Sedimentary Facies in the Active Plate Margin, edited by A. Taira and F. Masuda, pp. 483–494.

MIOCENE OFFSHORE TRACTIVE CURRENT-WORKED CONGLOMERATES—TSUBUTEGAURA, CHITA PENINSULA, CENTRAL JAPAN—

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Abstract. The Tsubutegaura Conglomerates occur in the middle part of the Miocene Morozaki Group, developed in southwestern Chita Peninsula, central Japan. Most of the group is characterized by storm-induced deposits from the uppermost bathyal environment (200~400 m deep). The Tsubutegaura Conglomerates, consisting of several hemilenticular or bunch-shaped bodies 10 to 40 meters across and a few meters high, were strictly distributed at one horizon in the storm sequence. Some of the hemilenticular bodies consist of a few layers. The framework gravels of the layers are angular to subangular and form clast-supported fabrics; a mud matrix is absent. The gravel size is variable, from pebbles to giant boulders. The finer gravels are characteristically imbricated in many places; the larger ones, i.e. boulders, often form gravel clusters as seen in alluvial channels.

Most of the gravels in the Tsubutegaura Conglomerates are of Ryoke gneissose rocks, which are assumed to underlie the Morozaki Group. Very undurable soft siltstone and carbonized woods are minor constituents.

No simple mass transportation model can synthetically explain all these sedimentary features; only submarine tractive current-worked deposits after some mass movements seem to be possible. Synsedimentary fault movements, previously clarified by other authors, are consistent with the idea of a submarine avalanche and a subsequent wash by offshore tractive currents induced by a tsunami.

1. Introduction

Numerous studies have been made on the roles of various events in the transportation and deposition of marine clastic sediments. Submarine avalanches and related sediment gravity flows, including turbidity currents, have been recognized as mechanisms and processes carrying sediments from shallow to deep water environments.

In the last several years, storm-generated sequences have been reasonably well documented in terms of their facies association in the stratigraphic records (AIGNER, 1985). Tsunamis have also been noted by KUENEN (1950), as early as 40 years ago, as one of the most important generative triggers of turbidity currents which bring shallow-sea bottom materials towards deeper bathyal and abyssal environments. However, they have not been studied further from the sedimentological view point.

Within the last several years, thick homogeneous sediments (called "homogenites") in the eastern Mediterranean Sea have been described. The characteristics and distribution of the sediments were interpreted by a model of tsunami-induced liquifaction. The collapse of the Santorini Caldera at about 3,500 years B.P. is assumed to be the triggering event (KASTENS and CITA, 1981; CITA *et al.*, 1984; HIEKE, 1984).

So-called "tsunami-ishi" (tsunami-transported stone) has been reported on and studied in examining the highest run-up level of the Yaeyama Earthquake tsunami, which occurred in 1771 (MIYOSHI, 1968, 1987; MIYOSHI and MAKINO, 1972; KATO and KIMURA, 1983).

Very recently, MINOURA *et al.* (1987) reported sand layers in an inter-dune pond brought and deposited by the run-up current of a tsunami triggered by the Japan Sea Earthquake of May 26, 1983. They found similar sand layers in 2 m long black organic muddy cores from the inter-dune pond, and stated that the sand layers were reworked by several historical tsunamis induced by earthquakes.

However, no remarkable reports of tsunami-affected offshore sediments of the arc-trench region around the Pacific have been published to date. In the present paper, we will preliminarily describe the outline of Miocene tsunami-worked offshore cobble layers which crop out on the western coast of the Chita Peninsula, near Nagoya, central Japan (Fig. 1). We hope that many examples of various types of tsunami-worked sediments, "tsunamite", will be found in Japan, in recent sediments and in the geological records, because great earthquakes and tsunamis occur frequently along converging plate boundaries.

2. *Geological Setting*

The Miocene Morozaki Group, more than 1000 m thick, mainly consists of siltstone interbedded with sandstone (DOI, 1983; YAMAOKA, 1984; KONDO and KIMURA, 1987).

