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An oceanic fragment in the Upper Cretaceous Miyama Formation of the Shimanto Belt, Kii Peninsula, Japan

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Abstract

An oceanic fragment comprising a complete pelagic sequence from basalt through chert to red shale was found in the Miyama Formation of the Shimanto Belt which is a typical accretion complex in Japan. The conformable sequence, from base, consists of MORB-type basalt, micritic limestone, CCH-type chert, TCH-type chert, MCH-type chert and red shale. CCH chert is alternating beds of calcareous chert and opaque-tuffaceous layers. TCH chert is non-calcareous interbedded chert with opaque-tuffaceous parting. MCH chert is bedded chert intercalated with clay parting. Radiolarian biostratigraphy confirmed that the sequence was continuous from Hauterivian-Barremian to Turonian-early Coniacian time. There also are systematic changes in geochemistry such as decreasing of negative Ce anomaly. These continuous changes of lithology might be due to the changes of depositional regime, that is, from the mid-oceanic ridge, ridge proximal regime above CCD, a slightly distant regime from the ridge, distant regime from ridge and approaching to a continent, and continental margin regime where hemipelagic sediments accumulated. The depositional regime had moved away from a mid-oceanic ridge to near a trench by ocean spreading in Paleopacific ocean. The complete sequence provides key information to reconstruct the original situations of chert and accretion complex in the Shimanto Belt.

Key words: Ashidani chert, chert, radiolaria, Ce anomaly, Miyama Formation, Shimanto Belt, Kii Peninsula, Paleopacific ocean

INTRODUCTION

The Shimanto Belt distributed widely along the Pacific coast of Southwest Japan, is one of the typical accretion complexes of the world. The strata in the Kii Peninsula have suffered less tectonic disturbance and metamorphism than those in the other districts of the Shimanto Belt. This feature is of advantage to reveal the original relationships between strata or rock masses, geologic ages and paleoenvironments. The Miyama Formation is a typical accretion complex, and contains many blocks of chert and greenstones which are interpreted as exotic in origin. In the Miyama Formation of Kii Peninsula we found a large block in which an almost complete succession from oceanic basalt to hemipelagic red shale is preserved without serious disturbance. This block offers good evidence not only of the tectonic setting of the Shimanto Belt but also of Paleopacific ocean environments.

This complete sequence was found and described first by Matsuyama (1983). Radiolarian biostratigraphy and lithology of this block were partly published in Kumon et al. (1986) and Kishu Shimanto Research Group (1986). Lithology, chemical data and their geologic meanings are fully described and discussed here.

GEOLOGIC OUTLINE

The Shimanto Belt occupies the southernmost zone of Southwest Japan, facing towards the Pacific Ocean. This belt consists mostly of accretion complexes from middle Cretaceous to early Miocene in age. The Shimanto Belt in the Kii Peninsula is divided into the northern Cretaceous belt and southern Paleogene to early Miocene belt. The Cretaceous belt is called Hidakagawa belt, and consists of the Hidakagawa Group (Fig.1). The group is subdivided, from north to south, into the Hanazono, Yukawa, Miyama, Ryujin and Nyunokawa Formations (Kumon et al., 1988).

The Hanazono Formation is Turonian to Campanian in age, and consists mostly of shale with sandstone, interbedded sandstone and shale,

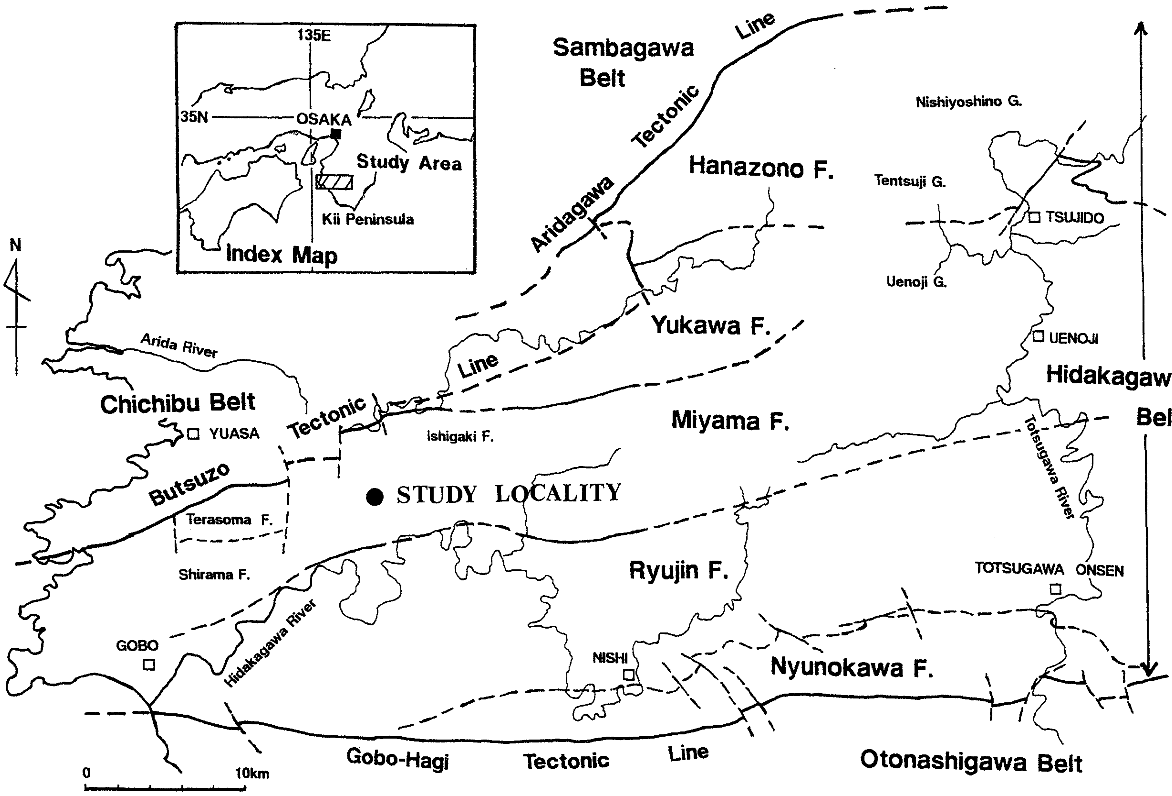

Fig.1. Geologic outline of the Hidakagawa Group in Kii Peninsula, showing the study locality.

