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Late Permian Anoxic Event and P/T Boundary in Pelagic Sediments of Southwest Japan

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The P/T (Permian-Triassic) boundary has been recently recovered in siliceous rock sequences of Southwest Japan. The sequence representing oceanic plate stratigraphy, comprises pelagic bedded cherts, embedded in the Jurassic accretionary complexes, and the boundary is marked by black carbonaceous mudstones indicating appearence of a drastic environemtnal change comparative to that of the K/T boundary in lithologic feature.

The sequence of Upper Permian bedded cherts is characterized by black or grey organic bedded cherts enriched by sulfide which gradually change from red bedded cherts of late Middle Permian age. The sequence of the P/T boundary and related rocks comprise:
1) grey to black *Neoalbaillella* radiolaria bearing bedded cherts, 2) grey siliceous claystones of possible boundary or Earliest Triassic, 3) black carbonaceous mudstones, and 4) Smithian (Early Triassic) conodont bearing grey siliceous claystones in ascending order. And at present apparent Griesbachian and Dienerian fossils have not been discriminated.

Occurrence of 1) black organic bedded cherts indicates the anoxia occurred already in the ocean, prior to the Latest Permian, i.e. the high sea level, warm oceans, high value of primary production. Concerning the size and structure of the Late Permian radiolarian skeletons, *Neoalbaillella* and some other polycystines are characterized by small, fine and complicated shaped of tropical features. Decreased amount of siliceous skeletons in 2) siliceous claystones indicates extinction of Permian polycystine radiolaria from latest Permian to earliest Triassic time.

The lithologic and radiolarian faunal variation in early Late Permian indicates shifting of sedimentary environment from oxic to oxygen depleted (or anoxic), which clearly coincides the timing of the volcanic activity of the continental flood basalt such as the Siberian Traps. And also this shifting is regarded to have occurred in middle Middle Permian, which is indicated by color change of bedded cherts from red to green and acid volcanic activity occurred in the surrounding terranes of intraplate oceanic arc setting. The enviornmental change of system and conditions between the greenhouse and icehouse preceeding to the last of the Paleozoic is regarded to be appeared in early Late Permian. The black carbonaceous mudstones intercalated in siliceous claystones of the P/T boundary, although probably not representing true anoxic conditions, seem to be correlated with many mass extinction events.

1. Introduction

The Permian/Triassic boundary (P/T boundary) has been investigated in the Tethyan regions, especially in the section of the shallow marine facies. The boundary problem has been pointed to the bio-chlonostratigraphical boundary itself and the mass extinction etc. The appearence and extinction of the major groups of the macro-organisms have been examined in detail, which is regarded to have been suffered the environmental change at and around the boundary. Planktonic microfossils from pelagic sediments, however, have not been examined enough to recognize change of system and condition of the ocean as a whole. Characteristic feature is that the boundary usually represented by the black carbonaceous mudstones, which is regarded to be correlated with the Oceanic Anoxic Events (OAEs).

As for the K/T (Cretaceous-Tertiary) boundary, both shallow marine facies and the pelagic sediments have been examined in detailed and their correlation has been attempted, on the basis of the accumulated K/T boundary data from the pelagic sediment cores. The development of the OAE is noted to be correlated well with many mass extinction events (Kauffman, 1986, 1988), and still it is contraversial of the primary triggers of the mass extinction.

Radiolarians and other planktonic organisms which aboundantly occur in siliceous sediments, have been affected at the K/T boundary, while those at the P/T boundary extinct mostly. In the study of the P/T boundary, siliceous rocks accreted to the orogenic belt are well dated columns by microfossils, and sedimentologic and geochemical analyses are the basic data for understanding of environmental change of condition and systems. Japanese geology has provided the foundation of this examination, because of the progress of radiolarian biostratigraphy of the numbers of the well documented Permian and Triassic standard sections.

Recent advances of sedimentological and geochemical analyses of the P/T boundary in the pelagic sediments have revealed shifting of the oceanic environment from oxic to oxygen depleted previously to the last of the Permian. The evaluation of relationship of the supposed OAE at this time and proximal causes of extinctions of planktonic silicic organisms could give better proposal of models of mass extinction, in comparison with other OAE of the geologic time.

