BASAL STRUCTURES OF THE PLEISTOCENE CHIKURA SUBMARINE SLIDING SHEET IN THE SOUTHERNMOST BOSO PENINSULA, CENTRAL JAPAN

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Abstract. The Chikura Submarine Sliding Sheet slipped toward the NNW, sometime between 0.9 and 0.65 Ma, on a landward-dipping back slope of a thrust in the imbricated thrust zone above the So-o Trough, where the Philippine Sea Plate was being subducted. The basal structures of the sheet are composed of three zones, a shear, an imbricated fault, and a brecciation zone, in an upward sequence. The shear zone constitutes the basal fault of the sheet. None of the faults in the shear zone contains gouge. In the imbricated fault zone, imbricated thrusts bifurcate from the basal fault, and dislocate and drag the surrounding strata in a ductile manner. The displacements of the thrusts diverge upward and produce the brecciation zone, where strata are broken into angular blocks and surrounded by a liquefied sandstone matrix. The deformation style in the basal structures is that of soft sediment. These basal structures are common in other submarine sliding sheets already precisely described. Thus, the structures of the Chikura are typical examples. If imbricated thrusts merge upward into a roof fault, the basal structures must form a duplex fault zone. The Neogene submarine sliding sheet on the Chuei Pass, Niigata Prefecture, described by Kodama et al. (1971), is another typical example with a duplex fault zone. The former example is called the imbricate-fan type, and the latter the duplex type. If the basal structures of a duplex or an imbricate-fan are found in an outcrop, together with the characteristics of soft-sediment deformation, it is probable that the base of a submarine sliding sheet occurs there.

1. Introduction

Submarine sliding is a common event in any geologic time and anywhere an adequate slope exists. Submarine slidings are particularly common in plate margin regions. However, it is difficult to determine in an outcrop whether a discordant plane corresponds to the base of a submarine sliding sheet or not, because (1) the basal structures characteristic of submarine sliding sheets are not yet clarified, and (2) epigenetic deformation tends to concentrate locally along the bases of the sheets and destroy their original structures. In order to establish criteria for how to recognize the base of a sheet, many case studies should first be made on well-preserved basal structures. The purpose of this paper is to describe an excellent example, the basal structures of the Pleistocene Chikura Submarine Sliding Sheet
in the southernmost Boso Peninsula, central Japan, and to try to develop tentative criteria for recognizing the bases of submarine sliding sheets elsewhere.

The Chikura Submarine Sliding Sheet is composed mainly of the upper part of the Plio-Pleistocene Chikura Group, and slipped toward the NNW sometime between 0.9 and 0.65 Ma. The sliding occurred on a landward-dipping back slope of a thrust, in the imbricated thrust zone above the So-o Trough (Fig. 1). The stratigraphy in and around the Chikura Submarine Sliding Sheet has been studied by means of key tuff layers, microfossils and paleomagnetism. Thus, the shape and dimension of the sheet can be reconstructed. The direction, timing and transportation distance are also evaluated. Furthermore, the basal structures are well-preserved; these are useful for achieving the goal of this paper.

Fig. 1. Surveyed area and bathymetry of its surroundings. Depth contours (in meters) are after Maritime Safety Agency of Japan (1982). Dotted area is deeper than 2500 m. Thrusts in the Kamogawa Submarine Cliff are after Nakamura et al. (1987). Thrusts with filled and open teeth are recognized with and without seismic evidence, respectively. NEJ, NA, PAC, and PHS in inserted map: Northeast Japan, North American, Pacific, and Philippine Sea Plates, respectively.

2. Geology of the Southernmost Part of the Boso Peninsula

The southernmost part of the Boso Peninsula is situated only about 30 km north of the convergent boundary between the Northeast Japan (North American?) and Philippine Sea Plates (Fig. 1). This region is underlain by thick marine sediments of late Miocene to Pleistocene age; these are folded and faulted along ENE-trends.

