Collapse and accretion of ancient seamounts : a Jurassic example from the Mino terrane, the Suzuka Mountains, central Japan

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https://doi.org/10.11501/3075545

出版情報：九州大学, 1993, 博士（理学）, 論文博士
バージョン：

VI. Structural relationship between Permian oceanic rocks and Jurassic terrigenous sediments

The central part of the mapped area is occupied by the oceanic rocks of the Suzuka unit (Fig. 2). The Jurassic terrigenous rocks of the Hikone unit are extensive in the eastern and western parts of the area and also occur totally surrounded by the Suzuka oceanic rocks. The Permian oceanic rocks are locally mingled complexly with the Jurassic terrigenous rocks. This complicated structural relation of the Permian oceanic rocks to the Jurassic terrigenous rocks plays a key role for understanding the accretion mechanism of the Permian oceanic rocks.

The Suzuka and Hikone units in the central part of the mapped area are at many places in fault contact with each other. Their boundaries can be traced as thrust faults which run north-south. The boundary thrust faults along the eastern and western margins of the Suzuka unit are gently dipping to the west and east, respectively (Fig. 3). Although the blocks of the diverse oceanic rocks are completely chaotically distributed inside these two thrust faults, the Hikone rocks tectonically overlain by the Suzuka oceanic rocks have the east-west structural trend, as represented by the direction of the scaly cleavage of black mudstone and by the preferred orientation of longer axes of lenticular-shaped rock-bodies of siliceous rocks and sandstone embedded in black mudstone. The structural trend of the Hikone rocks is notably oblique with high angles against the two thrust faults.

In spite of the fact that the two units are in fault contact with each other at present, their primary relationship can be recognized on the basis of unsheared, block-in-matrix contact at a few outcrops. Though less extensive and frequent, significant is the

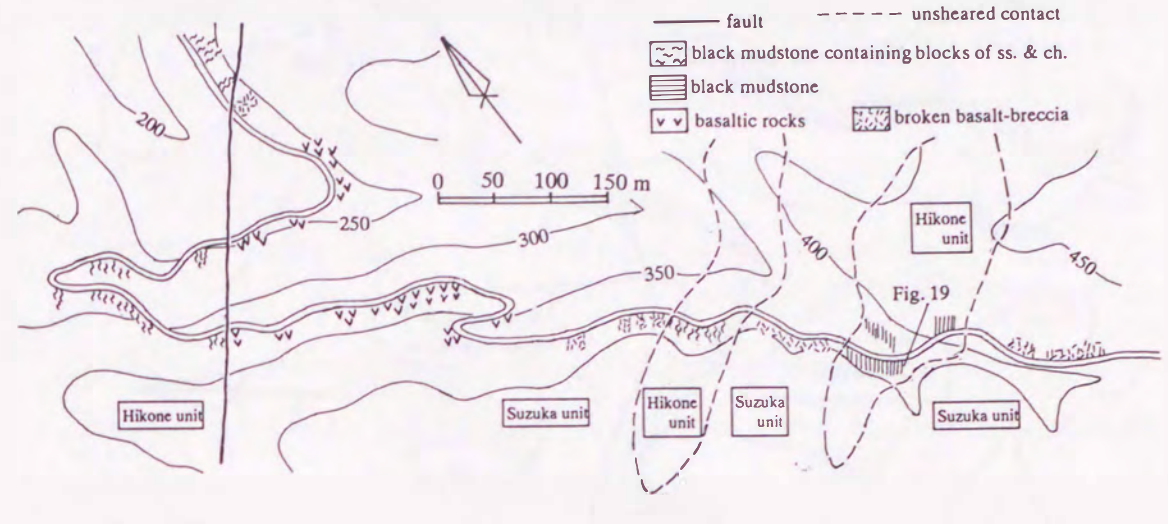

Fig. 18 Field map showing the narrow exposures of the Hikone unit within the Suzuka unit area. Locality is shown in Fig. 6.

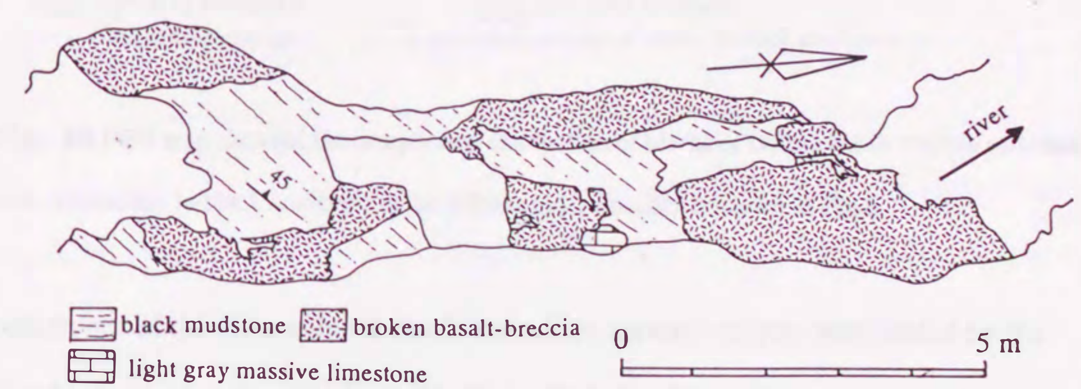

Fig. 19 Complicate intermixing of black mudstone and broken basalt-breccia at the boundary between the Hikone and Suzuka units. Locality is indicated in Fig. 18.