2. Pelagic P/T boundary section of Japan

The P/T boundary lies in the bedded chert sequence represented by oceanic plate stratigraphy (Isozaki et al., 1990) which was embedded in the Jurassic accretionary rocks widespread in the Tanba-Mino Terrane and the Chichibu Terrane (Yamakita, 1987; Yamashita et al., 1991; Ishida et al., 1992) (Fig. 1). These terrane rocks formed the two nappes, namely upper and lower nappes. The upper nappe, called TII suite of the Tanba Terrane (Ishiga, 1983) is older than that of the lower nappe (TI suite of the Tanba Terrane) concerning the relative age of both clasts (ranging from Late Carboniferous to Triassic greenstone and bedded chert sequences) and melange matrixes (Late Triassic to Middle Jurassic mudstones). The lower nappe is composed of the clasts (ranging from Triassic to Early Jurassic bedded cherts) and melange matrixes (ranging from Middle to Late Jurassic mudstones, partly ranging to Earliest Cretaceous in the Mino Terrane, Wakita, 1988). Age of the bedded cherts of the lower nappe started from the Early Triassic, and no accurate Permian microfossils have been reported. The P/T boundary occurred in the clasts of the upper nappe, but the lithologic feature and biostratigraphic components resemble each other as for the Early Triassic section of TII and TI suites. The sequence of bedded cherts are described below from the upper nappe of the Tanba Belt.

The examined section in the Sasayama area consists of the Middle to Late Permian bedded cherts and the Early Triassic bedded cherts, and between them 2 m thick sheared zone interrupts the sequence (Ishida et al., 1992). This zone of about 50 cm was probably composed of the sheared black carbonaceous siliceous mudstones and these rocks are highly deformed. The Permian and Triassic cherts are different mutually in the point of lithology, their color, and geochemistry (Yamashita et al., 1992; Ishida et al., 1992).

2.1. Lithology

Lithology of the Permian section: The Permian section consists of the bedded cherts (of about 20 m thickness) showing variety of thickness of a single bed, and overlying siliceous claystones (of about 70 cm thickness). The lower part of the section (corresponds to the upper part of the *Pseudoalbaillella longtanensis* Zone to *P. globosa* Zones, of lower to middle Middle Permian) consists of red to reddish brown cherts, while middle part of the section is characterized by greenish red cherts. Noteworthy is the thick bedded white to whity grey cherts of about 50 to 70 cm appeared in midst of this part (nearly corresponds to lower part of the *Follicucullus japonicus* Zone of upper Middle Permian). The white chert rarely yields radiolarians and spongy spicules. The upper part of the Permian section is composed of greenish grey to grey cherts which corresponds to the upper part of the *F. japonicus* to *Neoalbaillella ornithoformis* Zones of Upper Permian. Thickness of the *Neoalballella* bearing cherts range from 2 cm to over 10 cm and vary irregularly. And again, white cherts of about 20 cm thickness marked the base of the greenish grey chert (Fig. 1). This has also produced seldomly radiolarians.

Lithology of Lower Triassic section: The Lower Triassic section consists of the thinly alternating beds of cherts (single bed is usually 1 to 2 cm thickness) and siliceous claystones of nearly same thickness as that of cherts, of about 2 m thickness and overlying grey bedded cherts of over 3 m thickness. The bedded cherts consist of beds with 1 cm or less thickness and thinner siliceous shales or siliceous claystone partings of about a few milimeter thickness. These rocks yeilded small spumellarian radiolarians, conodonts and spongy spicules.

2.2. Color change and presumed environmental change

The rock color change indicates conditions of depositional environment, whether it was oxic or anoxic, for black colored cherts abound in organic carbon and/or pyrite, while red colored cherts dominate hematite (Ishida et al., 1992).