2.1 Stratigraphy

The first systematic study of the stratigraphy in the southernmost part of the Boso Peninsula was made by Naruse et al. (1951). Recently, stratigraphic studies have been
greatly improved by the application of tephrochronology, biostratigraphy and magnetostratigraphy by many workers, such as MAIYA (1972), MAEDA and IMAMIYA (1978), SHIBUYA and SHINADA (1986), NAKAO et al. (1986), and SUGIYAMA (1986). KOYAMA and KOTAKE (1987) and KOTAKE (1988) summarized these studies using their original data, and presented the precise stratigraphic subdivisions (Fig. 2). We briefly introduce this stratigraphy, based mainly on KOTAKE (1988). The complete bibliography of the stratigraphy is presented in KOTAKE (1988).

**Ishido Group (late Miocene)**

This group is composed mainly of siltstone with tuff layers. It is unconformably overlain by the Chikura Group.

**Hedate Formation (early Pliocene)**

This formation is composed of alternating beds of scoriaceous coarse sandstone and

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![Fig. 2. Stratigraphy of the southernmost part of the Boso Peninsula based mainly on KOTAKE (1988). RD in the Mera Formation designates the Rendaiji Gravel Member.](image-url)
siltstone. The sandstone includes abundant silt fragments of granule to cobble size. The thickness of this formation is more than 350 m; it is unconformably overlain by the Chikura Group.

*Chikura Group (about 3.0 to 0.9 Ma)*

This group is divided into seven formations: the Shirahama, Shiramazu, Mera, Minamiasai, Hata, Mano, and Kanamari Formations, in an upward sequence.

*Shirahama Formation:* This formation is composed of alternating beds of tuffaceous sandstone and conglomerate. It is more than 120 m thick.

*Shiramazu Formation:* This 450 m thick formation is composed of turbidite of tuffaceous sandstone and siltstone.

*Mera Formation:* This formation is composed mainly of massive siltstone with tuff and sandstone layers, and is 400 m thick. This formation is intercalated with the Rendaiji Conglomerate Member, consisting mainly of angular silt fragments of pebble to cobble size.

*Minamiasai Formation:* This formation is lithologically divided into two parts, a lower (100 m thick) and an upper (350 m thick). The upper part is composed of alternating beds of sandstone and siltstone, and the lower of massive siltstone with tuff layers.

*Hata Formation:* This formation is composed of laminated tuffaceous sandstone and siltstone with abundant tuff layers. Two key tuff layers, NJ and KO, are widely traceable, and a key tuff layer, OR, occurs in the Sakuna Anticline, as precisely described in KOTAKE (1988). NJ and KO are equivalent to the TY and KS of SHIBUYA and SHINDAI (1986), respectively. The formation thickness is 480 m. This formation is not distributed north of the Uda Fault (Fig. 3).

*Mano Formation:* This formation is divided into three parts: the lower (tuffaceous sandstone with tuff layers), the middle (tuffaceous silt with tuff layers), and the upper (alternating beds of tuffaceous coarse sandstone and silty sandstone). The total thickness is 150 m. The age of this formation is determined biostratigraphically to be between the age of the middle Hata Formation and that of the middle Kanamari Formation.

*Kanamari Formation:* This formation is composed of alternating beds of tuffaceous sandstone and siltstone with abundant tuff layers. It conformably overlies the Hata Formation, and is unconformably overlain in turn by the Toyofusa Group. Its thickness is more than 350 m.

*Toyofusa Group (about 0.7 Ma to 0.4 Ma)*

The lithology of this group exhibits remarkable lateral changes. The lower part of the group consists of the Kamo Formation, to the north of the Uda Fault, and the Takigawa Formation, to the south of the Uda Fault. The upper part consists of the Higashinagata Formation, including the Takigawa Conglomerate Member to the north of the Uda Fault.

*Kamo Formation:* This 200 m thick formation is composed of fine to coarse tuffaceous sandstone.

*Kanamaribata Formation:* This formation is composed mainly of alternating beds of coarse tuffaceous sandstone and siltstone. It yields abundant fossil shells and bryozoa. The thickness is 280 m.

*Higashinagata Formation:* The lithology of this formation changes remarkably from south to north: it is composed mainly of massive siltstone near Komoguchi, and of an alternation of conglomerate to sandstone and massive siltstone south of Komoguchi. The conglomerate-dominant facies north of Komoguchi is called the “Takigawa Conglomerate Member.” The total thickness reaches a maximum of 450 m.