greenstones and chert. The Yukawa Formation is Aptian to Turonian in age, and composed of thickly bedded sandstone, alternations of sandstone and shale, and shale. The Miyama Formation is Turonian to early Campanian in age, and composed mainly of sandstone, interbedded sandstone and shale, and shale with frequent intercalations of chert, greenstones and acidic tuff. The Ryujin Formation consists of bedded shale with alternating beds of sandstone and shale, thick-bedded acidic tuff and greenstones. The Nyunokawa Formation is composed mainly of sandstone, alternation of sandstone and mudstone, and conglomerate, rarely with greenstones. The Ryujin and Nyunokawa Formations are assigned to late Campanian to Maastrichtian in age, although the later may be slightly younger than the former.

Only the Hanazono and Miyama Formations contain cherts and associated greenstones. The Miyama Formation has abundant cherts and greenstones, and yields abundant radiolarian fossils from both chert and mudrocks. In contrast, the Hanazono Formation is metamorphosed more strongly than the Miyama Formation, and radiolarian fossils are poorly preserved in the formation. The Miyama Formation has two different lithologic units, “flysch” and “chert-greenstone” units. The flysch unit is composed of sandstone and interbedded sandstone and shale. The chert-greenstone unit consists of muddy sediments with abundant blocks of chert, greenstone, acidic tuff and sandstone. The genuine age of Miyama Formation is Turonian to early Campanian, although the ages of chert range from Tithonian to early Coniacian. The cherts and associated greenstones have been regarded as exotic blocks in olistostromes (Nakazawa et al., 1983; Kumon et al., 1988).

LITHOLOGY OF THE CHERT SEQUENCE

There are many basalt and chert blocks in the Miyama Formation. We have investigated many cherts in the chert-greenstone units of the Miyama Formation, referring to their lithology and radiolarian age, and found almost a complete chert sequence at Ashidani in Nakatsu-mura, Wakayama Prefecture (Fig.1). Along the small valley, the sequence from basalt to red shale can be recognized as shown in Fig.2. The basal part is slightly altered green basalt with pillow texture. On the top of the basalt, micritic limestone rests conformably. The chert has three different lithology, that is, calcareous chert with tuffaceous and/or opaque parting (CCH chert), non-calcareous chert with tuffaceous and/or opaque parting (TCH chert), and relatively pure chert with clay parting (MCH chert). Three types of chert, CCH, TCH and MCH overlie successively. Red shale also lies on the MCH chert conformably. Although there exist a minor fault near the boundary of both lithology, the transitional relationship can be confirmed at eastern end of boundary.

Basalt

Basalt is dark green in color. It has pillow structure, and includes small limestone blocks among pillow blocks near the top of basalt layer as interpillow limestone. Massive basalt is observed in an outcrop separated 10 meters below this pillow basalt. These basalts have intergranular or intersertal texture. Mafic minerals are generally altered to clay minerals.

Limestone

Laminated limestone, 20 to 30 cm thick, overlies conformably the pillow basalt (Fig.2). The limestone is gray white to pinkish brown with thin intercalatins of brownish dark red. The limestone is micritic and contains hematitic pigments. Dark brownish red layers are composed of abundant opaque minerals such as hematite, and is similar to the black opaque parting of the overlying CCH chert. Lower part of this lithology is white in color and is relatively pure limestone, but upper part is pinkish brown, and has abundant hematitic pigments. Limestone layers become thin in the upper part of this limestone formation.

CCH chert

CCH consists of red bedded chert and reddish black opaque layers. Bedding planes are often irregularly wavy, and beds are cut by minor faults in places. This lithology rests on the laminated limestone conformably as shown in Fig.3 Sketch A. It is 8 meters thick.

Chert beds of CCH are brownish red, and 2 to 10 cm thick. Chert is composed of minor radiolarian tests and abundant interstitial matrix. The matrix is cryptocrystalline to microcrystalline quartz associated with minute brownish impurities and cryptocrystalline carbonate. Radiolarian tests are 0.1 to 1 mm in diameter and scattered sporadically among the matrix. They are composed of mosaic microcrystalline quartz slightly larger than the quartz crystals of matrix. Some tests are elongated parallel with bedding. Brownish impurities are much abundant in the interstitial matrix and are almost absent in the tests. XRD analysis indicates the presence of hematite and calcite. Chlorite fills the cavities of a few tests. The ratio of radiolarian test to interstitial matrix is fairly variable, but usually less than that in chert beds of the overlying TCH and MCH cherts.

Opaque layers are a few to several centimeters thick, rarely attain to 10 cm or more, and reddish black in color. They are composed mostly of small opaque minerals. The opaque minerals look brownish red in very thin sections, and white gray in reflection light. XRD analysis of the layers indicates the presence of hematite. The opaque