The color of the Permian bedded cherts changes from reddish to blackish as a whole of the section, but in detail red to reddish brown bedded cherts change into greenish red bedded cherts in an interval of about 12 m thickness and this change was repeated again (Fig. 1). Then the greenish grey bedded cherts of about 5 m thickness overlies these

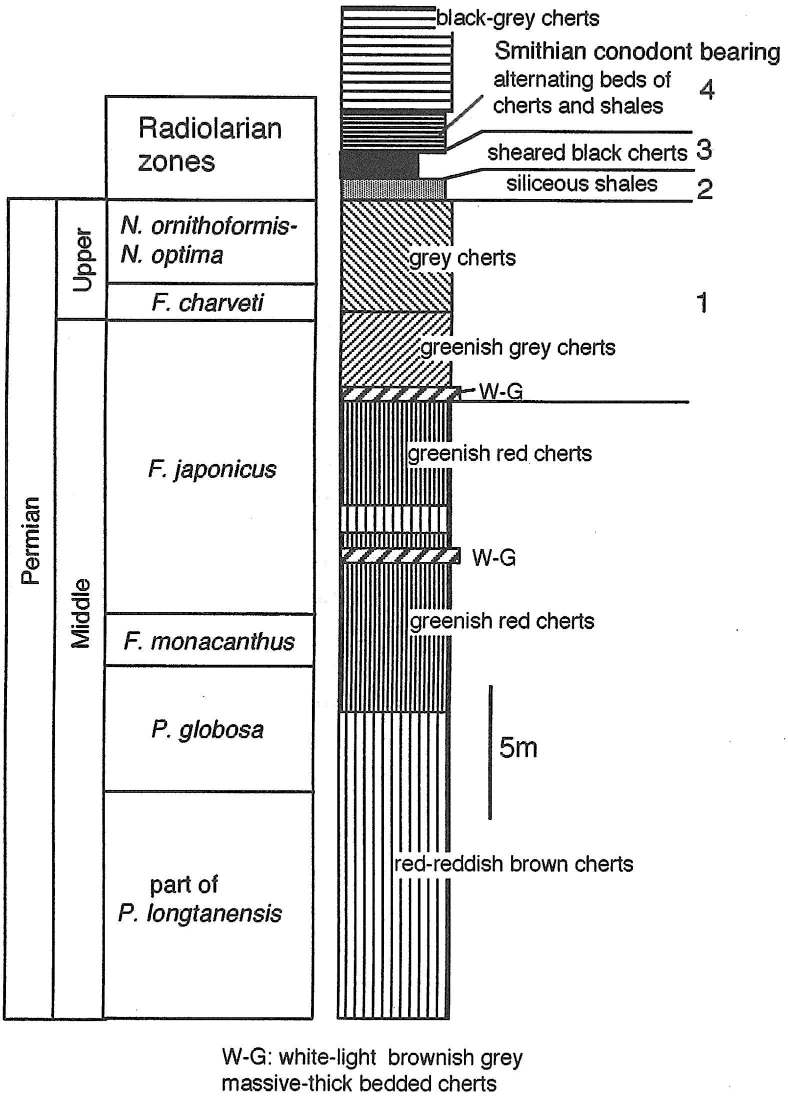

Fig. 1. Columnar section indicating P/T boundary in Sasayama, Hyogo Prefecture Southwest Japan, slightly modified from Ishida et al. (1992).

bedded cherts and finally this changes into grey to blackish grey bedded cherts. As mentioned above, important notice is appearence of white thick, partly massive chert beds in the *Follicucullus japonicus* Zone. As will mention to this characteristic beds, the white chert is related with the OAE in the Toarcian (Lower Jurassic) bedded cherts. The boundary between the Middle and the Upper Permian lies in the upper part of the greenish grey bedded cherts.

The Triassic bedded cherts show blackish grey to greenish grey and apparent color change has not been observed.

2.3. Age of the bedded chert sequence

The Permian sequence examined is correlative to the radiolarian zones ranging from the Middle Permian *Pseudoalbaillella globasa* to the Late Permian *Neoalbaillella ornithoformis* Zones of Ishiga (1990), and 7 zones recently proposed (Ishiga, 1991) are wholly discriminated. However, lacking of some lower part of *Follicucullus charveti* Zone is supposed, judging from the absence of *Albaillella triangularis* which dominantly occurs in this part.