### 2.2 Geologic structure

The geologic structure of this region is characterized by E-to ENE-trending faults and
folds (Fig. 3). There are two faults, the Uda and the Kawaguchi Faults, both of which are NNW-dipping reverse. From north Chikura to Komoguchi, the Uda Fault has a vertical displacement of more than 600 m, while the Kawaguchi Fault, extending 3 km north of Shirahama, has a vertical displacement of less than 100 m. The Uda Fault has not moved since the beginning of the deposition of the Toyofusa Group, because the fault does not displace the rocks of the Toyofusa Group.

There are two main types of folds, those with wavelengths of 1 to 2 km, and those with wavelengths of less than several hundred meters. The folds of the former type, the Sakuna Anticline and the Kanamari, Nemoto and Nagaogawa Synclines, have long axial traces from the eastern to the western margins of this area. They are believed to have grown under regional NNW-trending compressive stress, in association with motion on the NNW-dipping reverse faults described above. This is because (1) their axial traces are almost parallel to the strikes of the faults, and (2) they show south vergence. The basal fault, indicated by solid lines with solid circles, is explained in the succeeding sections.
3. Basal Structures Associated with Stratigraphic Omissions in the Chikura Group

3.1 Stratigraphic omissions in the Hata Formation

The precise correlations in the Hata Formation, which were made by means of the key tuff layers NJ and KO, reveal the following omissions in the stratigraphic succession in the Hata Formation, as shown in Fig. 4 (Kotake, 1988; Sugiyama, 1986). (1) In the southern limbs of the Nagaogawa and the Kanamari Synclines, the lower part of the Hata Formation intercalating NJ is absent. Both boundaries d–e and g–h, between the Hata and the underlying Formations, are almost parallel to the neighboring bedding planes of both Formations. (2) To the east of the Nemoto Syncline, the upper part intercalating KO is absent. The boundary m–n between the Hata and the overlying Kanamarin Formations is oblique to the neighboring bedding planes of both Formations. (3) In the western part of the southern limb of the Kanamari Syncline, the boundary k–j between the Hata and the underlying Mera Formations makes a high angle with the neighboring bedding planes of both Formations. (4) In the southern limb of the Sakuna Anticline, NJ is absent toward the east.

Kotake (1988) explained the cause of these omissions as follows. Boundaries d–e and g–h in Fig. 4, both of which are between the Hata and the underlying Formations, are disconformities. The boundary m–n, between the Hata and the overlying Kanamari Formations, is an angular unconformity, as is the boundary k–j, between the Hata and the

Fig. 4. Traces of the basal fault of the Chikusa Sheet. The basal fault corresponds to the base of the disturbed part in section 3. OR, NJ, and KO are the key tuff layers in the Hata Formation. Locs A to J (in the open circles) indicate outcrops displaying the disturbed part. The abbreviations of the formation names are the same as those in Fig. 3. Points a to k on the boundary between the Hata and underlying formations, and points m, n, and p on the boundary between the Hata and overlying formations are explained in the text.
underlying Mera Formations in the western part of the Kanamari Syncline, NJ, in the southern limb of the Sakuna Anticline, is not traceable toward the south, because it is cut by a fault parallel to the bedding planes, whose outcrops occur at A and B.

From the explanations of KOTAKE (1988) mentioned above, the following inferences can be drawn with respect to the submarine topography during the sedimentation of the Hata and Kanamari Formations. The disconformity h–g connects eastward with the angular unconformity g–p–f at g, and westward with the conformity h–i at h. The disconformity h–g and the conformity h–i correspond to wide, flat seafloors. The angular unconformity g–p–f corresponds to a rather high submarine cliff above the seafloor. The cliff was not buried by the Hata Formation, and still remained during the sedimentation of the Kanamari Formation. The disconformity d–e, which probably continues to the disconformity g–h to the south, connects with the conformity d–c–b at d. On the other hand, the conformity p–n connects with the angular unconformity m–n at n. The former corresponds to a rather wide, flat seafloor during the early stages of the Kanamari Formation, and the latter is a small submarine channel eroded into the upper part of the Hata Formation. Thus, the inferences from KOTAKE’s (1988) explanations present the existence of very complicated submarine topography during sedimentation of the Hata and the Kanamari Formations. Although such complexities usually cause remarkable facies changes, no facies changes in support of them are reported. Therefore, it is necessary to re-examine KOTAKE’s (1988) explanation for the stratigraphic omissions in the Hata Formation.