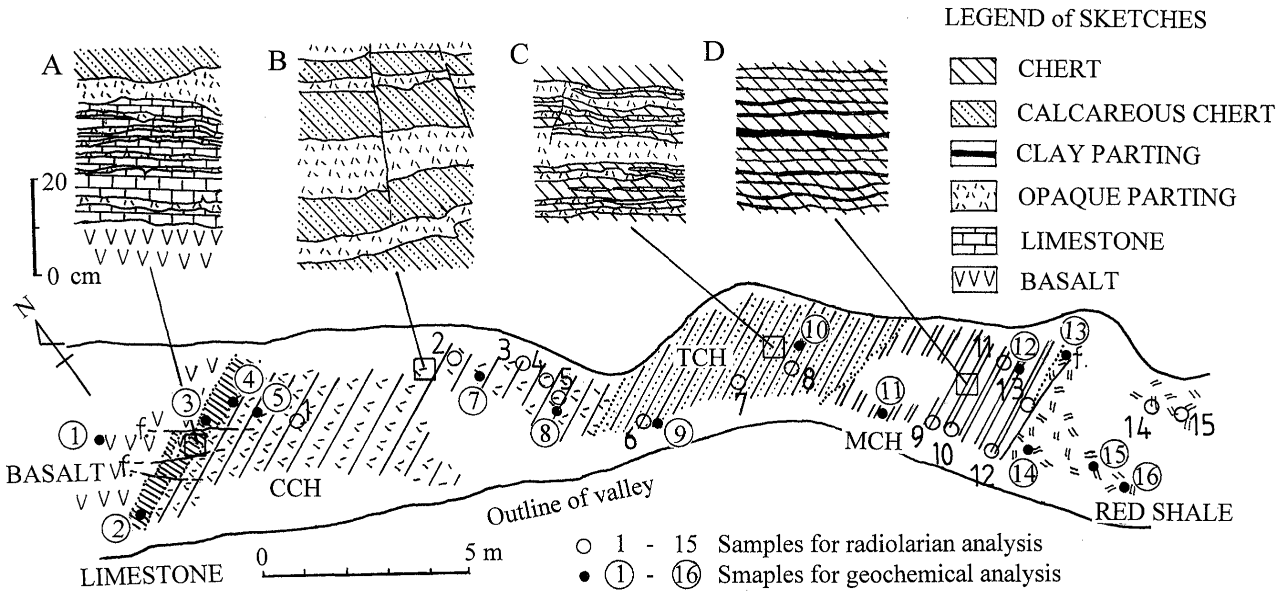

Fig.2. Sketches of outcrop showing a complete sequence from basalt to red shale at Ashidani in Nakatsumura, Wakayama Prefecture, Japan. Nos. 1 to 15 are for radiolarian samples and ① to ⑯ (lack ⑥) are for geochemical samples.

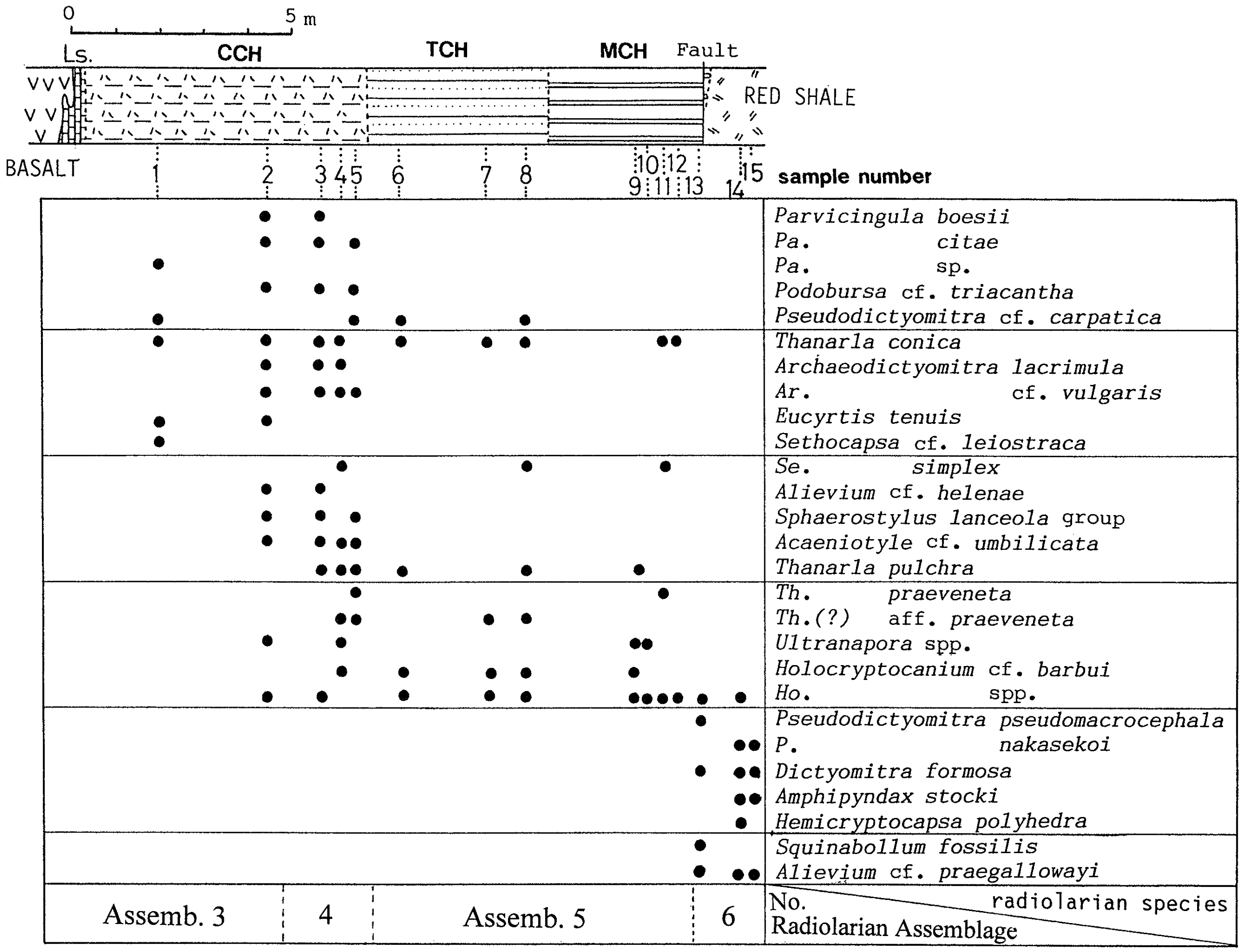

Fig.3. Radiolarian occurrence and its list from the basalt to red shale sequence. Radiolarian assemblages are as follows (after Kumon et al., 1986).
Assemblage 3: *Eucyrtis tenuis* Assemblage(Hauterivian to Barremian),
Assemblage 4: *Acaeoniotyle umblicata* Assemblage(Aptian to early Albian),
Assemblage 5: *Holocryptocanium barbui* Assemblage(late Albian to Cenomanian),
Assemblage 6: *Dictyomitra formosa* Assemblage(Turonian to early Coniacian)

layers in CCH are often calcareous, and foraminifer and coccoliths can be seen among opaque minerals. A part of opaque layers contain abundant plagioclase and basaltic fragments, and form thin layers or laminae. The fragments are mostly silt to fine-grained sand size, and plagioclase are of rectangular to irregular shape. Opaque stringer texture similar to iron rich stringer of Nisbet and Price (1974) is sometimes observed under microscope.

