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Radiolarians and terranes: Mesozoic geology of Japan

Nobody can understand the geology of Japan without the knowledge of radiolarian biostratigraphy and the concept of terranes. In the past decade, considerable research has been carried out on radiolarian fossils, particularly those in the basement rocks of Paleozoic and Mesozoic ages. The results indicate that Jurassic formations are widespread and that they constitute an accretionary complex. After establishing a new series of radiolarian fossil zones, we have reexamined the stratigraphy of the basement rocks and have recognized many tectonostratigraphic terranes in the Japanese Islands. Discussion on the tectonic history of the Mesozoic terranes is extended to that of eastern Asia in relation to accretion and dispersion processes.

Introduction

The Paleozoic to Mesozoic group of rocks underlies a major part of the Japanese Islands, and it has been investigated stratigraphically since the 19th century, chiefly on the basis of fusulinaceans and macrofossils. In contrast to this school of biostratigraphy, studies of radiolarians (rads), particularly using the scanning electron microscope, were undertaken in the 1970s and became widely popular thereafter. In fact, of more than 400 papers published on rads in Japan since 1926, more than 80 percent appeared in the 1980s. These papers, written mainly by enthusiastic young geologists, have offered startling new evidence for the geologic age of the "Paleozoic" group. The most noticeable papers present the findings of Jurassic rads from "Paleozoic" provinces, and it has been demonstrated that the "Paleozoic" group actually forms a Mesozoic *mélange* complex.

It used to be believed that paleogeographic reconstruction could be made by collecting paleoenvironmental data and by compiling them according to their ages and similarities. However, the newly obtained age data have revealed that adjoining geologic units bounded by a significant discontinuity have different geologic histories. The terrane concept has been accepted, and the term is used now especially by the geologists who have been working in the "Paleozoic" provinces.

Thus, the geology of the Japanese Islands prior to the opening of the Sea of Japan is discussed here in terms of collage tectonics on the eastern continental margin of Asia in Mesozoic time.

Radiolarian biostratigraphy of the Paleozoic to Mesozoic group

Radiolarian biostratigraphic research and age assignment by means of rads were not done successfully until the 1970s. Our knowledge of rads has improved greatly, however, in the past decade, which is shown by several leading papers such as those written by Nakaseki and Nishimura (1979) on Late Triassic rads, Yao and others (1980) on Middle Triassic to Middle Jurassic rads, Mizutani and others (1981) on Middle to Late Jurassic rads, and Ishiga and Imoto (1980) on Permian rads.

Mesozoic radiolarian assemblage zones were set up first by Yao and others (1980) in chert-clastic sequences that were assigned to the Middle Triassic to Middle Jurassic on the basis of conodonts and stratigraphic relationships. Subsequently, many assemblage zones have been proposed, though locally, that range in age from Permian to Cretaceous. Integrating these data with their own observations, Matsuoka and Yao (1986) established the Jurassic rad zones as defined by biohorizons. At present, the rad zones in Japanese late Carboniferous to Jurassic time are compiled as shown in figure 1. Of these zones, the Jurassic ones are correlated broadly with the rad zones of the Atlantic Ocean, Mediterranean Tethys, and North American regions (Yao, 1990). According to the latest report of the Ocean Drilling Program (ODP), the rad zones of late Middle Jurassic to earliest Cretaceous time in the central western Pacific Ocean floor correspond well to those of the Japanese Islands.

Systematic investigations of "Paleozoic" stratigraphy and the age assignments based on our rad scale indicate that chert or siliceous shale in the "Paleozoic" group commonly contains rads of Permian, Triassic, or Jurassic ages. The occurrences of these rads suggest that the group is a *mélange* complex that is composed principally of a Carboniferous to Permian greenstone and limestone (seamount) facies; a Carboniferous to Permian shale and chert (pelagic) facies; and a Triassic bedded chert, Jurassic chert and siliceous shale (sometimes carrying manganese carbonate nodules), and Jurassic clastic facies in which granite-bearing conglomerate is intercalated sporadically.

Mesozoic terranes of the Japanese Islands

We have reviewed and reexamined all the classic data in order to present the whole tectonic history of the Japanese Islands, where we have recognized many disparate terranes as shown in figure 2. They are metamorphic terranes (Hida, "Sangun," Sanbagawa, and Abukuma), Paleozoic terranes composed mainly of Paleozoic folded formations (Akiyoshi and South Kitakami), an early Mesozoic terrane (Maizuru), *mélange* and disrupted terranes (Mino, Chichibu, and North Kitakami), a much younger terrane of an accretionary complex (Shimanto), and the Cenozoic terrane of Izu. Our discussions extend to intraterrane features and to interterrane relationships.