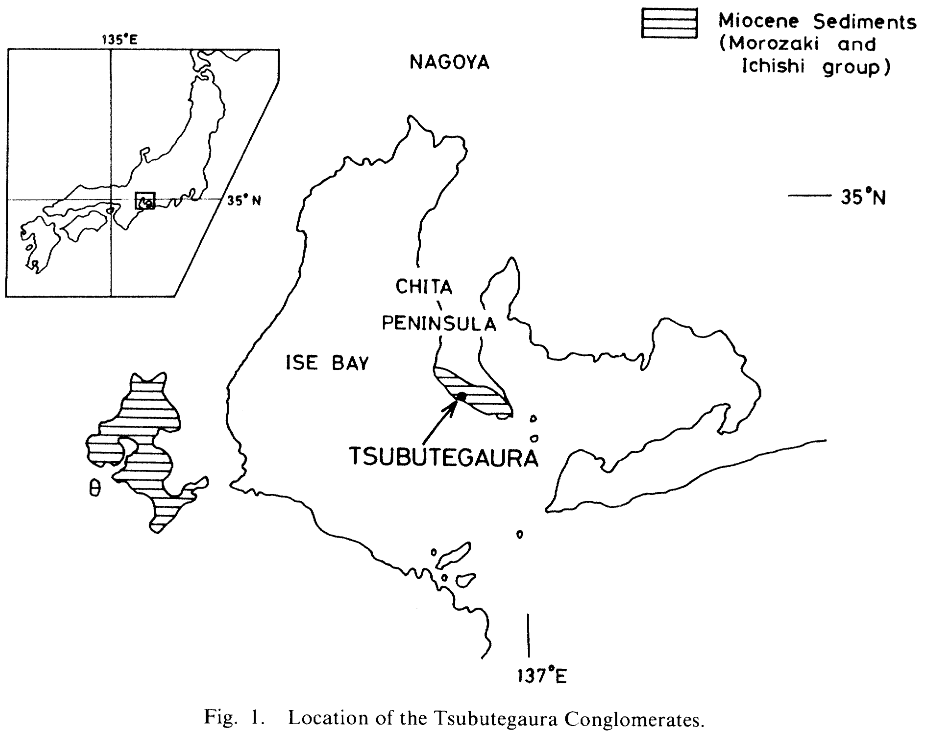

Fig. 1. Location of the Tsubutegaura Conglomerates.

These beds are formed of cycles of fining-upward sequences, except for the lowest formation where the clasts are generally coarser in size. Many tuff beds are intercalated in the group and provide a good key for correlation of the strata.

The Tsubutegaura Conglomerates, which have been noted by their large conspicuous boulders, occur at the middle horizon of the group. A few other conglomerate layers are observed in the group; most of them, however, are muddy conglomerates, common in turbiditic sequences, and which may also occur in storm depositional sequences.

The sedimentary environment of the Morozaki Group has been examined based mainly on fossil pelecipods (SHIKAMA and KASE, 1976; YAMAOKA, 1985), asteroids (YAMAOKA, 1987), crustasceans (TAKEDA *et al.*, 1986), and fish otoliths (OHE and YAMAOKA, 1980). Many of these fossil species from the mudstone of the Middle to Upper Morozaki Group are related or similar to living animals which inhabit the sea bottom at 200–400 m depths. In contrast, fossils from the sandstone layers show delivery from a shallow sea bottom of 100–200 m depth. Similar results were obtained from benthic foraminifera.

Structures such as sandstone dikes, diapir folds, convolute bedding, and ball-and-pillow structures occur in the Morozaki Group, showing synsedimentary tectonics in and around the sedimentary basin (HAYASHI, 1985, 1987).

Any sedimentological studies of the Morozaki group were not carried out before the present report. However, the predominance of storm-induced density current deposits can be inferred based on rhythmic silt/sand alternations, graded bedding, the lack of typical Bouma sequences, clear boundaries between sandy and silty divisions, and the generally fine-grained character of the sandy division compared with typical turbidite sandstone. Apparently, the deposition of the Tsubutegaura Conglomerates was a peculiar and exceptional episode in the sedimentary history of the Morozaki Group.