The euhedral shape of some plagioclase grains, abundant basaltic rock fragments and no terregenous grains such as quartz suggest that the detritus in the opaque layers was derived directly from a site of volcanism. Opaque minerals also seem to be formed with some relation to the submarine volcanism under oxidizing condition. Therefore, we regard the opaque layer(parting) as tuffaceous layer(parting) or lamina.

TCH chert

TCH is mostly reddish in color, and consists of bedded red cherts and dark red partings. Chert is composed of radiolarian tests and interstitial matrix. Radiolarian tests are abundant and range from 0.1 to 1 mm in diameter. The matrix consists of cryptocrystalline to microcrystalline quartz and a lot of minute impurities. Carbonate is very rare or absent. The impurities are mostly hematitic or other iron materials. Clay minerals such as illite are also contained in a very small amount, increasing upward. The thickness of chert layers is 0.5 to 2 cm, thinner than that of CCH chert.

Parting layer of TCH is dull dark red or reddish black in color. It is composed mainly of small iron-bearing opaque minerals with a small amount of clay minerals. The opaque minerals in the parting seem to be mostly hematite, because they look same as opaque minerals in the parting of CCH and XRD analyses indicate hematite peak. In places parting layers contain abundant radiolarian tests as laminae. They are similar to the opaque layers of CCH, but lack calcareous fragments. Tuffaceous laminae of plagioclase and basaltic fragments are also common in the parting of TCH. The parting layers are 1 to several centimeters in thickness, and occasionally thicker than chert layers. The thickness of chert and parting layers often varies laterally, and they show wavy bedding. The total thickness of TCH is about 5 meters.

MCH chert

MCH is thinly bedded red chert with red clay parting, and is 4 meters thick. Chert is composed mainly of abundant radiolarian tests and interstitial matrix of cryptocrystalline to microcrystalline quartz. Radiolarian tests are abundant. Impurities such as ironic pigment and clayey materials are scattered in the matrix, but are almost absent in radiolarian tests. The thickness of chert beds is 1 to 3 cm. The lower boundary is sharp, and radiolarian tests are concentrated in the lower part of the bed. In the upper part of the bed, ratio of radiolarian test decreases, and chert gradually changes to clay parting.

Clay parting is 2 to 10 mm thick, and consists mostly of iron-bearing materials and clay minerals such as illite. Some iron-bearing materials are hematite, but its amount is much reduced, compared with the partings of CCH and TCH, on the basis of XRD analysis. Minute detrital grains of quartz and plagioclase are rarely contained in the parting. Dark brown stringers which are almost same as iron rich stringer of Nisbet and Price (1974), are developed well in the parting and poorly in the upper part of chert bed. The stringers run parallel or subparallel to bedding planes, and often form an elongate braided texture.

Red shale

Dull red shale lies conformably on the MCH chert. It consists mostly of clay minerals such as illite and reddish iron-bearing materials, associated with minor, very small grains of quartz and feldspar. Although some reddish iron-bearing materials are scattered sporadically in a matrix, most of them are concentrated as dark brown or opaque stringers. Red shale is similar to the clay parting of MCH, but stringers are less concentrated than those of MCH parting.

RADIOLARIAN BIOSTRATIGRAPHY

Extraction of radiolarian fossils was attempted from the chert and other sedimentary rocks, using dilute HF acid, resulting in fifteen specimens which contain fairly well-preserved radiolarians. The species identified are listed in Fig.3.

Radiolarian fossils from CCH are characterized by *Parvicingula boesii*, *P. citae*, *Podobursa* cf. *triacantha*, *Archaeodictyomitra lacrimula*, *A.* cf. *vulgaris*, *Eucyrtis tenuis*, *Sphaerostylus lanceola* group, *Acaeniotyle* cf. *umbilicata* etc. They confidently indicate late Early Cretaceous age. The lower and middle parts of CCH are relatively poor in radiolaria, but specimens from Nos. 1 and 2 are differ from the specimens of upper part by the presence of *Eucyrtis tenuis* and *Sethocapsa* cf. *leiostraca*. These species enable us to assign the radiolarians to *Eucyrtis tenuis* Assemblage of Kumon et al.(1986). *E. tenuis* Assemblage is regarded as Hauterivian to Barremian age.

The radiolarians from the upper part of CCH chert lack *Eucyrtis tenuis*, and contain *Acaeniotyle* cf. *umbilicata* and *Thanarla pulchra*. This difference seems to mean that the radiolarian assemblage in the upper CCH is part of the *Acaeniotyle umbilicata* Assemblage of Kumon et al. (1986) which corresponds with Aptian to early Albian in age.

Radiolarian fossils of TCH and MCH cherts are poorly preserved, and only a few species could be identified. *Thanarla conica*, *T. pulchra*, *T.* cf. *praeveneta* and *Ultranapora* spp. suggest middle Cretaceous age. Large globular nasselarians similar to *Holocryptocanium barbui* and its varieties, are abundant. Thus, we can tentatively recognize the radiolarian assemblage as *Holocryptocanium barbui* Assemblage (Kumon et al., 1986). The *H. barbui* Assemblage is assigned to late Albian to Cenomanian in age.