Recently correlation of the radiolarian biostratigraphy and conodont zones has been carried out in several zones, of which the Upper Permian examination is referred herein. Before going on to the correlation, radiolarian zonation is adopted from Ishiga (1991). The upper Middle to Upper Permian radiolarian zones proposed are the *Follicucullus japonicus, F. charveti, Neoalbaillella optima* and *N. ornithoformis* Zones in ascending order. The bottom of the *F. charveti* Zone marked by occurrence of *F. charveti,* which together with *F. bipartitus* is main component of the *F. bipartitus-F. charveti* Assemblage (Ishiga and Miyamoto, 1986; Caridroit et al., 1985; Ishiga, 1990). This assemblage occurred from the Late Permian *Lepidolina kumaensis* Zone of the Kuma Formation, Kyushu (Ishiga and Miyamoto, 1986). Recent investigation also supports this correlation, i.e. the *Follicucullus monacanthus* Zone corresponds to the *Lepidolina multiseptata* Zone (Yamashita and Ishiga, 1990). The Uppermost Permian is characterized by the occurrence of *Palaeofusulina sinensis* and recent examination revealed that this fusuline zone in the Maizuru Belt, Southwest Japan could be correlated to the lower part of the *Neoalbaillella optima* Zone (Yamashita et al., 1992). This points *Neoalbaillella* bearing cherts can correspond to the Uppermost Permian, Changxingian in Chinese sense (Sheng et al., 1984).

Concerning the Triassic bedded cherts, Smithian conodont, *Neospathodus dieneri* was discriminated from thinly alternated beds of cherts and siliceous claystones (by S. Yamakita in Ishida et al., 1992), and some spherical shaped radioalrians were obtained.

2.4. Other sections of P/T boundary of Japan

Recent reexamination of the bedded chert sequences brought a success of discovery of the complete P/T boundary section in Tenjin'maru of Shikoku (Yamakita, 1987) and a possible Latest Permian sequence in Ubara of Kyoto Prefecture (Kuwahara et al., 1992). The Tenjin'maru section consists of 1) the Late Permian conodont bearing bedded cherts and siliceous claystones, 2) black carbonaceous mudstones of possible Latest Permian, 3) Early Triassic (probable Smithian) siliceous claystones. Noteworthy is the actual boundary lies probably in the black carbonaceous mudstones concerning the conodont study. The rock is characterized by high contents of carbon (over 5% of weight ratio), and also high contents of silica of about 80%. This rock is supposed to form in the high primary production and deposited in an anoxitic basin. An important component of the bedded cherts, radiolaria of itself has been regarded to be bloomed in a condition of the high primary production where active upwelling was supposed (Sano and Kanmera, 1988). And a natural consequence to such a condition of the present sea is maginal sea, etc.

However, depositional environment of the Late Paleozoic to Early Mesozoic bedded cherts is assorted with that of an oceanic island or sea mount by the geochemical examination of the altered basalt which underlies the bedded chert sequence. And moreover, paleomagnetic examination revealed that the depositional sites of the Permian and Triassic red bedded cherts could be near the paleoequator (Hattori, 1982; Shibuya and Sasajima, 1980).

In these circumstances, an idea comes that the depositional environment could be changed through the stages of the formation of altered basalts to the stages of the bedded chert sequences. The Permian bedded cherts and Triassic thinly alternated beds of cherts and siliceous shales contain grains of orthopyroxene and hornblende (Ishida et al., 1992) which are supposed to have come from the islands where possible intermediate volcanic activity is expected. This is concordant to the supposition of the depositional sites of the black bedded cherts in the marginal sea.

3. Feature of radiolarian shell construction and climatic difference in Middle and Late Permian time

Neoalbaillella radiolaria rose from some *Pseudoalbaillella* in early Late Permian, and they are different from other Albaillellaria in a feature of small (approximately 200 μm length), and pored framework of shell. *Neoalbaillella* is characterized by the pored framework, while *Pseudoalbaillella* and *Follicucullus* are covered with unperforate thick shell. The pore structure is regarded to the first appearence of character of the Mesozoic type Nassellaria (see Ishiga, 1990; Takemura and Nakaseko, 1981), but in different view, *Neoalbaillella* could be regarded to be a ornamented, delicated and fine structures as those of the tropical radiolarians rather than those of the cool water.