3. *Description*

The Tsubutegaura Conglomerates occur along the Tsubutegaura beach over a distance of about 150 meters, trending in a northwest-southeast direction. They consist of several hemilenticular or bunch-shaped bodies 10 to 40 meters across and a few meters high (Figs. 2 and 3). Each conglomerate body is found at a distance of several meters from its neighbors, seemingly arranged in an almost straight line. These conglomerates are mainly composed of pebbles and boulders, and in a few cases, intercalations of sandstone layers are found.

All conglomerate bodies lie strictly at one stratigraphic horizon, covered by a well-laminated white tuffaceous sandstone (Fig. 4) and underlain by a pale bluish-gray siltstone. Where the conglomerates are absent, the tuffaceous sandstone conformably covers the siltstone (Fig. 5) with small local signs of erosion such as flute marks. Some cobbles and boulders in the conglomerates stick out into the overlying sandstone, which in turn infiltrates the voids in the conglomerates.

A marked feature of the Tsubutegaura Conglomerates is the monomictic composition of the gravels; that is, almost all of the gravels are gneiss or gneissose igneous rocks originating from the "Ryoke metamorphic belt", with the minor exception of rip-up clasts from the subjacent siltstone bed and carbonized wood fragments.

The Tsubutegaura Conglomerates are peculiar in carrying some giant boulders as large as their bed thickness. The largest boulders in the conglomerates, reaching 3 meters in diameter, appear in the northwestern terminal hemilenticular body. The northwestern terminal body is the smallest in body size, and consists of several boulders and cobbles, but lacks smaller clasts (Fig. 6).

Fig. 2. View of the Tsubutegaura Conglomerates, the terminal first body (1), second (2), third (3), and a part of the fourth (4) body, and overlying sandy beds. Rounded reworked blocks are scattered on the offshore side of the beach.

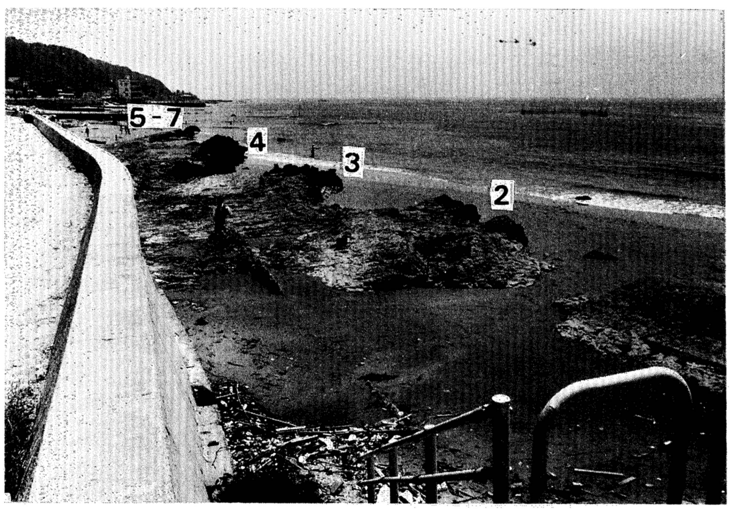

Fig. 3. View of the Tsubutegaura Conglomerates (second to seventh body), and overlying sandy alternation dipping northeast (left side).

The inner structures of the conglomerates are variable. The fourth body from the northwestern terminus shows the most typical sedimentary structure (Fig. 7). Except for the northwestern portion, the hemilenticular body is composed of two units, a lower layered unit and a thick upper conglomerate unit.

The lower unit is subdivided into two layers, a thin conglomerate layer and a calcareous laminated sandstone layer. The thin conglomerate layer, which is not continuous but occurs intermittently, consists of subangular pebbles of gneissose rocks and is only 50

