STORM BARNACLE BEDS AND THEIR DEFORMATION IN THE MUROTO-MISAKI OLISTOSTROME AND MÉLANGE COMPLEX, SHIKOKU

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Introduction The Shimanto Terrane of the Outermost Zone of Southwest Japan includes olistostromes of various dimensions in several belts, of which the largest is the Misaki-Olistostrome Belt (KANMERA, 1977; Misaki means a cape in Japanese). This olistostrome belt extends from southern Kyushu to Central Honshu northeastward, and the typical exposures are located in Toi-misaki (KANMERA, 1977); Ashizuri-misaki (KIMURA, 1985), Muroto-misaki (SAKAI, 1977, 1981; TAIRA *et al.*, 1980), Shiono-misaki (HISATOMI *et al.*, 1980), and Ooigawa area (SUGIYAMA, 1980). Oligocene to early Miocene shallow marine molluscan fossils have been reported from the olistoliths of this belt, however, no detailed study of the sedimentary facies and internal structures of the olistoliths has been hitherto done, although it is important to know how they were formed and from where they were transported. Recently, barnacle and vertebrate fossils were discovered from the Muroto-misaki olistostrome and mélangé Complex (SAKAI & HASEGAWA, 1980; SAKAI, 1981). This paper presents a brief note on sedimentary facies of the storm barnacle beds and their gravitational deformation.

Storm barnacle beds The barnacle shell beds are found in black mudstone exposed on a wave cut terrace at the western corner of Port Nabae on the west coast of the Muroto Peninsula (Fig. 1). The barnacle beds and interbedded mudstones occur as a discrete block in the Muroto-misaki olistostrome and mélangé Complex that contains massive sandstones, turbidites and pillow basalts of various dimensions (SAKAI, 1981).

The barnacle beds are interbedded with ubiquitously bioturbated silty to sandy mudstone layers at intervals of 5 to 20 cm as shown in Figs. 2 & 5. Forty barnacle beds are present within a sequence of 10 m in thickness. They show lenticular bedding with a scoured sharp-base and an undulatory top surface (Figs. 2 & 3). Many of the barnacle beds contain rip-up clasts of mudstone and marl pebbles at their base, derived from the underlying bioturbated mudstone. Some burrows in the underlying mudstones are filled with barnacle debris. No grading of barnacle carapace is observed. These sedimentary structures suggest that the barnacle debris were transported as traction load.

The barnacle beds are petrographically classified as arenaceous bioclastic rudstone. More than 95% of the bioclasts are fragmentary barnacle carapaces ranging in size

Fig. 1. Geological outline maps to show the location of the barnacle beds.

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Fig. 2. A representative section of storm barnacle beds at Port Nabae.

from a few mm to 2 cm (Fig. 4). The terrigenous grains in the barnacle beds and accompanied sandstone layers consist mainly of fine- to medium-grained quartz, feldspar and mica, and contain rare rounded glauconite.

The mudstones are rich in muscovite flake and carbonaceous matter, and strongly bioturbated to show a mottled structure. Burrows with a thick coated calcareous tube, probably formed by annelid, are common. They are disposed obliquely to subparallel to the general stratification surfaces (Fig. 3).

The sandstone layers exhibit lenticular bedding like the barnacle beds (Fig. 2). They are laminated with some carbonaceous and micaceous flakes. Flaser- and ripple cross-beddings are common in thin sandstone layers, and planar to trough cross-beddings are present in thick sandstone layers which scoured the underlying barnacle beds (Fig. 2). Pri-

mary bedding of sandstones is destroyed by strong bioturbation.

Various kinds of fossils were discovered; gastropods, pelecypods, bryozoa, calcareous sponge, echinoid spines, foraminifers, shark teeth and a vertebrate bone from the barnacle and sandstone beds and foraminifers and radiolarians from the mudstones (SAKAI, 1981; SAKAI & HASEGAWA, 1980; ISHIKAWA, 1982). All fossils but molluscs and foraminifers are fragmentary. A vertebrate bone of 20 cm long cuts a set of underlying laminae, and is covered with overlying laminae along the outernal shape (SAKAI & HASEGAWA, 1980, plate 35-2). This mode of occurrence suggests that the bone was transported by tractive current.