4. Change of circumstances revealed by geologic columns in Meso-Paleozoic terrances of Southwest Japan

The lithologic and biostratigraphic (especially radiolarian biostratigraphic) examina-

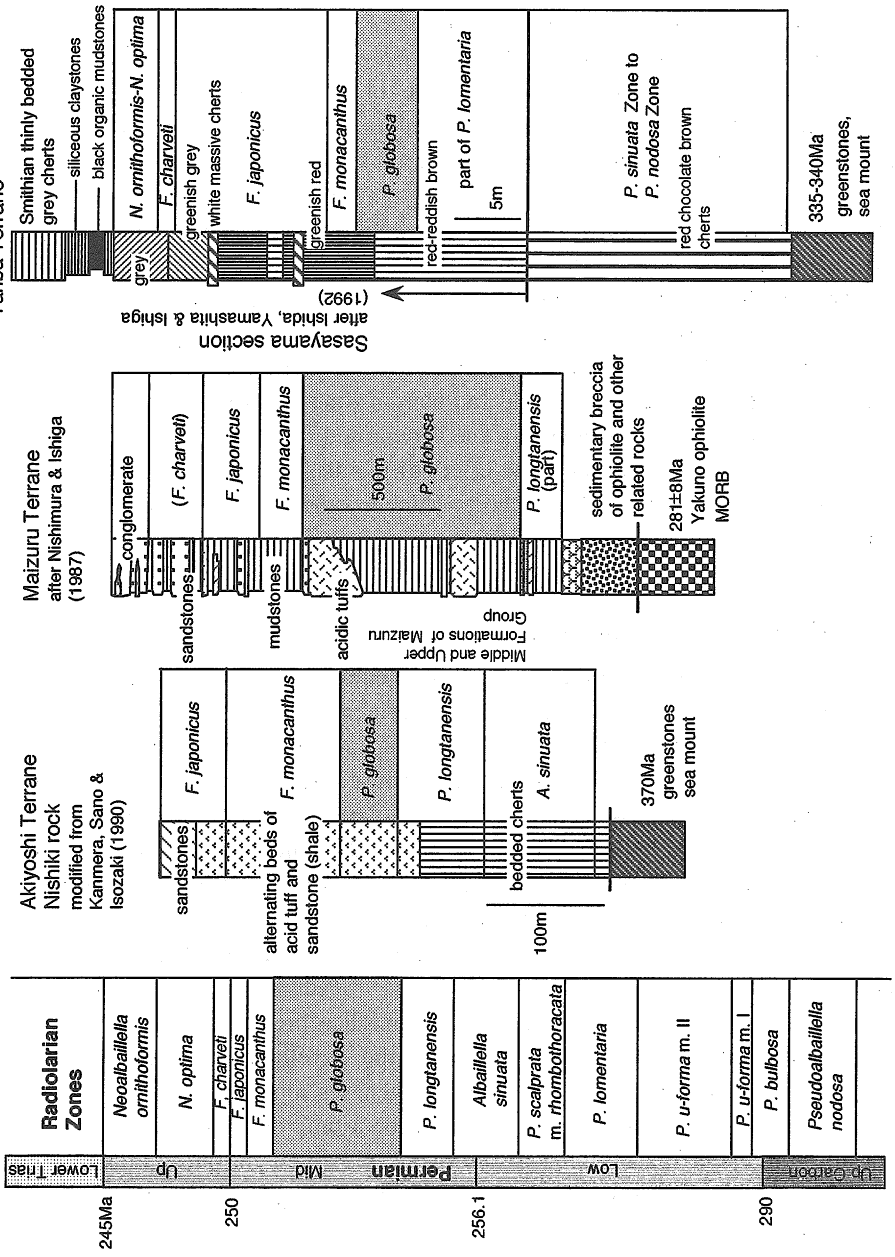

Fig. 2. Correlation of the pelagic bedded chert sequence of the Tanba Terrane and rocks related to the Tanba Terrane on the basis of radiolarian zonation are indicated. Note color change of bedded cherts corresponds well to the acid volcanic activity at the middle Middle Permian *Pseudoalbaillella globosa* Zone.