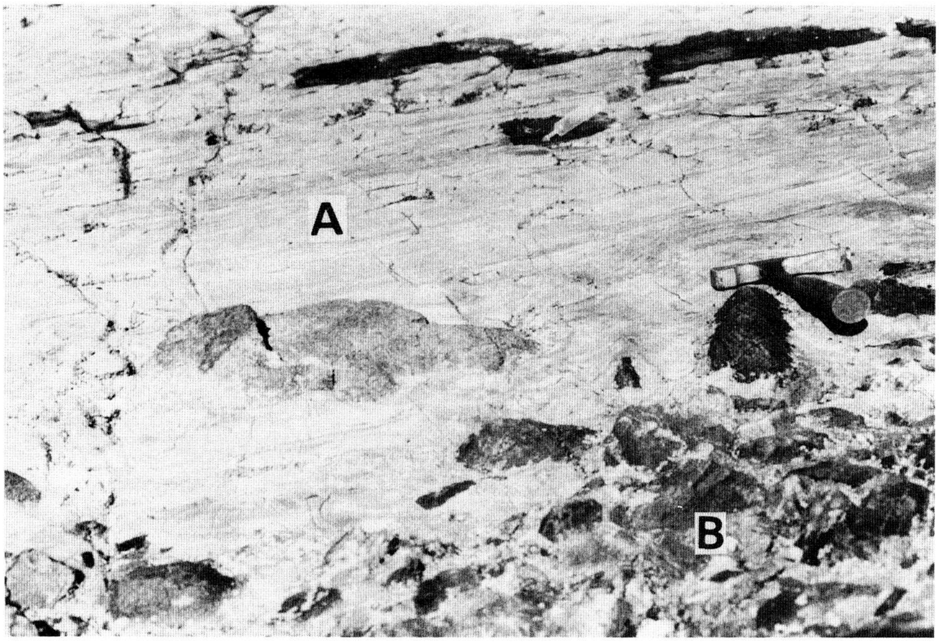

Fig. 4. Pale white well-laminated tuffaceous sandstone (A), overlying the upper conglomerate unit (B). Boulders of the conglomerate stick out into the overlying tuffaceous sandstone.

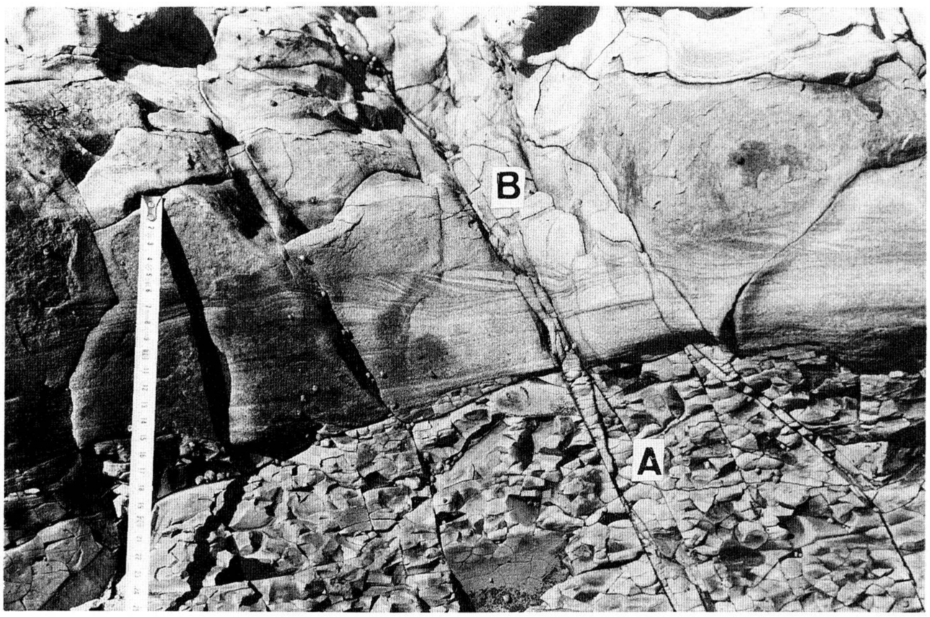

Fig. 5. Bluish-gray siltstone (A) covered by laminated white tuffaceous sandstone (B). Note the lack of the conglomerates between the sandstone and siltstone. Cross lamination in the sandstone indicates northwestern currents (from left to right).