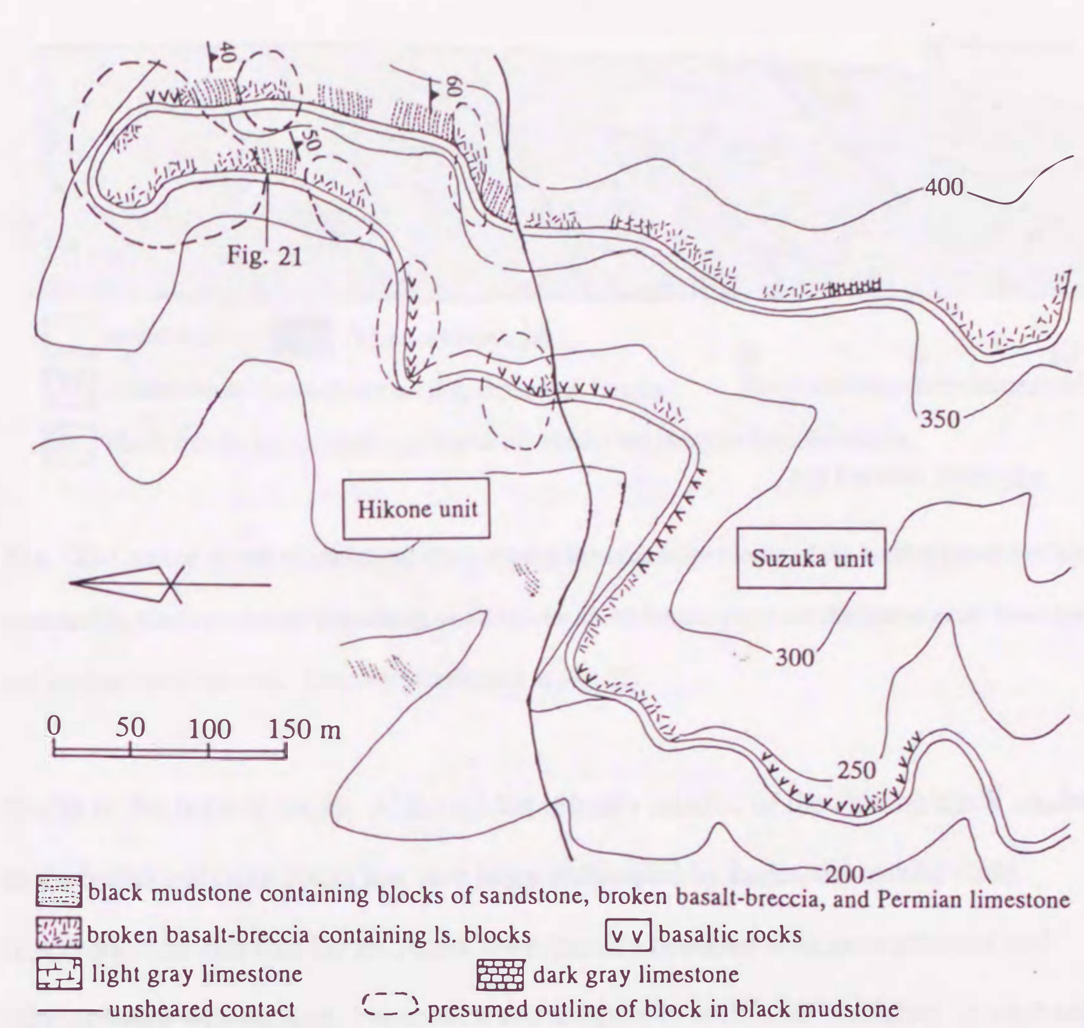

Fig. 20 Field map showing the complicated distribution of blocks of broken basalt-breccia and basaltic rocks embedded in black mudstone in the Hikone unit. Locality is shown in Fig.6.

occurrence of the Hikone black mudstone which appears entirely surrounded by the Suzuka oceanic-rocks (Figs. 18, 19; Plates 20A ,B). The Hikone black mudstone at a few localities crops out as laterally discrete and narrow, elongated lens-shaped intercalations within the Suzuka oceanic rocks. The intercalations can be traced at most for 1 km and are commonly less than a few tens of meters wide. The intercalations are irregularly exposed and randomly oriented with no structural trend. The black mudstone occurring as the tracts within the Hikone oceanic-rocks has a small amount of isolated

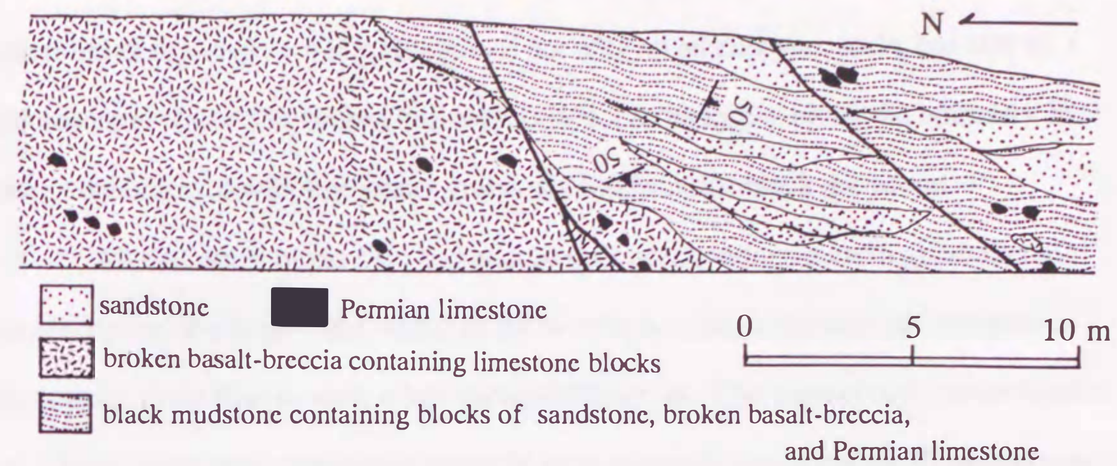

Fig. 21 Outcrop sketch of unsheared wavy contact between large blocks of the broken basalt-breccia and surrounding black mudstone containing small blocks of sandstone, Permian shallow-marine limestone, and broken basalt-breccia. Locality is indicated in Fig. 20.