tion have been proceeded in siliceous rocks of the Paleozoic terrane in the Inner Zone of Southwest Japan, of which the activity of oceanic plate geneses and volcanic eruption have been regarded to suffer not only circumstances of neritic environment but also pelagic one. The examined pelagic rocks were accreted to the oceanic side of the Paleozoic terranes, such as Ultra-Tanba Terrane or the Maizuru and/or Akiyoshi Terranes (Ishiga, 1990). These Paleozoic terranes are characterized by the dominant occurrence of acid volcanic rocks and pyroclastic rocks (Kanmera et al., 1990; Nishimura and Ishiga, 1987; Tokuoka et al., 1987 etc.). And in the Maizuru Terrane, granitic and volcanic rock (mainly rhyolite lava) activity has recently been recorded (Hayasaka, 1990; Ishiga et al., 1989), and the matured oceanic island arc setting is applied to part of the Yakuno ophiolite of the basement of the Maizuru sedimentary rocks (Fig. 2). Acidic tuffs are dominated in the radiolarian zone, *Pseudoalbaillella globasa,* in Akiyoshi and Maizuru Terranes (Fig. 2), and the color change of the bedded cherts from red to green coincides with this radiolarian zone. Although the depositional basin of pelagic cherts in the Tanba Terrane is regarded to be far from the island arc or continent of the Paleozoic terranes, the effect of the acid volcanism appeared in the gradual change from red cherts to green cherts which in other words, precursory change from oceanic oxic environment to the anoxia.

5. Change of systems and conditions in Late Permian time

Recently Masuda (1989) complied the environmental change through the Phanerozoic adapted from the data of oxygene isotope, continental glaciation, mass extinction, vail curve and sea level change (Fig. 3). Timing of each event surprisingly coincides and Late Permian is the time of the end of the icehouse stage. The Gondwana Icecap had already diminished at this time and the sea level was restored (Fig. 3). To understand the OAEs, the acritarchs are also indicated in this figure with numbers of species per period adopting from Tappan and Loeblich (1973). It is well known that the acritarchs have developed at and around the anoxic event and they showed acme especially in Late Ordovician. In Permian, acritarchs were rather highly populated than those of the Late Carboniferous and Triassic. Radiolarian population is also indicated, for this is an indicater of the duration of silica precipitation, which closely related to the ophiolite genesis, in other words, the development of the sea floor. Again the radiolarian blooming and the ophiolite geneses much correspond well with each other. Although the Late Permian is said to be a time of relatively low sea-level (Holser et al., 1987), but the Permian is one of the plate generation cycle among the ophiolite cycle (Ishiwatari, 1989). The scenario of the plate genesis and the extinction of the organisms related to anoxia is that, the development of the sea-floor produced rather wider ocean and/or deeper basin enrich in fertilization, and also provided convenience for blooming of microplanktons such as radiolarians and acritarchs etc. The remains of these plankton might be primary cause of the oxygen depleted basin