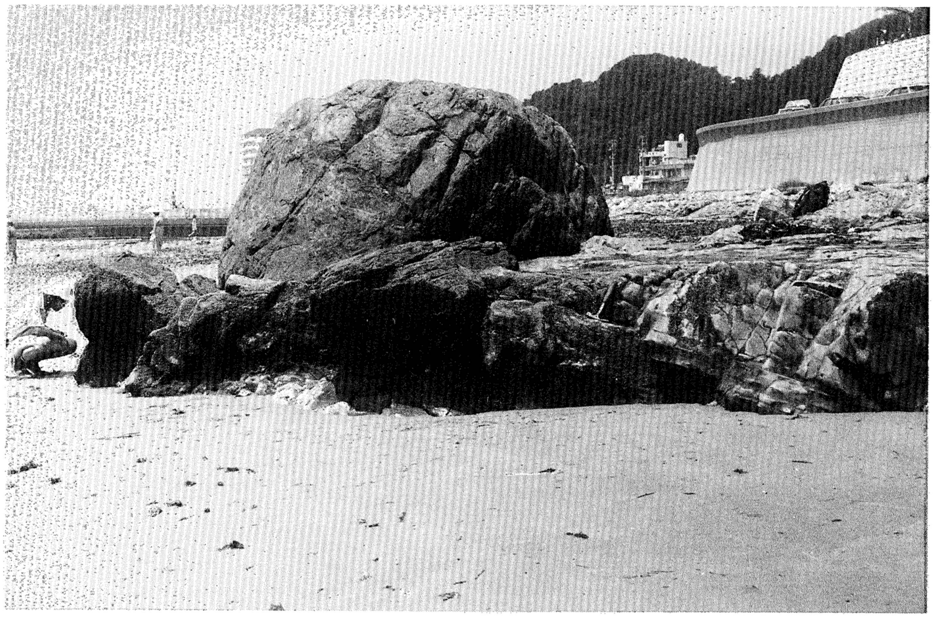

Fig. 6. Northwestern terminal body. The boulder is the largest in the Tsubutegaura Conglomerates. The high roundness of the boulder is very exceptional among the conglomerates.

Fig. 7. The northwestern part of the fourth body underlain by siltstone (A), and covered by tuffaceous sandstone (E). The body is composed of two units (three layers), the thin lower conglomerate of the lower unit (B), the sandstone layer of the same unit (C), and thick upper conglomerate unit (D).

centimeters thick at maximum. It rests conformably on gray siltstone with a small scale scour and fill structure. The conglomerate layer is clast-supported and massive. The voids in the gravels are filled by sand of the overlying sandstone layer.

The calcareous sandstone layer ranges in thickness from several to 30 centimeters. Parallel lamination is very common, though it is rarely contorted by loading of cobbles in the thick upper conglomerate unit as reported by HAYASHI (1985, 1987).

The principal part of the Tsubutegaura Conglomerates is the thick upper conglomerate unit, which carried giant boulders. The giant boulders tend to lie in the northwestern terminal of each conglomerate body. The conglomerates are thicker at their northwestern terminal, and gradually thin out southeastward. In other words, the conglomerate bodies have a bunch-like form in sectional view, with giant boulder gravels in their northwestern terminals. The true original shapes of the bodies, however, are not apparent because their southwestern extension has been broken and is lost by present coastal erosion. The northeastern extension of the conglomerate bodies is also uncertain, because of the overlying storm-induced sand/silt alternation.

The fabric of the thick upper conglomerate unit is clast-supported. The gravels in this unit are angular to subangular, bladed in form, and asymmetrical as seen in fluvial gravels. The framework of the gravels is crudely bedded and, as a matter of interest, characteristically imbricated northeastward (Figs. 8 and 9). The longest axis of the gravels is in the bedding plane and is arranged transverse to the imbrication. The larger gravels accumulated into gravel clusters such as those seen in alluvial channels (Figs. 10 and 11). Obstacle and wake fabrics, usually seen in recent stream gravel clusters (DAL CIN, 1968; BRAYSHAW, 1984), are also seen in the conglomerates. The imbrication and gravel clusters in the Tsubutegaura Conglomerates show that the gravels have been selectively transported and deposited by northeastern tractive currents.