blocks of the oceanic rocks. Although the primary relation of the Hikone black mudstone to the Suzuka oceanic rocks has been often obliterated by faults, the careful field observation reveals that the two units are primarily bounded with an unsheared and lithologically well defined, but uneven and irregularly undulated boundary by each other.

The Hikone black mudstone locally contains isolated blocks of the Suzuka oceanic rocks (Figs. 20, 21; Plates 20C, D). The blocks comprise the Permian shallow-marine limestone, basaltic rocks having the destruction fabrics of various styles, and Jurassic chert. The blocks are laterally discrete, isolated, and elongate lens-shaped. Their size ranges from a few centimeters to a few tens meters. These blocks of Permian and Jurassic oceanic rocks are wholly embedded in a matrix of the Hikone black mudstone. In addition to the occurrence of the Suzuka oceanic-rock blocks entirely enclosed in the Hikone black mudstone, significant for the consideration of the primary relationship between the two units is a complicated intermixing of the Hikone black mudstone and Suzuka broken basalt-breccia along their unsheared boundary. The intermixing of the materials is recognized not only on an exposure scale, but also on a microscopic scale. The broken basalt-breccia, for an example, along the boundary has been contaminated with fine quartz grains derived from the black mudstone.

All the results of the field and microscopic examinations mean a gravitational emplacement of a large-sized wedge of the Suzuka oceanic rocks onto the terrigenous sediments of the Hikone unit, when unconsolidated yet. The Suzuka unit can be labeled as a large-sized exotic rock-body comprising an aggregate mainly of the Permian oceanic rocks displaced down onto and locally intermixed with the Jurassic terrigenous rock of the Hikone unit.

VII. Discussion

A. Reconstruction of depositional setting of Permian oceanic rocks

The microscopic examination as well as the field observation indicates that no coarse terrigenous clastic grains are contained in the Permian oceanic rocks of the Suzuka unit. It is not that terrigenous rocks laterally and vertically pass into the Permian oceanic-rock successions. The total lack of coarse terrigenous clastic materials in the Permian succession means their accumulation in an open-ocean realm far beyond an input of coarse land-derived materials.

The Permian oceanic rocks of the Suzuka unit were subdivided into the four successions characterized by basaltic rocks, shallow-marine limestone, allochthonous limestone, and chert, respectively. The age of the basaltic rock succession though not dated, is best referable to the Early Permian, for related basaltic rocks occur in the middle Lower Permian part of the shallow-marine limestone succession.

1. Shallow-marine limestone succession

The shallow-marine limestone succession is similar in the lithostratigraphy to the Funabuseyama and Amanokawara Formations in the Funabuseyama area (Sano, 1988a), Horikoshitoge and Akuda Formations in the Hachiman area (Horibo, 1990), and Nabeyama Formation in the Kuzuu area (Kobayashi, 1976). All of these rock-units are exposed as large-scaled masses setting in the Mino terrane and its equivalent. In spite of the fact that the shallow-marine limestone succession differs in age from these rock-units, the lithologic affinity means their similarity in the depositional setting.

The lithostratigraphy of the Funabuseyama, Horikoshitoge, and Nabeyama Formations is summarized as follows; well bedded, organic matter-rich lime-wackestone and packstone in the lower and massive to thick-bedded, partly dolomitized lime-packstone and grainstone in the upper. All these bioclastic limestones are rich in diverse shallow-marine skeletal debris. According to the facies interpretation by Sano (1988a) and Horibo (1990), the lower and upper units are referred to sediments in a quiet, poorly water-circulated, stagnant, lagoonal mud flats and sediments in sand bars to shoals and lagoonal mud flats with a higher water-energy, all sitting on a carbonate bank at shallow water-depth, respectively. The lithostratigraphy of these successions is interpreted to represent an environmental change on shallow-marine carbonate banks. The environmental change is best expressed as an upward-increase of the water energy on a carbonate banks upon a seamount.

The lithostratigraphy of the lower and middle members of the Suzuka shallow-marine limestone succession is comparable with that of the entire successions of Funabuseyama, Horikoshitoge, and Nabeyama Formations. The lower and middle members of the Suzuka shallow-marine limestone succession comprise bedded, carbonaceous lime-mudstone and wackestone rich in mollusks and algae and massive packstone and grainstone dominated by fusulines, crinoids, and algae and characterized by oolitic grains. The similarity of the Suzuka shallow-marine limestone succession in the lithostratigraphy to the Funabuseyama, Horikoshitoge, and Nabeyama Formations implies the similar trend of the environmental change. An increase in the water energy going upsection is considered to be the trend of the environmental change common throughout the Permian shallow-marine carbonate succession having a bank-top of the Mino terrane.

The rock-associations of the Amanokawara and Akuda Formations are characterized by talus deposits of limestone-breccia. Clasts of the limestone-breccia are polymictic, comprising diverse types of shallow-marine limestone. Sano (1989a) and Horibo (1990) interpreted the Amanokawara and Akuda Formations to be sediments in a marginal terrace to upper slope of a carbonate bank on a seamount, respectively.