3.2 Basal structures associated with the stratigraphic omissions in the Hata Formation

The strata of the Hata Formation are disorderly brecciated and chaotically mixed, with a matrix of liquefied sandstone just above the lithologic boundary between the Hata and the underlying Formations. This is clearly observed at Locs. C, D, and E in the southern limb of the Kanamari Syncline and at Locs. F, G, H, and J in the southern limb of the Nagaogawa Syncline (Fig. 4). The full sequence from the underlying Formation across the disturbed beds to the Hata Formation is well-exposed at Locs. G, H, and J. The outcrop at Loc. H is precisely described below as a typical example of the disturbed parts.

Between the undisturbed beds of the Hata and the underlying Mera Formations, the disturbed zone is exposed in an outcrop about 40 m in length along the north-trending valley (Fig. 5). The undisturbed beds of the two Formations are almost parallel to each other, and the disturbed interval is divided into three zones: shear, imbricated fault, and brecciation zones, in an upward sequence.

Shear zone

This zone is parallel to the undisturbed beds of both Formations, is 170 cm in width, and divided into two subzones: fragmentation-dominant (140 cm in width) and sheardominant (30 cm in width), in an upward sequence (Figs. 6 and 7). The fragmentation-dominant subzone is composed of angular siltstone fragments in a siltstone matrix (Fig. 7), its weathered surface resembles a conglomerate bed (Fig. 8). This is why the fragmentation-dominant subzone has been misinterpreted to be a basal conglomerate resting on an unconformity. In the lower part (from the lower boundary to the F3 fault), the fragmentation is so weak that the original textures of the siltstone and laminated sandstone layers of the Mera Formation can still be recognized. The size of the siltstone fragments becomes smaller upward, from more than several centimeters (lowermost part) to several millimeters (uppermost part). The F3 and f5 faults run parallel to this zone (Fig. 6). The hanging wall of these faults is interpreted to have been downthrown northward, because minor faults, such as f7, which occur between F3 (sole fault) and f5 (roof fault), show a downthrown
Fig. 5. Sketch of the disturbed part along the N-trending valley at Loc. H in Fig. 4. Coordinates d and h indicate horizontal and vertical scales in meters. Attitude symbols are drawn with north upward on the figure. $F_i$ to $F_5$ and $F_6$ faults. Ud: undisturbed beds, SZ: shear zone. a to e: measuring points of bedding plane attitude (see Fig. 12). Solid arrow: slip sense of fault.

Fig. 6. Detailed sketch of the shear zone and the basal part of the imbricated fault zone. $f_1$ to $f_3$: minor faults, S: sandstone layer of the Mera Formation. A and B: locations of Figs. 10 and 8, respectively. Open arrow: slip sense of minor faults. Other symbols are the same as those of Fig. 5.
Fig. 7. Photograph of the main part of the shear zone.

Fig. 8. Rock sample of the fragmentation-dominant subzone at B. Note conglomerate-like texture.
convergence.

The shear-dominant subzone is composed of the Hata Formation, which is densely faulted parallel to the zone. $f_3$ in Fig. 6 is a continuous fault which forms the upper boundary of the zone. The faults become more closely spaced, from several centimeters (upper) to less than 1 cm (lower). Furthermore, minor faults roughly parallel to the faults in this subzone are also found in the fragmentation-dominant subzone, and in dislocated siltstone blocks beneath $F_B$ (Figs. 9 and 10). These relationships suggest that the relative displacement between the Hata and the Mera Formations is mostly concentrated along the boundary between the two subzones. This is also supported by the above-mentioned fact that fragmented siltstones in the fragmentation-dominant subzone become smaller in size toward $F_B$, the boundary between the two subzones. On the other hand, $F_B$, the lower boundary of the shear-dominant subzone, is not composed of a single fault plane, but mainly of several faults that are adjacent to each other. This suggests that the rocks of the shear-dominant subzone were repeatedly scraped off from the fault planes, broken into angular siltstone blocks, and mixed with siltstone blocks of the Mera Formation fragmented by the faulting. No fault gouge is found along any of the faults in the shear zone.