Radiolarians in the uppermost part of MCH chert and red shale are well preserved, and characterized by *Pseudodictyomitra pseudomacrocephala*, *P. nakasekoi*, *Dictyomitra formosa*, *Hemicryptocapsa polyhedra*, *Squinabollum fossilis*, and *Alievium* cf. *praegallowayi*. Based on these species, these radiolarians are confidently assigned to *Dictyomitra formosa* Assemblage of Kumon et al. (1986). This assemblage corresponds with Turonian to early Coniacian age.

On the basis of radiolarian biostratigraphy, this chert sequence and overlying red shale represent a continuous sequence from Hauterivian-Barremian to Turonian-early Coniacian age without substantial breaks. It is noteworthy that the sedimentation rate of the chert is very low, about 0.4mm/1000y on average, compared with Early

Cretaceous chert of Franciscan Complex (1mm/1000y; Murray et al., 1991) and Triassic and Jurassic chert of Tanba Belt (1 and 2.8 mm/1000y, respectively: Matsuda et al., 1980, Hori et al., 1993).

GEOCHEMISTRY OF THE CHERT SEQUENCE

Major and trace elements of basalt, limestone, CCH chert, TCH chert, MCH chert and red shale were analyzed by XRF and INAA(Instrumental Neutron Activation Analysis). The number of samples analyzed are 1, 3, 3, 2, 2 and 4 respectively. XRF analysis was carried out by using the JEOL JSX-60S7 system of Shimane University and INAA was carried out under the Visiting Researcher's Program of Research Reactor Institute, Kyoto University.

Basalt

Major chemistry of the basalt lava shows affinities with ocean tholeiite, similar to other basalts in the Miyama Formation(Y. Miyake and F. Kumon, unpub. data). Based on discrimination diagrams of rare earth elements, this basalt plots in N-MORB or ocean floor basalt as shown in Fig. 4. Zr-Zr/Y diagram by Pearce and Norry (1979) also shows oceanic-floor basalt, although it is plotted in IAT(island-arc tholeiites) area near MORB on the TiO_2-MnO-P_2O_5 diagram by Mullen (1983). The chondrite-normalized REE pattern and the spider diagram normalized to N-MORB also indicate slightly enriched MORB characters (Fig.5). Therefore, this basalt can be regarded as enriched N-MORB.

Sedimentary rocks

Sedimentary environments were evaluated from geochemical characteristics, that is, NASC-normalized REE pattern diagram (Fig.6) and average comparison diagram (Fig.7) normalized by PAAS (Post Archean Australian Shale).

REE patterns of micritic limestone show distinc-

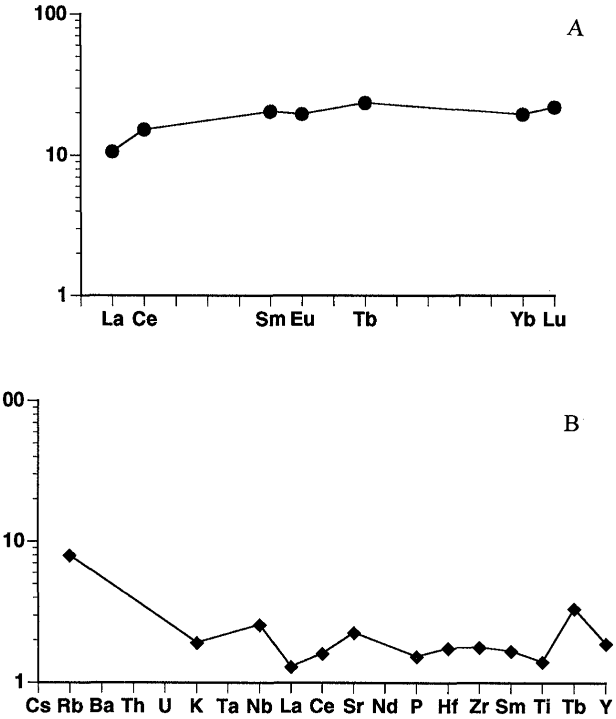

Fig.5. Chemical characters of the basal basalt on two diagrams A: Spider diagram normalized by chondrite according to Wood et al. (1979), B: REE pattern diagram normalized by N-MORB.

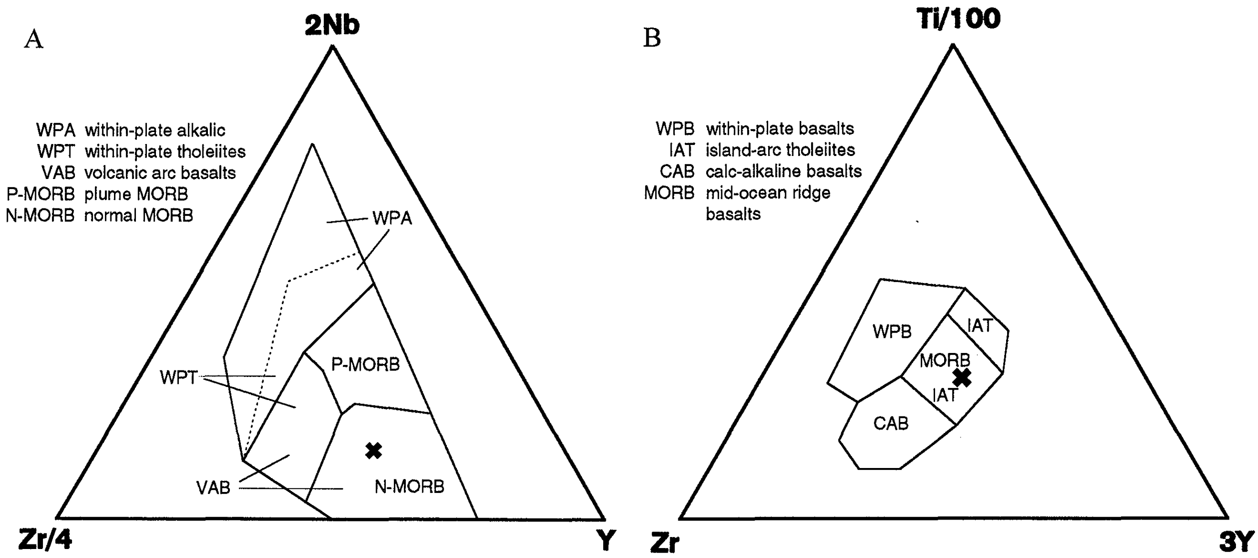

Fig.4. REE characters of the basal basalt on discrimination diagrams. A: Nb-Zr-Y diagram according to Meschede (1986), B: Ti-Zr-Y diagram according to Pearce and Cann (1973).

