Asano reported a fauna from a mud volcano in Taiwan. During the succeeding four years he published 35 papers on foraminifera including a monograph on the Nodosariidae (1938), and his name as a foramniferologist became widely recognized. His research at that time was mainly concerned with the subject of systematic description and geographic distribution of Pliocene to Recent benthic foraminifera. A series of monographs on "The foraminifera from the adjacent seas of Japan collected by the S.S. Soyo-maru, 1922-1930" was one of his research subjects at that time, although it was much later in 1956-1960 when the world saw these works in print.

Paleonotologists who worked on foraminifers during the decade from 1935 to 1944 numbers more than ten including a few women micropaleontologists. Among them were Kazuhiko Ishizaki and Tsuneteru Oinomikado. Ishizaki produced important taxonomic works on *Ellipsonodosaria* and *Streblus* and also published many other papers on faunas from Japan and Taiwan. Unfortunately, however, he had fallen victim to the war. Oinomikado was a pioneer in the field of applied paleontology in Japan. He founded a micropaleontology laboratory in an oil company soon after the war, and cultivated young micropaleontologists for the exploration of oil and gas resources.

Period from 1945 to 1989

The year 1945, when the long war which lasted for 15 years was finally brought to the end, saw no scientific activity. However, a single paper dealing with foraminifera appeared in the following year in each of the publications issued by the Japan Academy and Geological Society of Japan. During most of the latter half of the 1940's when the harsh economical situation prevailed, research work was continued only by those who started their research during the war. Just then, around 1950, the "apres guerre" generation began to participate in the work of foraminifera.

It is noteworthy that several contributions by Japanese workers appeared in the U.S. journals including *Journal of Paleontology* in those days. Domestically, a bibliography of Japanese papers on Cenozoic and Recent foraminifera was published by Oinomikado (1951) and a serial "Illustrated catalogue of Japanese Tertiary smaller foraminifera" was compiled by Asano (1950-1952). According to the foreword given by L.W. Stach to Oinomikado's bibliography, these publications were "results of a project sponsored by the Natural Resources Section, General Headquarters, Supreme Commander for the Allied Powers, to aid exploration for subsurface resources of fuels in Japan." It can be said that a close friendship between Colonel H.G. Schenck, the then chief in the Natural Resources Section and primarily professor of geology at Stanford University, and his Japanese acquaintances who specialized in micropaleontology bore fruits in procuring much needed funds to promote studies of foraminifera. The appearance of these publications stimulated much work on foraminifera in Japan and also assisted in making the internal activities known widely abroad and in reviving international interchanges of scientific information and materials.

Under the extensive educational reform plan initiated by the Japanese Government, old "imperial" universities lost their honorable prefix and many new-system universities were founded in 1948, and geoscience departments were established there one after another. These new universities as well as old ones had to face a difficult problem of the lack of new reference books and literature. This situation put serious difficulties in the way of study, especially among young workers. Under such circumstances, Asano's catalogue provided them with a fundamental literature to struggle for foraminiferology. Furthermore, it should be noted that Asano issued a small-sized Japanese newsletter in Japanese entitled *Yukochu*, which was devoted solely to the subject of foraminifera from 1953 to 1960. This publication served as a source of overseas news and also provided an outlet of presenting research results for those who complained of poor publishing conditions at that time. The *Yukochu* was succeeded in 1960 by the journal *Kaseki* which became an official publication of the Palaeontological Society of Japan.

Many students majoring in foraminiferal paleontology graduated from Tohoku, Kyoto, Tokyo, Tokyo Bunrika (the predecessor of the present University of Tsukuba), and other universities in the 1950's. Around the 1960's Japanese foraminiferology reached another peak of production because of a rush of publications of numerous dissertations by these new graduates.

Trends in the Postwar Foraminiferology

Trends in the foraminiferal research during the latter half of this century are concisely outlined in the following lines.

1. Development of benthic foraminiferal biostratigraphy

Compared with earlier studies, the subject of investigation becomes expanded in terms of geographic coverage as well as the span of geologic ages. The geographic coverage expanded from Hokkaido to the north to Kyushu to the south. There is a growing tendency to go back in time, for example, from the Plio-Pleistocene to Miocene, and further to Paleogene and Cretaceous. However, studies on Jurassic and Triassic faunas are left almost untouched. Many works presented during the 1950's and 1960's were apparently under the influence of R.M. Kleinpell, whose notable work entitled "Miocene stratigraphy of California" (1938) found a wide audience in Japan. Biofacies studies on subsurface sections opened up a new aspect of petroleum geology in Japan.