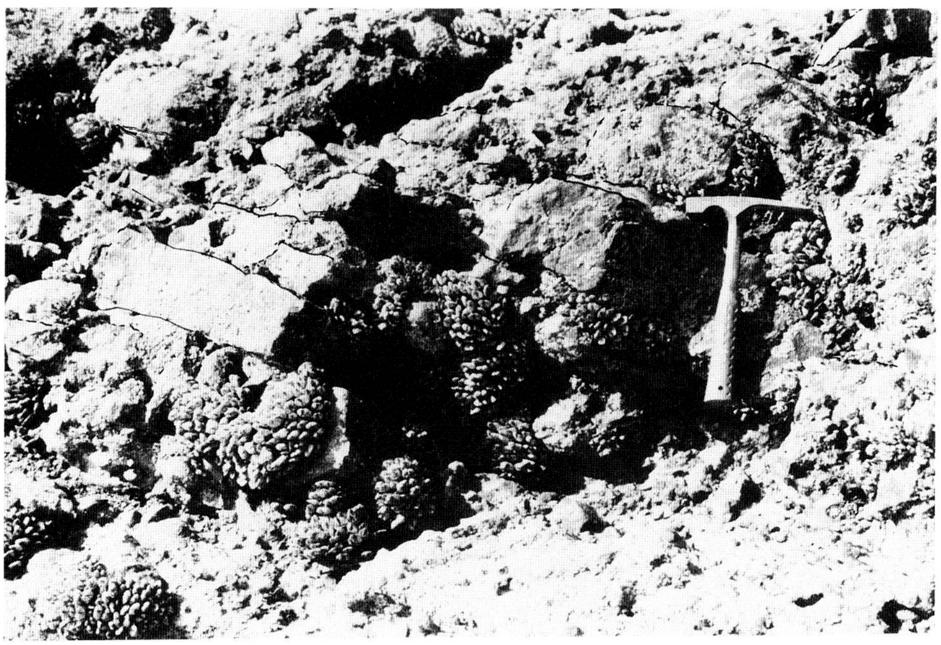

Fig. 8. Imbricated cobbles, Note the very angular shapes and sorting of the cobbles. The lower part of the conglomerate layer is masked by coastal animals.

Fig. 9. Well-developed imbrication of angular, well-sorted cobbles.

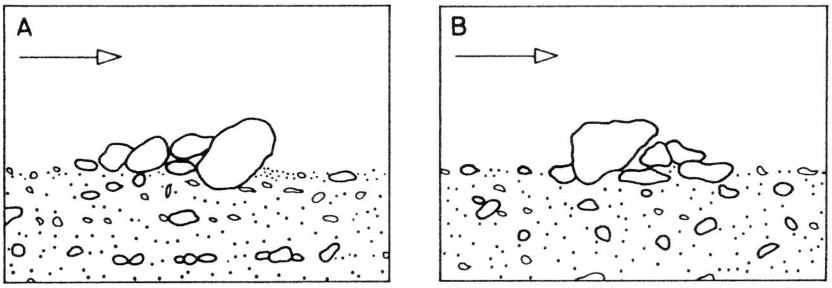

Fig. 10. Sectional view of gravel clusters (obstacle and wake fabrics in alluvial channels). A: Gravels accumulated at a stoss side. B: Wake fabric developed behind an obstacle (after DAL CIN, 1968).

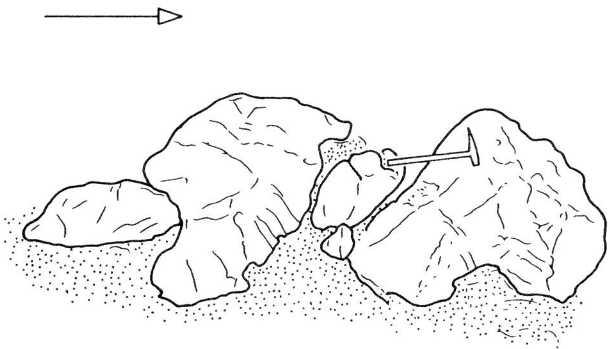

Fig. 11. Gravel clusters formed by boulders showing a tractive current from left to right. Seen from the northwest.

At the northeast side of the giant boulder gravels, relatively well-sorted, smaller gravels are concentrated. The arrangement of the smaller gravels is random, as may be seen in the stoss side of a unidirectional current going past a bluff body. The random gravel part is thicker near the giant boulder gravel, and suddenly thins out away from them. The random gravels are covered and armored by coarser-grained bedded cobbles.