Lithologically comparable with the Amanokawara and Akuda Formations is the upper member of the Suzuka shallow-marine limestone succession. Its major component is limestone-breccia comprising polymictic limestone-clasts of diverse types of shallow-marine limestone.

With an emphasis upon the lithologic affinity to the previously described rock-units of the Mino terrane, the lithostratigraphic and microscopic examinations lead the author to a facies interpretation of the Suzuka shallow-marine limestone succession. The rocks of its lower and middle members are assigned to deposits which accumulated on a carbonate bank, where lagoonal mud flats with low water-energies and sand bars and shoals with higher energies were included. Limestone-breccia of the upper member is referred to as limestone talus deposits in an upper slope of the carbonate bank.

2. Allochthonous limestone succession

The rock-unit of the allochthonous limestone succession is peculiar to the Suzuka unit. No comparable rock-unit has been known in the Mino terrane and its equivalent.

All the rocks of the allochthonous limestone succession have reworked fabrics. On the basis of resedimentation processes inferred by the predominant sedimentary structure and fabric, the reworked carbonates and basaltic sediments are divided into three major groups; sediments redeposited chiefly by turbidity flows, sediments displaced mainly by debris flows and grain flows, and isolated blocks transported as rock-fall deposits.

Sediments redeposited by turbidity flows include limestone-sandstone and reworked lime-mud and packstone. These sand- to silt-grained calcareous sediments are characterized by the common graded bedding and parallel lamination. Volcaniclastic mudstone usually associated with these graded carbonate rocks are also interpreted to have been redeposited by dilute turbidity flows (Coniglio and James, 1990).

Limestone-basalt-conglomerate is best interpreted to be debris flow deposits. Their common diagnostic sedimentary fabrics are the completely disorganized and densely packed clast-fabric, totally unsorted clast-size, and total absence of graded structures. It is noted that the absence or scarcity of a lime-mud matrix in limestone-basalt conglomerate is considered to have resulted from the dissolution of lime-mud by a strong pressure-solution effect.

Limestone blocks of the upper member of the allochthonous limestone succession are rock fall deposits which were transported by free fall or rolling of individual talus blocks into reworked carbonates and basaltic sediments of several kinds. The polymictic clast-type of the blocks implies their different source areas, including a lagoonal mud flat, sand bar and shoal, bank margin.

All the reworked limestone particles of the allochthonous limestone succession are best interpreted to have been derived from the time-equivalent Permian shallow-marine limestone succession by mass-gravity transportation, including rock falls, debris flows, grain flows, and turbidity flows. With an emphasis upon the particle transportation most possibly from the Permian shallow-marine limestone succession, the high angularity of the reworked limestone particles, and the total absence of deep-marine biotas in the Permian allochthonous limestone succession, its most possible depositional site is assigned to an upper slope of a carbonate bank, on the top of which the shallow-marine limestone accumulated.

3. Chert succession

Lithologically comparable with the Suzuka chert succession are the Hashikadani Formation (Sano, 1988a) and Shimadani Formation (Horibo, 1990). Both of the rock-units occur in close association with the Permian shallow-marine carbonate units of the Mino terrane.

The chert sections of both of the Hashikadani and Shimadani Formations are composed of ribbon-bedded radiolarian chert with intercalations of dolomite breccia and dolomite sandstone. With an emphasis upon the reworked fabrics, Sano (1988a) interpreted the intercalations of dolomite-breccia and dolomite-sandstone to be reworked sediments displaced down from a nearby shallow-marine carbonate buildup down into a deeper basin, where the Hashikadani chert accumulated.

The Permian chert succession of the Suzuka unit is also characterized by interbeds of dolomite rocks in the radiolarian ribbon chert section. Suetsugu (1981MS) identified an arenitic to lithic texture in the dolomite rocks. Thus, the Suzuka Permian chert is considered to have accumulated in a deep-water basin, into which dolomitic sediments were displaced down by sediment-gravity flows. The rocks of the shallow-marine limestone succession are the most possible provenance of the reworked dolomite rocks.

4. Reconstruction of depositional setting of Permian oceanic rocks

All lines of stratigraphic, paleontological, and petrographic evidence allow the author to draw the paleogeographic reconstruction of the Permian oceanic rocks of the Suzuka unit. The sedimentary model for the Permian oceanic rocks of the Funabuseyama area (Sano, 1989b) provides the best analog to the paleogeographic reconstruction.

Significant for the paleogeographic reconstruction is the contemporaneity among the shallow-marine limestone succession, allochthonous limestone succession, and chert succession. The shallow-marine limestone succession and allochthonous limestone succession are dated as a the middle Early Permian by means of fusulines. The age of the chert succession is approximately referred to the Early Permian by a few species of conodonts detected by Suetsugu (1981MS). Although the chert succession has not been precisely dated, the three rock-succession are nearly coeval with one another.

The shallow-marine limestone succession of shallow-marine bank-top facies and the chert succession of deep-marine basin facies are laterally linked by limestone of the allochthonous limestone succession and dolomite rocks of the chert succession. Both of the carbonates have district reworked fabrics. The shallow-marine limestone succession, allochthonous limestone succession, and chert succession are interpreted to have primarily passed laterally into one another.

To be discussed is the pedestal rock of these time-equivalent oceanic rocks having different facies. The shallow-marine limestone succession has a small amount of basaltic volcaniclastic rocks in the lowest part and the allochthonous limestone succession is characterized by a great admixture of basaltic debris. Thus basaltic rocks are the most possible pedestal of these Permian oceanic rocks, though the uncertainty in the pedestal of the chert succession still remains. The rocks of the basaltic rock succession of the Suzuka unit is considered to have underlain these Permian oceanic rocks.