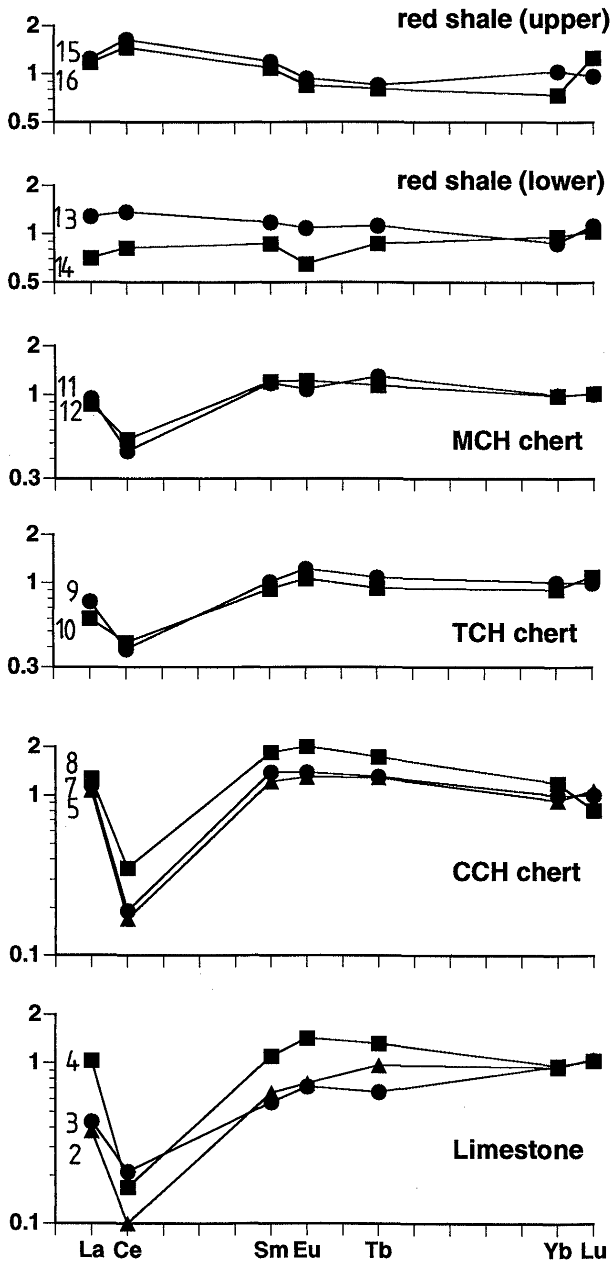

Fig. 6. REE pattern diagrams normalized by NASC (North American Shales Composite). Each normalized REE value is recalculate (Yb* + Lu*)/2 to unity for the convenience of comparison.

tively negative Ce anomaly (Ce/Ce*=0.26) and depletion of light rare earth elements (LREEs). Those patterns closely resemble that of sea water, and strongly suggest a hydrothermal effect. CCH cherts, the lower part of chert sequence, also have large negative Ce anomaly (Ce/Ce*=0.18). CCH chert, about 7 m thick, is similar to the chert of Franciscan Complex which shows large negative Ce anomaly and was assigned to ridge influenced regime (Murray et al., 1991). CCH chert and limestone are clearly enriched in Fe, Mn, (Ca), P, Ni, Zn, Y and REEs except Ce (Fig.7). Arsenic is also enriched in CCH chert, which is not shown in the figure. Those elements except Ca are usually enriched in hydrothermal metalliferous sediment. Depositional regime of those sedimentary rocks is undoubtedly assigned to the proximal ridge.

TCH and MCH cherts, middle and upper parts of chert sequence, show moderately negative Ce anomaly (Ce/Ce*= 0.55 and 0.5 respectively) and are enriched slightly in Mn, P, Ni, Y and REEs. Those cherts are assigned to oceanic basin floor sediment of Murray et al. (1991) which is distinguishable from oceanic ridge and continental margin sediments. Partly owing to a small number of analyses, negative Ce anomaly and enrichment factor do not show clear systematic changes through TCH and MCH cherts.

Red shales are depleted in alkaline earth elements (Ca, Sr and Ba) and slightly enriched in Mn. A slight positive Ce anomaly is detected in these shales. The upper part of the shale sequence is more positive than the lower part. Murray et al. (1991) assigned chert with zero or positive Ce anomalies to continental margin regime.

Lithological change from chert to shale and chemical characteristics of red shale indicate that the depositional regime moved to near a continent. Positive Ce anomaly implies the chemical condition of ancient sea water, although Murray et al. (1991) did not refer to it. In modern pelagic sediments, only NW Atlantic deep sea sediment shows positive Ce anomaly (Thomson et al., 1984). It reflects the higher Ce concentration in northern part of Atlantic sea water than those of other oceans. Musashino (1990) suggested that the positive Ce anomaly of chert and siliceous shale of Triassic and Jurassic age in Tanba Belt, Japan indicated the cerium-rich sea water of Panthalassa (Paleopacific) ocean. Positive Ce anomaly of the red shale of Turonian age identified in this article together with the Early Cretaceous chert of Franciscan Complex (Murray et al., 1991) may indicate that Ce-rich Paleopacific sea water persisted until Late Cretaceous time.