The shear-dominant subzone is composed of the Hata Formation. In the fragmentation-dominant subzone, the lower half, below $F_3$, was derived from the Mera Formation, and the upper half is composed of a mixture of both formations (Fig. 6).

Imbricated fault zone

This zone is characterized by NNW-verging imbricated faults, $F_1$, $F_2$, $F_3$, and $F_4$ (Fig. 5), and $f_1$, $f_2$, $f_3$, and $f_4$ (Fig. 6). The lower part of this zone is shown in Fig. 11. These faults

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Fig. 9. Photograph of the shear-dominant subzone and the upper part of the fragmentation-dominant subzone. Rectangle A, located at A in Fig. 6, corresponds to the area shown in Fig. 10.
Fig. 10. Detailed photograph along $F_B$ at A in Fig. 9. Note the shear structure in the fragmentation-dominant subzone.

Fig. 11. Photograph of the lower part of the imbricated fault zone. Note the minor fractures parallel to the imbricated faults $f_3, f_4$, and $F_3$. 
strike in the same direction as, and dip northward more gently than, the shear zone. They dislocate their hanging walls up to 30 centimeters in a NNW-downthrown sense. Associated with $F_1$ and $F_3$, a NNW-downward verging drag fold occurs. Furthermore, these imbricated faults have the same slip-sense as the shear zone. These facts suggest that these imbricated faults and the drag fold were formed associated with the NNW-downthrown movement of the Hata Formation relative to the Mera Formation, along the shear zone. This is supported by the evidence that the poles of the imbricated faults in this zone and the faults in the shear zone are located nearly on the same great circle, the pole of which indicates the axis of the drag fold (strike: N72°E, dip: 8°E) (Fig.12)

**Brecciation zone**

Siltstone, alternating beds of sandstone and siltstone, and felsic tuff, all of which are constituents of the Hata Formation, are broken into angular blocks in various sizes, and accumulate chaotically within a liquefied sandstone matrix (Fig. 13). The siltstone blocks are irregularly brecciated and contain numerous fractures. Brecciated siltstones are not divided into small, widely separated pieces, although liquefied sandstone was frequently injected from the matrix into the fractures.

The lower boundary of this zone is not obvious, because it grades downward into the underlying imbricated-fault zone. Along the upper boundary, shear structures are not found. Furthermore, nowhere did we observe sedimentary structures indicating that the overlying undisturbed beds abut the brecciation or erode into it. The upper boundary probably corresponds to the front where the blocks of rocks were exfoliated from the main part of the undisturbed beds and fell down into the brecciation zone. Therefore, the brecciation zone was formed after the deposition of the overlying undisturbed beds.

**Original arrangement of the basal structures**

These structures are schematically illustrated in Fig. 14, restoring the undisturbed beds of the Hata and the underlying Formations to their original horizontal attitudes. They were formed as a result of the NNW-trending movement of the Hata Formation, relative to the

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*Fig. 12. Stereographic projection of the faults in the shear and imbricated fault zones, strata forming a drag fold in the imbricated fault zone, and the undisturbed beds of the Mera and the Hata Formations on the lower hemisphere. Dotted line indicates the great circle, the pole of which corresponds to the axis of the drag fold.*
Fig. 13. Blocks of brecciated siltstone (BS) and matrix of liquefied sandstone (LS) near $d=36$ and $h=2$ in Fig. 5 in the brecciation zone.

Fig. 14. Basal structures schematically reconstructed. Striped arrow indicate the transportation direction of the Hata Formation. Small solid arrows along individual faults indicates sense of slip. SZ: shear zone.
underlying Mera Formation, along the shear zone. The movement was caused by faulting, 
the displacement of which was concentrated along the shear zone. Therefore, the shear zone 
is regarded as the basal fault of the disturbed part and the overlying undisturbed beds of the 
Hata Formation. The basal fault runs from Locs. H to C, and probably extends northward 
through Loc. B to Loc. A, because a fault parallel to the adjacent bedding planes is observed 
(KOTAKE, 1988). The Kawaguchi Fault, the Sakuna Anticline, and the Kanamari and the 
Nagaogawa Synclines were formed after the motion of the basal fault.