The rocks of the shallow-marine limestone succession, allochthonous limestone succession, and chert succession are reconstructed as Lower Permian sediments on the top, upper slope, and lower flank of a basaltic seamount. The shallow-marine bank-top facies and deep-marine basin facies are laterally linked by reworked carbonates of the allochthonous limestone succession and chert succession.

Worthy to note is that the Suzuka oceanic-rock assemblage is older than that of the Funabuseyama area (Sano, 1989b), Hachiman area (Horibo, 1990), and Kuzuu area (Kobayashi, 1979). The Suzuka shallow-marine limestone succession dates back to the middle Early Permian, while the bottoms of the Funabuseyama, Hashikadani, and Nabeyama Formations are of late Early Permian, late Early Permian, and early Middle Permian in age, respectively. The chronologic difference of the initiation of the carbonate sedimentation may imply that the Mino terrane contains remnant of several seamounts, instead of one huge seamount. Each of the several seamounts was successively generated through an off-ridge volcanism in an open-ocean realm and then overlain by shallow-marine and deep-marine oceanic sediments.

B. Mechanisms of internal destruction of basaltic rocks and intermixing of oceanic rocks

Careful field- and microscopic examinations reveal that the Suzuka oceanic rocks comprise an aggregate of stratally disrupted, isolated, various-sized masses of basaltic rocks, Permian shallow-marine limestone, allochthonous limestone, chert , and Jurassic siliceous rocks (Figs. 3, 22). The basaltic rocks usually have internal destruction fabrics, while other oceanic rocks have no deformation structures except for brecciation by injections of the pulverization products of the basaltic rocks. The structural difference shows that the internal destruction of basaltic rocks took place before the intermixing of the oceanic rocks.

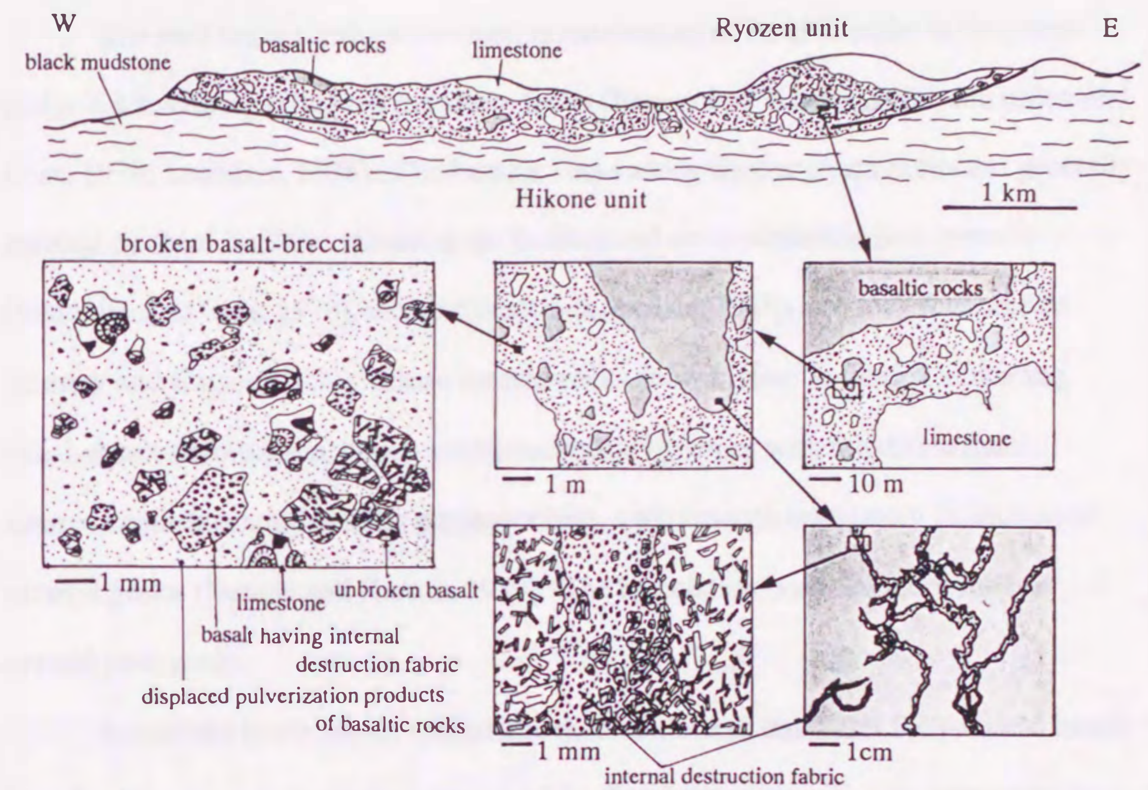

Fig. 22 Hypothetical profile (E-W direction) of the Suzuka oceanic rocks, which are collapse products of the seamount comprising an aggregate of various sized blocks of basaltic rocks and limestone. Fine dots show fine demolished products. All the blocks are chaotically embedded in reworked pulverization products of basaltic rocks. It is noted that basaltic rocks have been crushed in a brittle manner, while limestone not. Boundaries between the Ryozen and Hikone units are unsheared and irregularly rugged. Near the boundaries, black mudstone of the Hikone unit contains blocks of the Permian oceanic rocks.