The Hida terrane, for example, consists of a granitic, polymetamorphosed basement complex ranging in age presumably from the Precambrian to the Triassic, and it is overlain unconformably by a Jurassic to Cretaceous clastic sequence. It is juxtaposed with the Mino terrane of a mélangé complex, which is composed of a Jurassic radiolarite, a Triassic bedded chert, and a Permian greenstone-limestone mass that is associated with coeval shale and chert, all enclosed in Jurassic to Lower Cretaceous clastic deposits. These two terranes, the Hida and Mino, were stitched together by Upper Cretaceous to lower Paleogene rhyolite effusive rocks. Between the Hida and Mino terranes, a suture zone exists as a narrow tectonic belt, in which irregular blocks of varying sizes (serpentinite, greenschist, and blueschist associated with metamorphosed ophiolitic rocks, middle to upper Paleozoic limestone, clastic rocks, and volcanic rocks) are

Figure 1.—Late Carboniferous to Jurassic radiolarian fossils and their assemblage zones in the Japanese Islands. (1) *Pseudodictyomitra primitiva* Matsuoka and Yao. (2) *Parvicingula mashitaensis* Mizutani. (3) *Gongylothorax sakawaensis* Matsuoka. (4) *Dictyomitrella(?) kamoensis* Mizutani and Kido. (5) *Unuma echinatus* Ichikawa and Yao. (6) *Hsuum hisuikyense* Isozaki and Matsuda. (7) *Mesosaturnalis hexagonus* (Yao). (8) *Parahsuum simplum* Yao. (9) *Canoptum triassicum* Yao. (10) *Triassocampe nova* Yao. (11) *Yeharaia elegans* Nakaseko and Nishimura. (12) *Triassocampe deweveri* Nakaseko and Nishimura. (13) *Neobaillella ornithoformis* Takemura and Nakaseko. (14) *Follicucullus scholasticus* Ormiston and Babcock. (15) *Pseudoalibaillella u-forma* Holdsworth and Jones. Scale bar equals 0.1 mm. Abbreviations: C, Carboniferous; E, Early; M, Middle; L, Late. In Jurassic and Triassic ages: T. yaoi, *Tricolocapsa yaoi*; S. naradaniensis, *Stichocapsa naradaniensis*; P. (?) grande, *Parahsuum (?) grande*; T. elkhornensis, *Trillius elkhornensis*; E., *Eucyrtidiellum*; K., *Katroma*; A. compactum, *Archaeospongoprunum compactum*. In Permian and Carboniferous ages: N., *Neobaillella*; F., *Follicucullus*; P., *Pseudoalibaillella*; A., *Alibaillella*.

sliced and interleaved together. Some of the fragmentary units in this suture zone can be correlated with those of the Akiyoshi and "Sangun" terranes.

The Akiyoshi terrane is composed principally of Carboniferous to Permian limestone and underlying greenstone plus Permian chert and shale; all of these are deformed severely and are overlain unconformably by slightly deformed, Triassic, coal-bearing formations. The Paleozoic group in the Akiyoshi terrane represents an older accretionary complex that was related to the collision and disruption of ancient seamounts, which were associated with the surrounding pelagic chert and shale during latest Permian time. The Akiyoshi terrane itself has undergone no intense metamorphism, whereas the "Sangun" and Sanbagawa terranes are metamorphic terranes that are composed commonly of metamorphic rocks of greenschist to blueschist facies. Isotopic ages of the "Sangun" metamorphic rocks reveal that three metamorphic events are detectable or that the terrane may well be composed of three subterrane; the metamorphic events are supposed to be of Carboniferous to Permian, Triassic, and (or) Jurassic ages. On the other hand, the isotopic ages of the metamorphic rocks of the Sanbagawa terrane range from 128 to 50 Ma and cluster in the interval from 110 to 60 Ma.

The Chichibu terrane is another mélangé and disrupted terrane that extends much of the length of the Japanese Islands on the Pacific side. It is sometimes divided into two subterrane, North Chichibu and South Chichibu, between which the Kurosegawa terrane is sliced in a fragmentary fashion (these subterrane and the Kurosegawa terrane are so small in size that they are not shown in fig. 2).