INTERPRETATION OF BASALT-CHERT SEQUENCE

The successive change of lithology from basalt to red shale as mentioned above is a result of systematic change of sedimentary environment of the depositional site. One reasonable interpretation for this change is proposed as follows (Fig.8).
Basalt lava flowed out in a mid-oceanic ridge in Hauterivian-Barremian time or slightly before Hauterivian time. The depth was shallower than CCD, but not so shallow as neritic condition. Calcareous sediments such as coccolith and plankto-

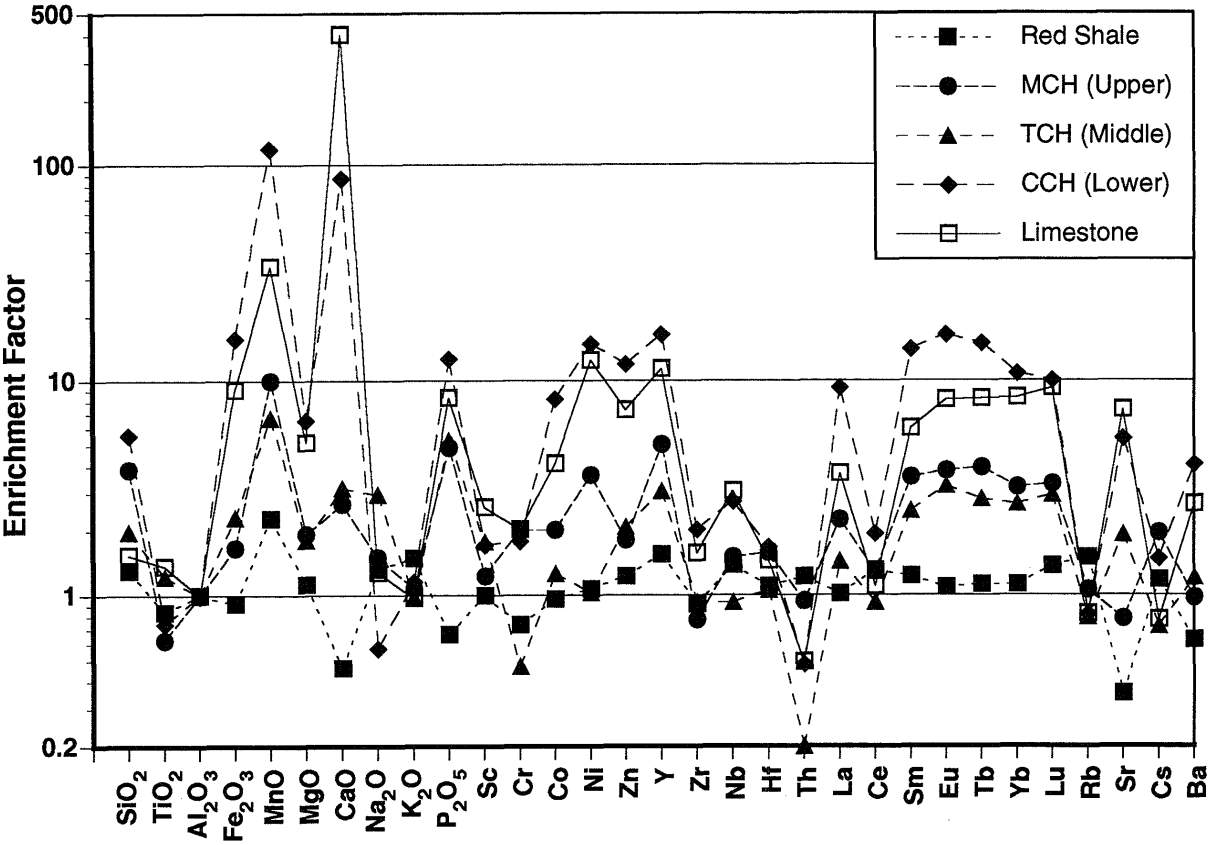

Fig. 7. Average comparison diagram normalized by PAAS (Post Archean Australian Shale). Each value of element indicates enrichment factor compared to aluminum.

nic foraminifer tests deposited and formed pelagic limestone. The depth of the depositional regime increased gradually, and the mixture of radiolarian tests and calcareous fragments of various origins accumulated on the limestone during Hauterivian to early Albian time. Submarine volcanism took place at the oceanic ridge and affected the depositional regime. Volcanic debris with hematitic opaque minerals were supplied to the regime intermittently, and formed opaque and tuffaceous partings. Hydrothermal activity also influenced the sediments near the site of volcanism.

The depositional regime became deeper than CCD probably in late Albian time. After then, only siliceous materials such as radiolarian tests accumulated, because calcareous detritus dissolved completely to sea water. Volcanism in the mid-oceanic ridge still affected the depositional regime, supplying tuffaceous and hematitic opaque detritus. TCH chert was formed under these environments.

The depositional regime became distant from the mid-oceanic ridge, and free from the influence of submarine volcanism probably in Cenomanian time. On the other hand, the terrigenous materials such as illite increased gradually, probably being due to the approach of deposition regime to a continent. These conditions resulted in the clay content in chert and clay partings of MCH chert.

Red shale is characterized by a small amount of terrigenous clastics such as quartz and feldspar of minute size, and can be regarded as hemipelagic sediments. This reflects approaching of the depositional regime to a continent, and the influence of acidic to intermediate volcanism on land and sediment supply from continental land.

These changes from basalt to red shale were caused by ocean floor spreading and systematic changes in sedimentary environments. In fact, many cherts in the Miyama Formation have any of these three lithologic types of chert, but a complete succession is rarely found. Cherts are often faulted and folded, and lack well preserved radiolarian evidences. Thus, this chert sequence offers a key to reconstruct the origin of the chert sequence.