1. Internal destruction of basaltic rocks

The internal destruction fabrics of basaltic rocks are characterized by pervasive, penetrative, *in situ*, and mechanical fragmentation of the primary textures in a brittle manner and by the scarcity of ductile deformation including flattening and contortion. The rare ductile deformation is represented by injection of finely pulverization pastes of basaltic rocks.

The well known textural destruction mechanism of basaltic rocks in the ocean realm is a fracturing related to transform faults (Barany and Karson, 1989; Simonian and Gass, 1978; Lonsdale, 1978). The basaltic rocks along the transform faults are generally crushed by shear fractures related to the faulting and are described as fault breccia (Simonian and Gass, 1978), tectonic breccia (Lonsdale, 1978), and tectonite breccia (Barany and Karson, 1989). These breccia-rocks show mylonitic fabrics indicating quasi-plastic deformation, which are characterized by zones with foliated textures, sutured contacts among basaltic porphyroclasts, and common undulatory extinction of mineral grains (Barany and Karson, 1989). The brecciation becomes more intense toward fault zones.

In contrast to the plastic and ductile deformations of transform fault-related basalt breccias, the internal destruction fabrics of the Suzuka basaltic rocks are dominated by a brittle deformation. It is noteworthy that the destruction styles and distribution of destruction products of basaltic rocks are by no means related to any fault and shear-fractures and the crushed basalt usually contains phenocrysts destroyed in a brittle manner. No plagioclase fragments occur that have been rounded by granulation and dispersed by shear displacement. Additionally, the internal destruction fabrics have no foliated textures characterized by fluxion structure and poligonization. No positive indication has been detected for rotation of the brecciated rock-pieces of basalt. The basaltic rock masses having internal destruction fabrics of various styles are unsystematically scattered. These characteristics suggest that the internal destruction of basaltic rocks have no connection with faulting. The internal destruction products of the Suzuka basaltic rocks are comparable with the products created by *in site* mechanical compressive crushing rather than the mylonitic rocks related to shearing and faulting (Higgins, 1971; Bell and Etheridge, 1973; Sibson, 1977; Wise *et al.*, 1984).

Such a compressive tectonic stress in a basalt seamount is possibly generated by gravitational creep. The gravitational creep is a progressive deformation of solid rocks by gravity over a long period of time (Radbruch-Hall, 1978) and is supposed to transform into a mechanical collapse or sliding (Nemcok, 1972). Hurutani (1980) summarized the process of large-scale gravitational collapse of a modern mountain. According to his explanation of this collapse process, the gravitational creep is generated by intense uplifting in the solid rocks of a topographic high, where the rocks are deformed by internal stresses mostly without continuous fractures.

On the modern steep outer trench slopes, seamounts get inclined trenchward due to the subduction of the oceanic plate (Cadet *et al.*, 1987). They are split by block faults nearly parallel to the trench axis (Fryer and Smoot, 1985; Kobayashi *et al.*, 1987; Konishi, 1989). The gravitational instability induced by the tilting of seamounts may provoke gravitational creep and subsequent huge collapse of a seamount. The internal destruction fabric in the basaltic rocks is interpreted to have been produced by internal compressional stresses during gravitational creeping.

2. Intermixing of oceanic rocks

All the oceanic rock masses of the Suzuka unit originate from a seamount and associated sediments deposited on and around it including various rock-types of basaltic rocks, late Early Permian shallow-marine limestone, late Early Permian allochthonous limestone, and Early Permian chert, and Jurassic siliceous rocks. They widely vary in size, ranging from a few millimeters to a few kilometers, and are completely disorganized without any structural and sedimentary trends and chaotically embedded in mechanically crushed, fine-grained basaltic materials.

Yamazaki and Okamura (1989) and Okamura (1991) proposed the formative models of chaotic rocks in the forearc wedges by interaction between a subducting seamount and an overriding forearc wedge. In their models, the subducting seamount extensively deforms the forearc wedges and the surface of the seamount is fragmented by the interaction with the overriding forearc wedge and accreted into the wedge. The accretion of oceanic rocks detached from the surface of the seamount occurs after the subduction of seamount slivers to considerable depth beneath an accretionary prism with high compressional and shear stresses. This process results in formation of a chaotic unit composed mainly of terrigenous sediments with oceanic rock blocks.

In contrast, the Suzuka unit has no terrigenous materials. Moreover, this unit lacks high P/T metamorphic minerals showing that the oceanic rocks have been deeply subducted beneath the accretionary wedges and has no deformation texture due to intense shearing. The oceanic rocks of the Suzuka unit except for basaltic rocks have never been internally crushed. If the oceanic rocks had been intermixed with each other by interaction between a subducting seamount and a forearc wedge, the limestones of the top of the seamount should have been extremely destroyed. This association of rock-types of the masses and chaotic intermixing of rocks varying in size, age, and lithology without shear structures reveal that the Suzuka oceanic-rock aggregate may result from sedimentary intermixing during mass transport related to a collapse of a seamount after destruction of basaltic rocks rather than tectonic intermixing by shearing beneath the accretionary wedge.

The various processes of mass transport have been documented and classified by Dott (1963), Fisher (1971), Hampton (1972), and many others. Among the mass transport processes, the general depositional mechanism of basalt breccia in the modern ocean floor comprises rock fall (Dott, 1963) as submarine scree and high-density mass flow at the foot of fault-scarps of normal faults in seamounts (Pautot *et al.*, 1987; Lallemand *et al.*, 1989) and of transform faults in spreading ridges (Barany and Karson, 1989; Fox *et al.*, 1976; ARCYANA, 1975; Lagabrielle *et al.*, 1986; Simonian and Gass, 1978). The mass-flow sediments deposited at toes of the fault scarps (Simonian and Gass, 1978; Amaliksen and Sturt, 1986; Barany and Karson, 1989) are generally characterized by unsorted clast-size, high diversity of clast-type, no internal stratification, and high angularity of clast-shape. These sedimentary properties closely resemble those of complicatedly intermixed oceanic rocks of the Suzuka unit. Therefore, the deposition of the aggregate of oceanic rocks may be regarded as the result of mass flows. During the transportation of the collapse products toward a trench by a mass flow, various-sized oceanic rock masses and finely crushed materials were chaotically mingled with each other.