The framework gravels of the major part of the Tsubutegaura Conglomerates are also mainly composed of gneissose rocks. Gravels of soft siltstone and carbonized wood are minor constituents. Voids in the framework gravels are filled by tuffaceous sand, as mentioned above, and gastoropod fossils are carried sporadically in the matrix.

As mentioned above, the base of the Tsubutegaura Conglomerates is distinct, and scours the underlying siltstone bed in some places. However, on the whole the major part of the conglomerates does not fill any channels.

The beds overlain by the Tsubutegaura Conglomerates are generally not disturbed. Some thixotropic deformations without any gravel loads are observed in some places in the underlying siltstone bed (Fig. 12), which indicates that the deformations were triggered by some shocks before the deposition of the conglomerates.

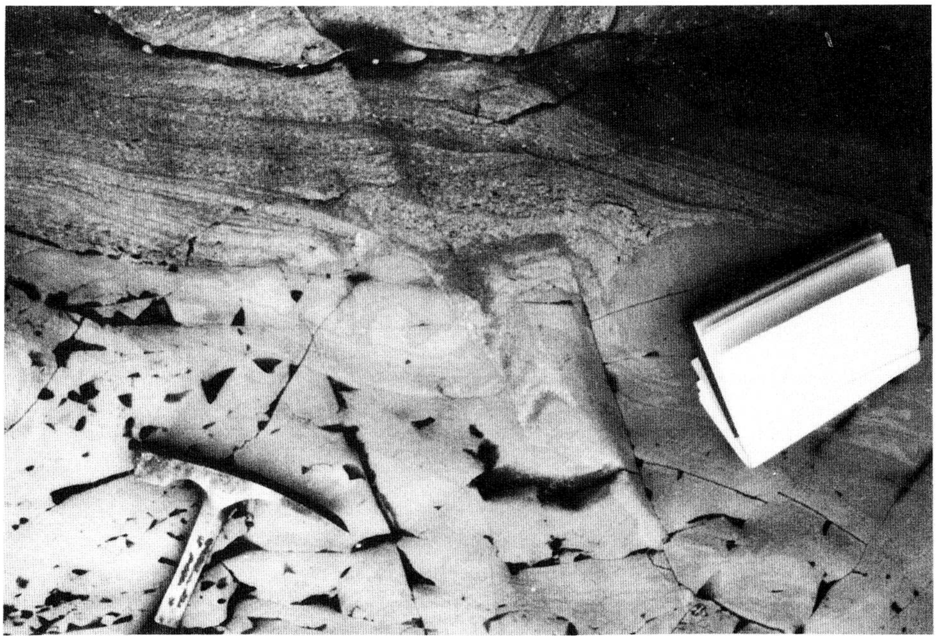

Fig. 12. Thixotropic deformation in the siltstone.

4. *Discussion*

As shown above, the middle and upper parts of the Morozaki Group are mainly composed of storm deposits and/or storm-induced turbidites deposited in submarine environments of about 200–400 m depth. The Tsubutegaura Conglomerates are part of the storm-related sequence, but their sedimentary features and coarse-grained textures are quite exceptional. The coarse-grained clastics, including giant boulders, show that the conglomerates have been deposited by extraordinarily powerful events.

It might be assumed that the conglomerates have been deposited by a submarine debris flow. Such an assumption, however, cannot be supported by the sedimentary features of the conglomerates and their surrounding geology. As pointed out in the previous section, the most interesting and important character of the Tsubutegaura Conglomerates is revealed by the sedimentary fabrics of their major part. Many submarine debris flow deposits may carry giant boulders as large as those in the Tsubutegaura Conglomerates, and they may be discordant with overlying and/or underlying strata. However, the sedimentary fabric characteristics of the major part of the Tsubutegaura Conglomerates, such as clast supported texture, bedding, and well-developed imbrication and gravel clusters show selective transportation and deposition; these are rather contrary to a debris flow origin model.