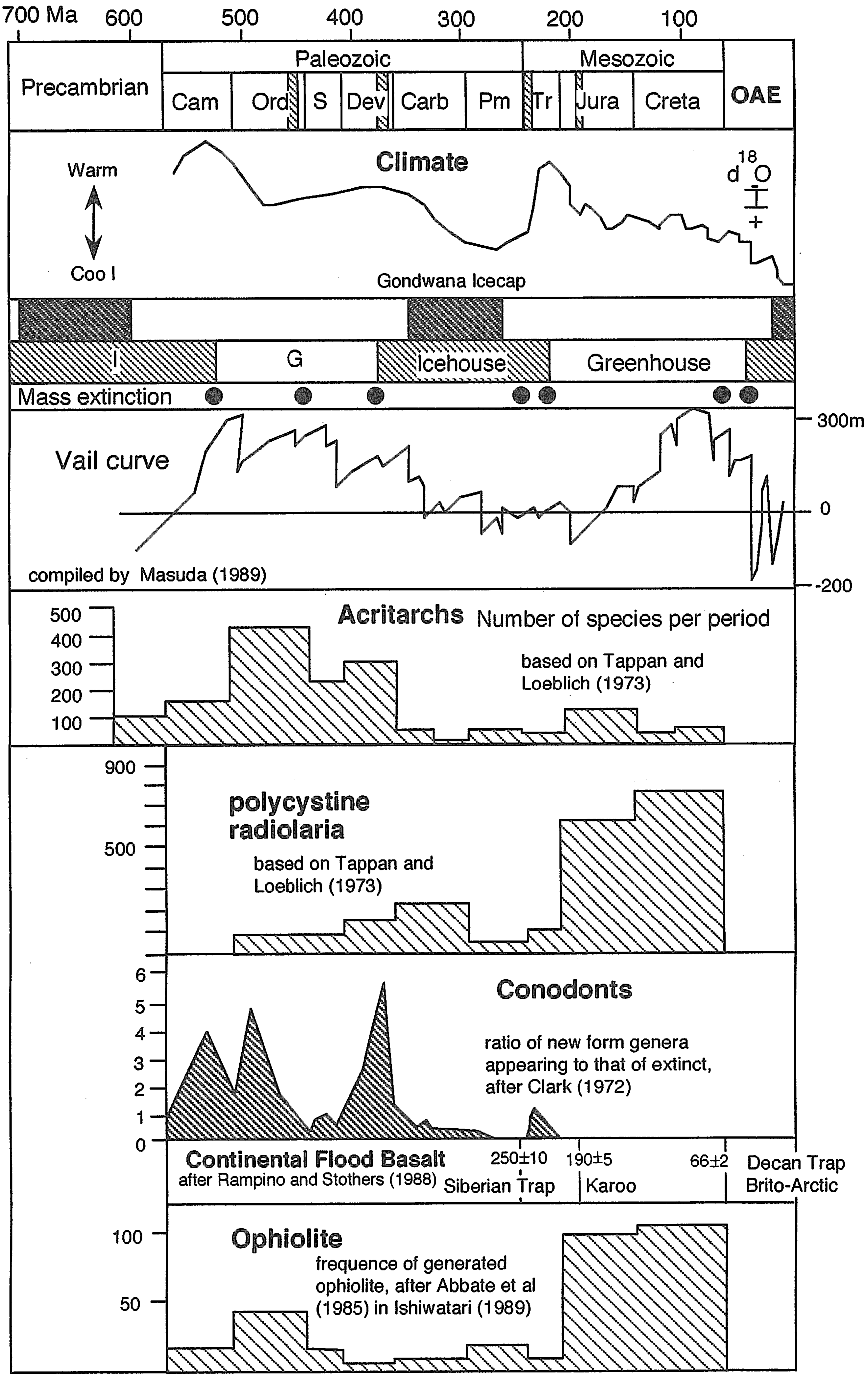

Fig. 3. Oceanic Anoxic Event, and other related geologic events and data are compiled. For references see figure and text.

condition and red-tide formed by acritarchs can attribute to the extinction of the heigher organisms in shallow marine condition. A possible effect of blooming of acritarchs is clearly indicated in Fig. 3, when it is compared to the appearence/extinction ratio of conodonts (data from Clark, 1972). Examples are picked up in Late Ordovician, Late Devonian and during Middle and Late Permian, where acritarchs had acme or rather prosperity.

As pointed out above, lithologic change of cherts occurred in the Middle to Late Permian bedded chert sequence (Ishida et al., 1992). The reddish color Middle Permian bedded charts gradually change into black or grey bedded cherts of the Late Permian which is characterized by the occurrence of *Neoalbaillella* radiolaria. These black cherts dominated organic carbon (2–3% of bulk composition) and is characterized by enrichment of sulfide, which is regarded to have been deposited in the regime of the anoxic environment. The anoxia of the geologic time have been related to the high sea level, warm oceans, and high primary production (abundant marine organisms), which is regarded to have occurred in the Greenhouse state (Masuda, 1991). On the other hand, the Lower to lower Middle Permian red cherts were deposited in oxic environment, of which the feature of ocenic environment was characterized by low sea level, cold oceans and relatively low primary production of the Icehouse state. Thus the shift from Icehouse state to Greenhouse one occurred in near the boundary of Middle and Late Permian time, and this event can be said to be recorded in the siliceous deposits.