C. Genesis of mixture of Permian oceanic rocks and Jurassic terrigenous sediments

The oceanic rocks of the Suzuka unit tectonically rest upon the black mudstone of the Hikone unit. The boundaries between the two units are originally irregularly rugged and unsheared, where the black mudstone and oceanic rocks are complexly intermixed with each other. Near the boundaries, isolated various-sized blocks of the Suzuka oceanic rocks are chaotically scattered in and supported by black mudstone of the Hikone unit.

The relationship between the Suzuka and Hikone units shows that the aggregate of oceanic rocks of the Suzuka unit was gravitationally displaced down onto terrigenous sediments. The isolated oceanic-rock blocks in black mudstone are interpreted to have been detached from the major flows of the oceanic rocks and then emplaced down into trench-fill sediments by gravity flows.

This transportion of oceanic rocks is supposed to have taken place before the consolidation of pulverization products of basaltic rocks. Irregularly rugged, complicated boundaries of the black mudstone and broken basalt-breccias mean their intermixing in prior to the lithification.

D. Formative process of Suzuka unit

As far as all lines of available evidence are concerned, the following process of formation of the Suzuka unit is deduced (Fig.23).

(1) Formation of a basaltic seamount and accumulation of shallow-marine carbonates and deep-marine chert on and around it in an open-ocean realm during the Early Permian time (stage 1 of Fig. 23).

(2) Accumulation of deep-marine limestone and chert on and around the seamount and redeposition of deep-marine limestone toward deeper basin where chert accumulated (stage 2 of Fig. 23). The Jurassic siliceous rocks of the Suzuka unit are considered to have been deposited on the lower slope or at the foot of a Permian seamount, because of the occurrence of exotic blocks of the Permian shallow-marine limestone. The Jurassic deep-marine limestone may have been accumulated on the seamount. On a modern seamount subsiding as approaching trenchward, the ancient limestone on the summit of the seamount is unconformably overlain by consolidated calcareous ooze (Cadet *et al.*, 1987; Konishi, 1989). The deep-marine limestone corresponds to such a chalk on the

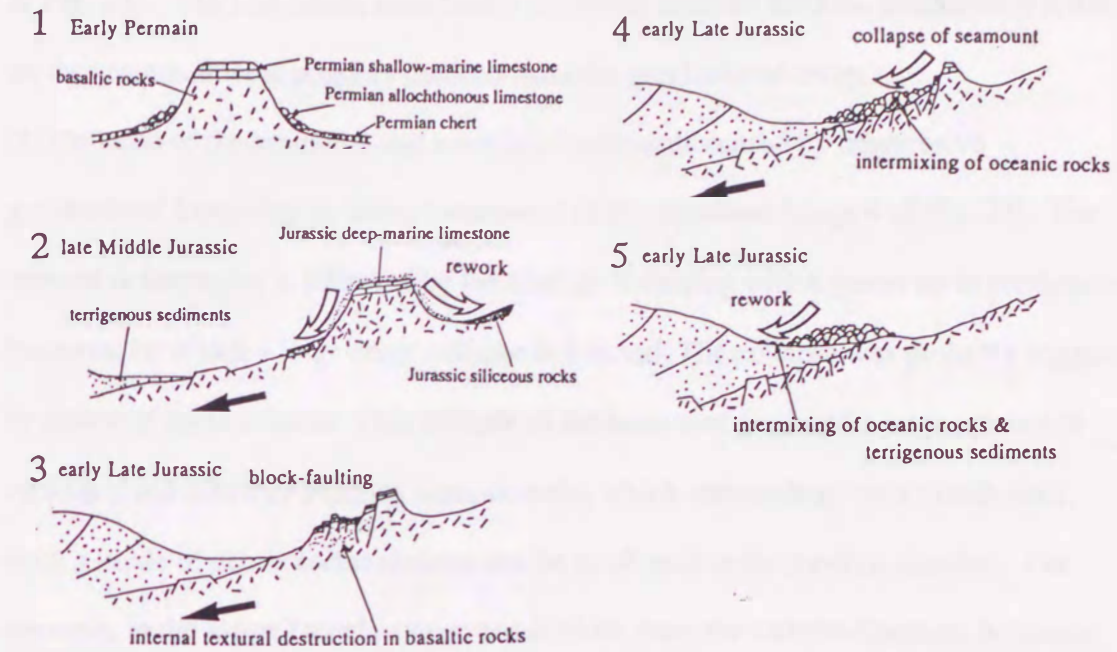

Fig. 23 A model to explain the formation of the Suzuka unit characterized by intensely crushed oceanic rocks. 1) Accumulation of shallow-marine limestone, allochthonous limestone, and radiolarian chert on the top, upper flank, and foot of a seamount, respectively, in the open ocean. 2) Accumulation of deep-marine limestone and radiolarian chert on the top and foot of the seamount, respectively. Deep-marine limestone is transported onto deeper sites. 3) Brittle destruction of basaltic rocks of the seamount by gravitational creep due to progressive tilting of the seamount as approaching to the trench. 4) Collapse of the seamount by progressive gravitational instability and action of normal faulting, when several varieties of oceanic rocks including Permian limestone and destroyed basaltic rocks with a small amount of Permian chert and Jurassic siliceous rocks were intermixed with each other. 5) Collapse products were redeposited onto the trench floor by gravity flows, where collapse products of oceanic rocks from the seamount were mixed with terrigenous sediments.

subsiding seamount and presumed to have emplaced down into chert as conglomerate.