Recent radiolarian biostratigraphy on the Shimanto Belt elucidated that cherts in the Cretaceous Shimanto belt were mostly Early Cretaceous in age, and their ages were older than the surround-

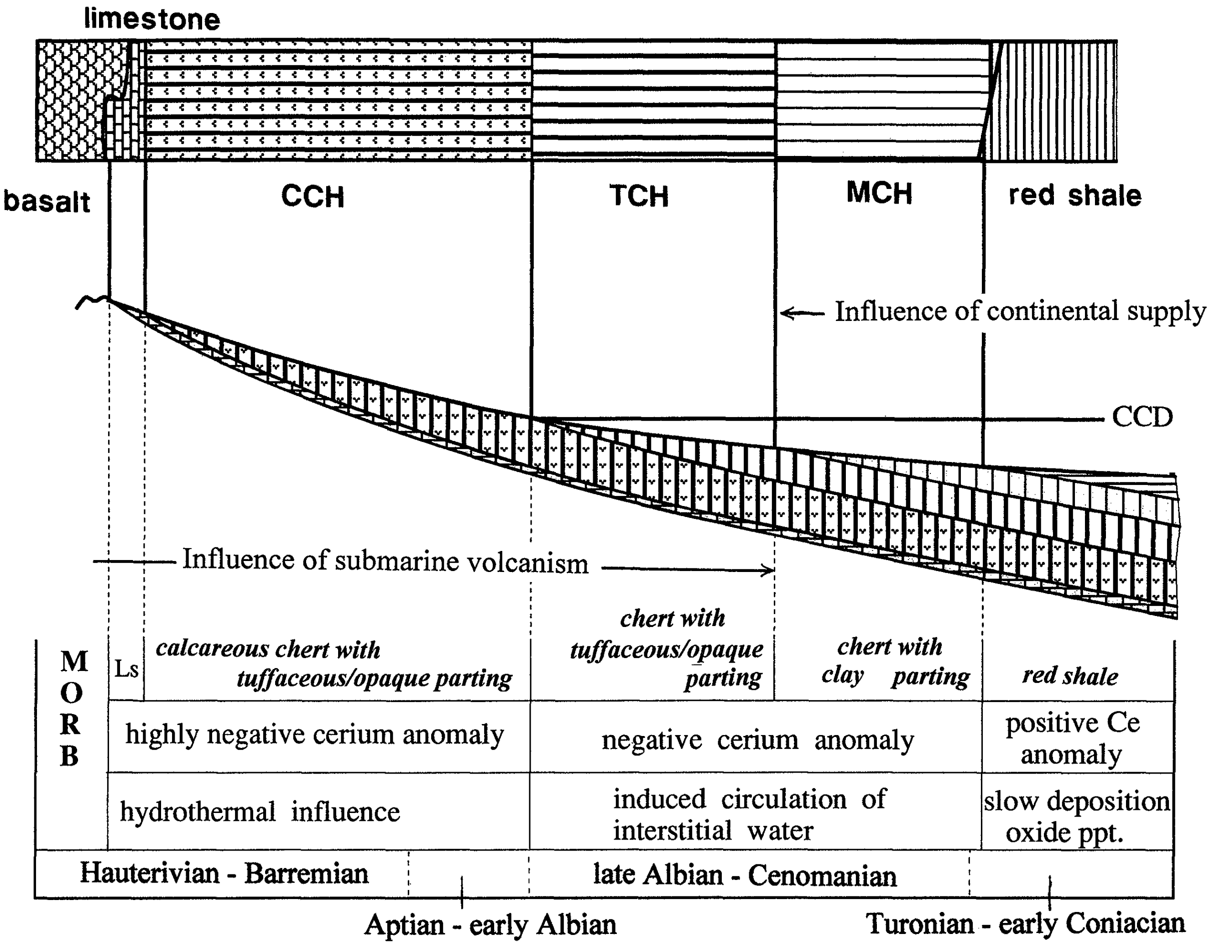

Fig.8. Reconstruction of depositional regimes of the basalt-chert-red shale sequence.

ing muddy clastic sediments (Nakaseko et al., 1979; Taira et al., 1980; Matsuyama et al., 1981; Matsuyama, 1983). Detailed field observation and radiolarian study revealed that cherts and associated basalts were exotic blocks of various sizes in muddy rocks (Nakazawa et al., 1983; Kishu Shimanto Research Group, 1986). The strata of the Miyama Formation are faulted and complexly folded in places, and form an imbricated structure as a whole. Therefore, the strata which were interpreted formerly as eugeosynclinal sediments, are regarded as a typical accretion complex now. The accretion complex is formed in a subduction zone where oceanic plate subduct under a continental or island arc crust. The sequential changes of depositional regime elucidated in chert sequence are important also to depict the history of subduction tectonics, because the cherts and associated basalts represent oceanic and pelagic components, contrasting with terregenous clastic sediments derived from a continental side.

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（要　旨）

Kumon, F., Matsuyama, H. and Musashino, M., 1997, An oceanic fragment in the Upper Cretaceous Miyama Formation of the Shimanto Belt, Kii Peninsula, Japan. *Mem. Geol. Soc. Japan*, No. 48, 100-109.（公文富士夫・松山尚典・武蔵野実，1997，紀伊半島四万十帯，上部白亜系美山層中に見いだされた海洋地殻断片．地質学論集，No. 48, 100-109）

MORB 型の玄武岩から，ミクライト質石灰岩・層状チャートを経て，半遠洋性の赤色泥岩にいたる連続的な遠洋性堆積物の重なりが，紀伊半島の上部白亜系美山層中に見いだされた．チャートは，下位から CCH，TCH，MCHの３つのタイプに岩質上細分される．CCH 型は，石灰質チャートと不透明鉱物に富む凝灰質層との互層であり，TCH 型は非石灰質のチャートと不透明鉱物に富む凝灰質層と互層である．MCH 型は非石灰質チャートと粘土鉱物を主体とする泥質薄層との繰り返しである．これらの重なりは，放散虫化石の検討により，Hauterivian-Barremian から Turonian-early Coniacian にかけての連続した堆積物であることが確認された．また，化学組成の検討から，Ce の負異常が系統的に減少していくことも認められた．このような岩質および化学組成の系統的な変化は，もともと中央海嶺付近にあった堆積場が，古太平洋の海洋拡大によって徐々に中央海嶺から離れ，水深を増加させて CCD よりも深くなり，かつ，徐々に陸域に近づいていった過程を反映したものと解釈される．この遠洋性の重なりをもった海洋地殻の断片は，四万十帯堆積物の起源や付加過程の解明に重要な情報をもたらすものである．