6. P/T boundary in the pelagic sediments and radiolarian extinction event

There have not been a successful record of Alabaillellaria radiolaria in crossing the Permian/Triassic boundary, and probably most of the polycystines, except palaeosceniids and actinomiids, may have extincted at this event (Fig. 4). The very early stage of the Triassic, simple spherical possible spumellaria occurred from the Sasayama section, but the well discriminated form has only been described from the upper Spathian or Anisian cherts dated by conodonts (see Matsuda and Isozaki, 1982; Sashida, 1982; Yamashita et al., 1991). The fauna is simple and characterized by appearence of palaeosceniids, *Eptinguim* and *Archaeospongopurunum*?. The advent of the nassellarian radiolaria which predately widely diversified, is in late Spathian or early Anisian (Yamashita et al., 1991). Therefore the Permian terminal event had considerable damage sufferred to the radiolarians and other plankton as well. According to the radiolarian event, the terminal Permian is proposed at the top of the black-grey bedded cherts and at least, the overlying siliceous shale could represent next stage namely earliest Triassic.

As is known at the K/T boundary, Emiliani et al. (1981) pointed important notice to the selected extinct and declines, and more important selective survival is indicated to the best explanation of a catastrophic, and very short ecological jolt. Namely, late Cretaceous radiolarians crossed the boundary, i.e. 95% of numbers of the genera were

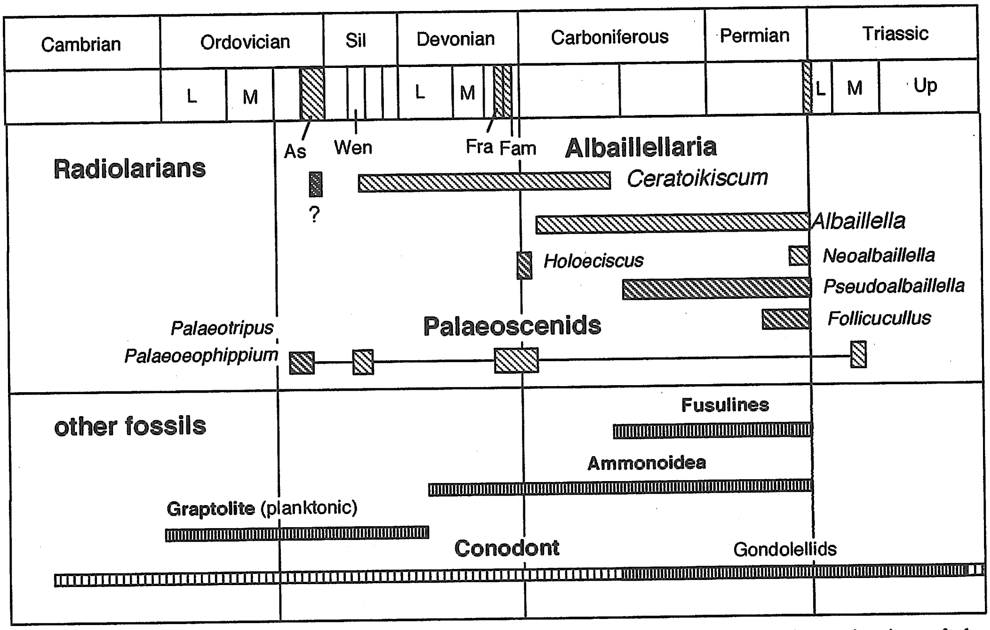

Fig. 4. Radiolarian and other fossils of which usually have been used for age determination of the accreted terranes. Note extinction of the Albaillellaria radiolaria at terminal Permian.

survived, and among siliceous marine plankton, dinoflagellates and diatom also show high percentage (78%, and 31% respectively) of the survival. The difference of the pelagic environments and other shallower environments is explained that the predominantly high latitude diatom and dinoflagellates fare much better than decimated calcareous plankton such as cocolithophorids and foraminifers. The radiolarian percentage is explained by common occurrence in high latitude and also at lower latitudes in deeper water, so that they would be better position than the shallower plankton to survive a presumed high temperature episode. Thus the P/T boundary event possibly differs its primary triggers of the extinction than that of the K/T boundary. Shifting of the Icehouse stage to the Greenhouse stage already occurred in middle Middle Permian time. Active volcanics of the Island arc or the continent were related to fast generation of the oceanic plate (Fig. 2) and formation of accretionary terrane and subduction, of which changes of condition and system of the ocean gave significant effect correlated to a decline or towards the extinction of the terminal Permian.

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