2. Systematic investigation on Recent foraminifera

With the progress of biostratigraphic research, it becomes increasingly necessary to investigate ecology of Recent faunas for correct evaluation of fossil assemblages. Such studies are not confined to the distribution and ecology of living foraminifera but involved with an improved understanding of the developmental process of thanatocoenoses in order to study paleoecology and to reconstruct paleoenvironments. Such integration of biostratigraphy with paleoecology during the course of research has helped to establish the concept of ecostratigraphy.

Before the war, most of the ecological studies did not go beyond the inner bay or lagoon, and materials for study were usually not collected by the authors themselves. In the 1950's such a research practice received a new direction with a great stimulus coming from overseas works, especially those done by a research group at the Scripps Institution of Oceanography. Under the leadership of F.B. Phleger in co-operation of F.L. Parker, this group was, in those days, producing in succession important contributions to foraminiferal ecology. A study in the lagoon Matsukawa-ura (Takayanagi, 1955) may be taken to have heralded a new wave of research in Japan. Moreover, Uchio studied at the Scripps and accomplished an important study on the ecology of faunas of the San Diego area (1960). The bathymetric distribution of foraminiferal biocoenoses in the seas surrounding the Japanese Islands was first elucidated by Kuwano (1962-1963).

Ishiwada (1951, 1963) demonstrated a close correspondence betweenn Recent benthic biofacies and various water masses characterizing different areas and water-depths off the Japanese Islands, and he analyzed fossil assemblages from the Plio-Pleistocene Kazusa Group based on these observations. At about the same time, O.L. Bandy was undertaking a similar paleoecological study of foraminifera, and his methodology (1960) as well as the approach taken by Ishiwada stimulated Japanese workers' interests in initiating biostratigraphic and paleoenvironmental analyses in the gas and oil fields.

A sediment sampling gear developed by the Scripps was introduced to Japan around that time, and since then it became a basic tool for studying marine sediments. Nowadays, most of the Japanese researchers working on Cenozoic foraminifera are generally concerned with the ecology of Recent faunas and their activities become global in extent ranging from the Arctic to the Antarctic.

3. Development of numerical analyses

With the advance of biostratigraphical and synecological studies, needs for numerical analytic methods were felt strongly. Such a need was emphasized by some workers as early as around the year 1950. With the first installation of a

computer at the University of Tokyo in 1965, Japanese universities have gradually entered into the Computer Age. Such numerical analyses as factor analysis and cluster analysis came to be effectively applied to studies of Recent faunas as well as late Cenozoic fossil assemblages. The transfer functions primarily developed by Imbrie and Kipp (1971) for the CLIMAP (Climate/Long Range Investigation Mapping and Predictions) project became an indispensable method for quantitatively estimating paleoceanographic conditions. It was rather late to develop adequate transfer functions applicable to paleoceanographic studies of the seas around the Japanese Islands. New transfer functions derived from planktonic foraminiferal data off the Pacific coast of northeast Japan were only recently applied to a study of mid-Quaternary bore-hole sequences (Takayanagi *et al.*, 1987).

4. Rise of Planktonic foraminiferal biostratigraphy and progress of international co-operation

Probably no one would deny that plankton biostratigraphy was a major breakthrough in micropaleontology of the 20th century and that planktonic foraminiferal biostratigraphy was the beginning. So far as the domestic situation is concerned, Hanzawa (1953) was the first one to emphasize the significance of planktonic foraminifera in stratigraphic correlation. Since Saito (1963) established a biostratigraphic scheme for the Japanese Miocene, a scheme conformable with those of Bolli (1957) and Blow (1959) in low latitudes, various workers gradually extended their area of research over various parts of the Japanese Islands. After completing his dissertation, Saito went to work at Lamont Geological Observatory and participated in the Deep Sea Drilling Project, which started its preparatory phase in 1968.

Nearly concomitant with the start of the Deep Sea Drilling Project in the United States, interchange of micropaleontological activities rapidly increased on an international basis. In 1967, three micropaleontology-related conferences were held in Europe one after another: SCOR symposium on "Micropaleontolgy of Marine Bottom Sediments" in Cambridge, the 4th Session of the Committee on Mediterranean Neogene Stratigraphy in Bologna, and the First Planktonic Conference in Geneva. It was the first time that several Japanese micropaleontologists could participate collectively in an international meeting.