(3) Internal destruction of basaltic rocks by gravitational creep resulted from progressive tilting trenchward of the seamount split by block-faults on the outer trench slope (stage 3

of Fig. 23). The limestones have hardly deformed because surficial sedimentary covers on the seamount were possibly escaped from the gravitational creep.

(4) Collapse of the seamount and associated sediments caused by progressive gravitational instability as tilting trenchward of the seamount (stage 4 of Fig. 23). The internal deformation is followed by the discrete fracturing which grows up to continuous fractures, by which a large-scale collapse is induced. The collapse was probably triggered by action of normal faults. This collapse of the seamount produced a large amount of various-sized debris of Permian oceanic rocks, which accumulated on a trench floor. Such a mode of debris accumulations can be confirmed in the modern trenches. For example, in the Japan Trench, a huge basalt block from the Daiichi-Kashima Seamount was observed near the trench axis (Pautot *et al.*, 1987).

(5) Redeposition of the collapse products onto trench-floor filled with terrigenous sediments (stage 5 of Fig. 23). A huge wedge of the collapse products of the seamount is supposed to have moved downslope onto the trench floor filled with terrigenous sediments by a gravity flow.

(6) Accretion of the collapse products of the seamount into Jurassic accretionary prism. The collapse products of the Suzuka seamount were accreted into the Jurassic accretionary wedge.

The tectonic events, including internal destruction of the collapsed oceanic rocks and their intermixing with terrigenous materials happened in a short time-span. The timing of the chaotic intermixing of the collapse products with the terrigenous materials is best approximated to be the late Middle to early Late Jurassic time as indicated by the age of the block mudstone of the Hikone unit (Yamagata, 1993).

VIII. Summary

In order to discuss the collapse and accretionary process of ancient seamounts, the Suzuka oceanic rock unit in the Jurassic accretionary complex of the Mino terrane has been investigated. The Suzuka oceanic rocks are divided into five lithologic successions: the upper Lower Permian shallow-marine limestone succession, upper Lower Permian allochthonous limestone succession, Lower Permian chert succession, basaltic rock succession, and Jurassic siliceous rock succession. These successions are interpreted as sediments on and around a basaltic seamount in open-ocean setting without input of coarse terrigenous debris. The Permian shallow-marine limestone succession is composed mainly of lime-mud/wackestone, lime-pack/grainstone, and limestone-breccia in ascending order, which possibly accumulated in lagoonal basin and foreslope of bank margin. The Permian allochthonous limestone succession comprises reworked limestone with clasts of basaltic rocks and is assigned to deposits by turbidity flow, debris flow, and rock fall on the lower slope of a seamount. The Permian chert and Jurassic siliceous rock successions are supposed to have been accumulated at its foot.

The field-properties reveal that the Suzuka unit is an aggregate of the isolated, stratally disrupted masses of these five oceanic rock successions. The masses of the oceanic rocks vary in size from a few millimeters to a few kilometers, completely disorganized, and randomly embedded in fine-grained destruction products of basaltic rocks. The oceanic-rock aggregate overrides on the early Late Jurassic black mudstone of the Hikone unit. The boundaries between these units are originally unsheared and irregularly rugged. The black mudstone neighboring the boundaries contains a large amount of various-sized blocks of Permian oceanic rocks.

The microscopic examination identifies the mechanical, internal destruction of primary textures of the basaltic rocks. The destruction is characterized by penetrative, pervasive, and brittle brecciation. The destruction fabrics have neither mylonitic structures such as fluxion and poligonization nor sedimentary structures of bedding, lamination, and grading. These structural characteristics indicate that the internal destruction products of basaltic rocks are resulted from *in situ* crushing rather than shearing or faulting.

The Suzuka oceanic rocks are best explained as collapse products of a Permian seamount along a convergent margin. The large-scaled collapse was caused by block-faulting of a seamount on the Jurassic trench-floor filled with terrigenous sediments. Prior to the huge collapse, the internal destruction of basaltic rocks may have been caused by gravitational, compressional stresses induced by the progressive tilting trenchward of the seamount split by block-faults on an outer trench-slope. The wedge of disrupted oceanic rocks was gravitationally emplaced down onto trench-fill sediments and then incorporated into an accretionary prism. These collapse- and accretion-related events are presumed to have taken place in the relatively short term of late Middle to early Late Jurassic on the basis of radiolarian biostratigraphy in the Jurassic siliceous rocks in the Suzuka oceanic-rock aggregate and the black mudstone of the Hikone unit.

IX. Acknowledgments

I thank Prof. H. Okada (Kyushu University) for his critical review and valuable comments on the manuscript. I also thank Prof. J. Yanagida (Kyushu University) and Prof. Y. Ogawa (University of Tsukuba) for their review of the manuscript and Associate Prof. H. Sakai (Kyushu University) for his advice. My sincere thanks are extended to Dr. K. Kanmera (Professor Emeritus, Kyushu University) for his useful suggestions and identification of fusulines. I am deeply indebted to Dr. Sano (Kyushu University), who read the early draft of the manuscript and offered many helpful discussions.

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