As has been pointed out by Saito and Hashimoto (1982), the South Kitakami terrane is an exotic allochthonous mass. It consists of a successive sequence, though bounded by numerous unconformities, that is composed of Silurian shallow-sea carbonate, Devonian acidic volcanic rocks, Carboniferous shallow-sea carbonate (interrupted by late Carboniferous folding), Permian shallow-sea carbonate overlain by coarse clastic deposits, and Mesozoic clastic deposits of a shelf facies. All these formations are similar to those of the Kurosegawa terrane.

The North Kitakami terrane, chiefly a Jurassic mélangé complex, has many traits in common with the Mino terrane or with the Chichibu terrane of southwestern Japan. The North Kitakami terrane is bounded on the south by a narrow suture zone, where an ophiolitic complex is found to occur together with sheared slivers derived from the North Kitakami and the South Kitakami terranes. The Abukuma

Figure 2.—Major terranes of the Japanese Islands (modified and redrawn on the basis of the terrane map of Ichikawa, 1990).

terrane to the south and southwest of the North and South Kitakami terranes is composed of metamorphic rocks that probably were derived from a Jurassic sedimentary complex.

Mesozoic tectonic history of the eastern continental margin of Asia

Along this trend of biostratigraphic studies in Japan, a reconnaissance survey has been carried out on the Asian continent as well. The Nanhada area, located in the northeastern part of China, is one such example where the geology was reexamined by using radiometric and terrane analysis (Kojima, 1989). This work has disclosed that the Nanhada terrane is identical to the Mino terrane in all aspects. The comparative studies indicate that the Nanhada and Mino terranes once formed a single large terrane prior to the opening of the Sea of Japan. By referring to the terrane map of China, we conclude that the eastern margin of Asia formed a collage zone of terranes in Jurassic to Cretaceous time.

In order to discuss the process by which these terranes were accreted, dispersed, and positioned finally at their current locations, the following two paleomagnetic investigations are worthy of note. Shibuya and Sasajima (1986) determined, after making a thorough examination of the folded Triassic bedded chert of the Mino terrane, that the rock was magnetized originally in the equatorial region. Z. Zheng (written communication, 1991) reported that the Upper Jurassic and Lower Cretaceous siltstones and shales in the Nanhada Range have paleomagnetic inclinations corresponding to a paleolati-

tude of approximately 33° N. In addition, the presence of luteite in a Permian limestone block that is embedded within the Jurassic mélange complex of the Mino terrane suggests that the block probably was derived from the current southern China region, because no luteite has been reported elsewhere so far, except in a platform region of southern China (Hattori, 1989).

Terrane accretions are inferred to have occurred in the southeastern peripheral zone of Asia after the formation of a collage of Triassic age in the main part of eastern Asia (fig. 3). Permian seamounts and Triassic bedded chert formations, both coming from the equatorial region, assembled together with the pelitic sediments of Jurassic age, and all were enclosed within the coarse clastic sediments derived from an older continental region. It is highly probable that the ophiolites in the suture zones between major terranes of the Japanese Islands represent an ancient oceanic crust that existed at the time of accretion. All terranes of Jurassic to Cretaceous age in the collage zone were transpressed, dispersed, and displaced along the margin up to northeastern China and the Sikhote-Alin region of the USSR, so the prevailing movement had to be of a sinistral sense. Most of the terranes were sliced and fragmented during this period, and strike-slip movements took place in a continental region and within the collage zones. Metamorphism was closely related to this tectonic history, as the accretion in Late Jurassic to Early Cretaceous time and the transpression in the ensuing time are, above all, responsible for the formation of the metamorphic terranes.

After extensive acidic magmatism of Late Cretaceous to early Tertiary time in the continental margin, rifting occurred within the collage zone. This is represented by Neogene andesitic volcanogenic

Figure 3.—Brief summary of the tectonic history of the Mesozoic terranes of the Japanese Islands (modified and redrawn on the basis of the map by Mizutani and others, 1990). Solid heavy line shows the structural trend of the Jurassic accretionary complexes (Mino and Nanhada terranes on the Sea of Japan side and Chichibu and North Kitakami terranes and their southern equivalent on the Pacific Ocean side). Dashed heavy line shows a connection of corresponding terminations of the trend that was displaced exclusively by Cenozoic movement.

rocks, generally called Green Tuff, that commonly are found in the Sea of Japan side of the Japanese Islands. This event stands for an incipient stage of extension in the island-arc formation and was followed by the opening of the Sea of Japan.

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