These conferences can be viewed to have produced a global effect which set a new trend in micropaleontology at least in three areas. First, it is fully recognized that micropaleontology received an innovative observation technique with the invention of the scanning electron microscope. Secondly, progress in the refinement of planktonic foraminiferal zonations in low latitudinal regions prompted similar biostratigraphic researches in mid-to-high-latitudes and further research on other plankton groups. Thirdly, the integration of plankton biostratigraphy with magnetostratigraphy has materialized a highly reliable means of stratigraphic correlation.

A deep sea drilling programme started under the name "Deep Sea Drilling Project (DSDP)" (1968-1974) was succeeded by IPOD (1975-1983), and then by ODP (1984-), and thus a natitonal project of the U.S.A. was transformed into a big international one. In the course of such a development participation of Japanese micropaleontologists in the project steadily increased.

A research project on the Neogene biostratigraphy of the Pacific region was activated in the 1970's. The Regional Committee on Pacific Neogene Stratigra-

phy (leader: Nobuo Ikebe) was established under the auspices of the IUGS-Commission on Stratigraphy on the occasion of the 24th International Geological Congress in Montreal, 1972. In addition, a new international project "Evaluation of the biostratigraphic datum-planes of the Pacific Neogene for the purpose of global-scale correlation" was initiated as the IGCP Project-114 also under the Ikebe's leadership. At the two international meetings held in Japan (1-CPNS, Tokyo in 1976; IGCP-114, Osaka in 1981) contributions made by Japanese workers were much appreciated. Furthermore, another IGCP Project-246 "Pacific Neogene events in time and space" is now in progress under the leadership of Ryuichi Tsuchi. Through these activities, planktonic foraminiferal biostratigraphy was executed in the Japanese Islands in coastal regions both on the Pacific and Japan Sea sides. Advances in plankton stratigraphy in integrating various fossil groups through closer co-operation among micropaleontologists resulted in the establishment of fine biochronologic scales for the Japanese Neogene.

5. Progress in isotope paleontology and paleoceanography

Since Emiliani (1955) undertook a Pleistocene paleotemperature study by means of oxygen isotopic analyses, chemostratigraphy has become progressively a discipline essential for corrlating deep sea sediments and for understanding paleoceanographic and paleoclimatic fluctuations on a global scale. So far as the writer knows, paleoceanography came first on the tapis among the international scientific community in 1973, at the meeting of SCOR Working Group 40 "Paleo-Oceanography" under the chairmanship of Tj. H. van Andel. The journal *Paleoceanography* was then founded in 1980, and meetings of the International Conference on Paleoceanography have been held continuously since its first assembly in 1984.

Beginning with a biostratigraphic and isotopic study of planktonic foraminifera from the Indian Ocean (Oba, 1965), Oba and his colleagues have pursued their work on post-glacial paleoceanography of the seas around the Japanese Islands. Similar isotopic studies were attempted on land and submarine sections of Pliocene to Pleistocene ages. It may take, however, a much longer time in Japan for paleoceanographic research to reach its maturity because of the lack of young scientists working on the subject.

6. Controversy on the geohistory of the Sea of Japan based on foraminiferal evidence

The timing of opening and paleoenvironmental changes of the Sea of Japan have long been the subject of animated controversy, in connection with such problems as the tectonics of marginal seas in the northwest Pacific, formation of the Neogene siliceous sediments in the Pan-Pacific region, etc. On the subject of historical materials of the Japan Sea, characteristics of Neogene foraminifera were discussed by various workers in the 1960's. The Quaternary history was unraveled on the basis of sediment cores by Ujiié and Ichikura (1973; Ichikura and Ujiié, 1976; etc.) and others. Furthermore, taking into account of distribution and ecology of Recent fauna, oceanographic fluctuations, particularly vertical structures, in the Sea since the Middle Miocene were interpreted by Matoba (1978, 1983). Foraminiferal biostratigraphic works on subsurface sections in the oil fields along the Japan Sea coast have produced a mountain of data related to the formation of the Sea of Japan.