Depositional environments The sedimentary features of the barnacle and sandstone beds mentioned above are interpreted as storm layers deposited in a shallow shelf mud zone. The deposition of coarse, allochthonous skeletal debris on highly bioturbated mudstones represent rapid influx of coarse sediments brought from shoreline or offshore bar on shelf muds during heavy storms. Moderate to good sorting of both barnacle fragments and sand grains suggests that they underwent considerable sorting process by wave action prior to resedimentation.

Abundant muscovite flakes and carbonaceous matter in mudstone and sandy laminae represent their deposition by suspension after storms. Strong and ubiquitous bioturbation of silty mudstone documents extensive benthic organic activity for relatively long duration of calm conditions after deposition. *Cruziana*-type ichnofacies in these beds, high content of sand and silt in the mudstones and frequent intercalations of storm barnacle and sand layers probably indicate their deposition in the transition zone between the lower shoreface and inner shelf.

Gravitational deformation The barnacle beds and interbedded mudstones have been obliquely cut by many, minor conjugate faults. The fault planes are sharp, and neither slickenstriae nor gouge are associated with them. The faults dislocate each bed step by step at intervals ranging in a few mm to 20 cm as shown in Fig. 5. Small clastic dykes which

Fig. 3. Lenticular bedding of a barnacle bed (B) and ubiquitously bioturbated shelf mudstone (M).

Fig. 4. Photomicrograph of arenaceous barnacle rudstone consisting chiefly of fragmentary barnacle carapaces (B) and a small amount of terrigenous clastic grains. A benthic foraminifera (F) is also seen.

are composed of barnacle fragments intrude into mudstones along some of the faults (Fig. 5c). This means that the barnacle beds were liquefied when the faults were formed. Therefore the storm beds seem to have been under early stage of consolidation with enough interstitial pore water when the faults were formed. The pole density diagram of one hundred minor fault planes (Fig. 6) shows that there are two sets of conjugate faults; one set exhibits N58°E, 66°SE and N70°W, 74°SW, and the other does N85°E, 76°SE and N50°W, 81°SW. The shear angles between these two sets of conjugate faults are 23 and 24 degrees, respectively. These values correspond to an intermediate shear angle of sandstone and mudstone under atmospheric confining pressure (HOSHINO *et al.*, 1972), and

Fig. 5. a. Stratal disruption of the barnacle beds by conjugate minor faults. b. Mode of occurrence of minor faults. c. Injection of a barnacle-fragments dyke into storm beds along a minor fault.

may support that these faults were formed in a shallow burial depth.

The same type of minor conjugate faults are commonly observed in sandstone olistoliths around Port Nabae. The interangles between the conjugate faults and bedding planes are consistent in every olistolith, although they have different shapes and attitudes. It means that the conjugate faults must have been formed in initial stage of submarine sliding when the formations kept nearly horizontal attitude. The principal stress axes after tilting correction indicate that the maximum stress axis inclines 10 to 20 degrees against the vertical line (Fig. 6). These informations about the minor faults cutting the storm beds suggest that they were formed by bedding-parallel-extension caused by gravitational force.

Such gravitationally disrupted storm beds and shelf mudstones have been incorporated into later tectonic reformation and have resulted in the formation of *mélange* which is composed of isolated blocks included in a sheared mudstone matrix. Separation of gravitationally disrupted strata has been strengthened by later compressional shear along the minor faults as is exemplified by lozenge-shaped boudins and anastomosing, undulating spaced cleavages (SAKAI, 1981, figs. 9 & 11) at Port Murotsu.

The Shijuiyama Olistolith (SAKAI, 1981) in the Muroto-misaki Complex is inferred to have been originally deposited in a sandy coastal