Some debris flow deposits may have matrix- and/or clast-supported fabrics. The head or uppermost part of a debris flow deposit may have a clast-supported, bedded and/or imbricated fabric (HIRANO and IWAMOTO, 1981; SUWA and OKUDA, 1983; SUWA et al., 1984), but such fabrics usually develop only partially, and gradually change into a matrix-supported massive texture. On the contrary, the Tsubutegaura Conglomerates, as shown in the previous section, have gravel bunch forms and no matrix-supported massive parts. The presence of the rip-up clasts of undurable soft siltstone in the conglomerates is also a negative indication for a debris flow origin, because debris flow transportation forces the collision of soft clasts against hard gneissose rocks and may pulverize them. The Tsubutegaura Conglomerates cannot be the head or uppermost part of a debris flow deposit.

The very monomictic gravel lithology and the predominance of angular clasts seem to suggest an avalanche deposit originating from a talus deposit. In the very angular shape of many gravels and the lack of a mud matrix, the conglomerates resemble washed talus deposits on a beach at the foot of a coastal cliff. However, the shallow bathyal paleodepth environment and the sedimentary facies of the Middle Morozaki Group clearly deny coastal topography as the conglomerate deposition environment. The lack of a mud matrix, the eroding structures and the included undurable siltstone clasts, picked up from the underlying strata, also deny a simple submarine talus deposit.

If submarine talus deposits are reworked and transported by a rapid tractive current to the shallow bathyal (200~400 m deep) sea floor, the resultant deposits may resemble fabrics with fluvial deposits. The fabrics of the Tsubutegaura Conglomerates are consistent with such a submarine tractive current origin.

As described above, the sedimentary fabrics of the conglomerates suggest that the tractive currents drove from the northeast direction. This is almost at right angles to the flow direction of the sandy deposits of the storm-induced turbidites in the Morozaki Group.

A tractive current transporting giant cobbles at a 200~400 m deep sea floor cannot be a tidal current. There is evidence of large fault movements on both the east and west sides of the Chita Peninsula (HAYASHI, 1987), and, as shown in the previous section, thixotropically deformed structures are peculiar in the underlying strata. From these facts, it is natural to consider that a severe earthquake and earthquake-induced tsunamis occurred just before the deposition of the conglomerates, and ebb currents containing much debris flowed down to the sea floor. Gravel-carrying violent tractive currents could occur as such ebb currents induced by gigantic earthquakes.

KATO and KIMURA (1983) suggested that giant limestone boulders could have been transported by the ebb currents of the Yaeyama Earthquake Tsunami, which occurred in 1771 on the southeast coast of Ishigaki Island, Okinawa.

Many oceanographers have reported on tsunami propagation wave lengths and wave heights, as well as coastal disasters caused by the run-up of tsunami (MIYAZAKI, 1971; MIYOSHI, 1987; ABE and ISHII, 1987). The properties of ebb currents of tsunami, however, have not yet been published. By the run-up of a tsunami, a large water mass is trapped on the coast, making a large water head, and resultant rapid ebb currents may occur. The off-shore velocity of rip-currents caused by seasonal storms can reach a maximum of about 1 m/sec (NAGATA, 1971). It is therefore very reasonable to assume that a tsunami-induced ebb current with much debris might flow down the sea floor with several meters per second velocity. In general, a tractive current flowing downward with several meters per second velocity can transport giant boulder gravels 2 or 3 meters in diameter (BAKER, 1984).

As a tsunami induced by an earthquake has several pulses, a tsunami-induced ebb current may also have several pulses. The seemingly orderly accumulation of the Tsubutegaura conglomerate bodies may result from these pulse movements.

In conclusion, no simple mass transportation model can synthetically explain all the sedimentary features of the Tsubutegaura Conglomerates. The reworking of submarine avalanche deposits by rapid tractive currents is evident for the major part of the conglomerates. Only the ebb currents of a tsunami triggered by a severe earthquake seem to be available sources of such powerful tractive currents.

Acknowledgements

We would like to thank Dr. T. Hayashi for drawing our attention to the interesting sediments, the Tsubutegaura Conglomerates. We also acknowledge the valuable advice and critical discussions of Prof. S. Okuda, Dr. H. Suwa, and their colleagues of the Disaster Prevention Research Institute, Kyoto University, Prof. M. Hirano of Osaka City University, Dr. E. Inoue of Kyoto Gakuen University, and Dr. W. Soh of the Ocean Research Institute, University of Tokyo.

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