7. Development of studies on Paleogene and Cretaceous foraminifera

There had been a void in the study of Paleogene and Cretaceous smaller

foraminifera since Yokoyama's initiation in the last century. After the war, an urgent need was felt to advance research in these areas for exploring domestic fuel resources in Japan. In responding such a need of that time, Asano made efforts to establish a foraminiferal biostratigraphy of major Japanese coal fields in such regions as Hokkaido, Joban and Kyushu, where the Paleogene System is noticeably distributed. In the 1960's, several workers engaged in research on Paleogene biostratigraphy and Murata (1961) proposed a benthic foraminiferal zonation for the Paleogene in northern Kyushu. However, it was not until quite recently that Nishi (1985, 1987) elucidated an Eocene-Miocene planktonic foraminiferal biostratigraphy in central Kyushu. On the other hand, a benthic foraminiferal zonation for the Eocene to lower Oligocene interval was accomplished in Hokkaido by Kaiho (1984). The K/T boundary, after a long and laborious search by various researchers, was finally located within the Nemuro Group (Kaiho and Saito, 1986). Although Cretaceous smaller foraminifera were first recorded by Asano as early as 1950, Cretaceous foraminifera from Japan had barely been known as a whole prior to the 1960's. Then, middle and upper Cretaceous faunas from the meridional zone and eastern part of Hokkaido were described by Takayanagi (1960) and Yoshida (1963), respectively. Outside Hokkaido records of occurrence are still limited in number.

8. Studies on Mesozoic and Cenozoic larger foraminifera

Hanzawa continued his work on larger foraminifera for more than 20 years after the war. His papers on Cenozoic foraminifera from Micronesia (1957) and Upper Cretaceous and Tertiary threelayered larger foraminifera (1962) may be labelled as his masterpieces during that time period. Since geological and paleontological research works in Southeast Asia commenced under the leadership of Teiichi Kobayashi in 1962, 20 research groups in total were dispatched to Southeast Asian countries between 1962 and 1981. Wataru Hashimoto and Kuniteru Matsumaru were most active in larger foraminiferal studies from those countries.

Regardless of the prewar or postwar days, researches on the Cenozoic larger foraminifera from the Japanese Islands have been centered upon the Eocene *Nummulites-Discocyclina* fauna and Miocene *Lepidocyclina-Miogypsina* fauna. In particular, many stratigraphers and paleontologists have shown interests in the latter fauna because of its wide distribution throughout Honshu island. Among the workers on this fossil group, Matsumaru and Ujiié have been active in paleontological studies.

9. Biological research on foraminifera

Biological studies on foraminifera have been inactive up to now in contrast to the development of general protozoan biology in Japan. Some ecological and ethological studies are under way at present (Kitazato, 1988, etc.), but biological information available on foraminifera as to a living organism is extremely insufficient to undertake paleobiological studies of fossil taxa.

10. Test ultrastructure and systematics of foraminifera

In the classification of the Foraminiferida, genetically controlled test compositions, mineralogy, ultrastructure, and methods of test formation are regarded as the most important (Loeblich and Tappan, 1988). Although a morphocharacter such as the test ultrastructure, particularly of smaller foraminifera, was almost left untouched till the late 1940's, its significance was clearly demonstrated by Reiss (1958, 1963, etc.). In Japan, Ujiié's works on some rotaliacean forms (1956,

1965, 1966) can be appreciated as important contributions in those days. Concerning the cassiduline morphotypes, Nomura (1983) established a new classification scheme by combining several elements of test ultrastructure and other morphocharacters. Similarly, Jung (1988) tried to reclassify the Japanese uvigerine group through a detailed examination of various structural elements. Such a trend in the systematics of foraminifera will lay a good foundation for further evolutionary studies.

Ending Remarks

The historical development of foraminiferology in Japan was outlined, laying particular stress on those studies of post-Paleozoic foraminifera. Before World War II, activities of Japanese workers were confined almost to the Japanese Islands and southeast Asia. However, there has since been an expansion to nearly a global extent through overseas researches as well as international cooperation. In the foregoing reviews of this discipline, the main stress is laid on scientific rather than educational aspects. It may be impertinent to overlook the latter aspects. Publications such as textbooks and atlases written in Japanese provide a means of estimating the spread of education and the size of student population. Two writings by Hanzawa, one on foraminifera in general and the other on fusulinids, both published in 1932, were the first textbooks on foraminiferology in Japan. In addition to these works, he later wrote two books on larger foraminifera (1943, 1968). After the war, general textbooks and various kinds of atlases on paleontology have appeared in a growing number, and chapters on foraminifera have come to occupy a certain portion of these books. Furthermore, textbooks and a manual on micropaleontological techniques were publisheded (Asano, ed., 1970-1976; Takayanagi, ed., 1978).

In the year 1990 that marks the 100th year since the initiation of research on benthic foraminifera in Japan, the 4th International Symposium on Benthic Foraminifera will be held in Japan. Such an event will provide not only one item in the celebration programme but also a remarkable bench mark from which any progress of foraminiferal research that will be made in the second century in this country can be appreciated.

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