4. Submarine Sliding Sheet in the Chikura Group

4.1 Geometry of the basal fault

The traces of the basal fault are indicated by solid lines with solid circles in Figs. 3 and 
4. The fault segments, d–e and g–h in Fig. 4, run almost parallel to the bedding planes along 
the lower boundary of the Hata Formation. These segments define a wide bottom to the 
submarine sliding sheet. However, the eastern segment g–f, east of the Nagaogawa Syncline, 
cuts diagonally through the bedding planes of the Hata and Kanamari Formations. This 
westward-dipping segment forms a rather steep fringe on the eastern side. The western 
segments, h–h and j–k, also cut diagonally through the bedding planes of the Hata 
Formation; j–k cuts diagonally through the Kanamari bedding planes as well. These 
eastward-dipping segments form a rather steep fringe on the western side. These lines of 
evidence suggest that the geometry of the basal fault was, as a whole, a wide flat bottom 
with rather steep fringes along both NNW-trending sides before the formation of NNW-
trending faults and folds. The bottom is about 6 km in width and extends more than several 
kilometers in the NNW-direction. The mass of rocks overlying the basal fault is composed 
of a small part of the Minamiasai Formation and the Hata and the Kanamari Formations. 
Its thickness is about 700 m, only 1/10 the length of the bottom side. The rock mass 
overlying the basal fault seems to have a thin plate-like shape.

4.2 Probable origin of the basal fault

The strata in the imbricated fault zone have been dragged in a ductile manner by the 
imbricated faults. Liquefied sandstone is dominant in the brecciation zone. Therefore, the 
basal structures were produced when the strata were unconsolidated and saturated with 
water. In the fragmentation-dominant subzone of the shear zone, the strata were broken 
into angular fragments in a brittle manner. This brittle deformation is believed to have been 
caused by the presence of excess pore pressure in a water-saturated environment. The 
absence of fault gouge in the shear-dominant subzone is also reasonably explained by this 
environment, as it is often observed in soft-sediment deformation. Thus, it is concluded that 
the basal fault formed in a water-saturated environment.

The most important problem is to determine what mechanism formed the basal fault 
and its associated structures. The following two lines of evidence are essential: (1) the basal 
fault formed in a water-saturated environment, and (2) the rock mass overlying the basal 
fault has a thin, plate-like shape, before it was deformed by faulting and folding. The 
probable mechanism explaining these two features is submarine sliding: the overlying mass 
is a submarine sliding sheet, and the basal fault corresponds to the base of the sheet. This is 
supported by the fact that intraformational disturbances in a submarine sliding sheet in the 
Triassic Inai Group were formed in a confined, deep-seated aquifer (KAMADA, 1980). In 
this paper, the submarine sliding in the Chikura Group is called the Chikura Submarine 
Sliding, and its sheet is called the Chikura Sheet.
4.3 Dimensions and timing of the Chikura Submarine Sliding

Strictly speaking, the bottom of the submarine sheet is not a completely flat surface, because the basal fault does not always occur at the same stratigraphic horizon. At Locs. G, H and J, it occurs several meters below the key tuff layer KO, while it is more than 100 m below this same layer at Locs. C and F (Fig. 15). A 50 m thick siltstone is missing at Locs. G, H, and J, although it occurs below the alternating beds of sandstone and siltstone at Locs. C and F. The siltstone is thought to have been broken into blocks that constitute the brecciated siltstone in the brecciation zone at Locs. G, H, and J. The segment of the basal fault from Locs. G to J corresponds to a flat bottom portion of the Chikura Sheet, as does that from Locs. C to F. However, the segment from Locs. F to G corresponds to a ramp which dips northward several degrees, judging from the NNW-trending horizontal separation between F and G. Another ramp is estimated to occur between Locs. C and B, because the segment dislocates the lower horizon toward the north. Therefore, the NNW-trending profile of the basal fault is estimated to show a staircase trajectory which has rather wide flats and small ramps dipping N several degrees.

The western half of the submarine sliding sheet, S, is schematically reconstructed in Fig. 16. The longitudinal length does not exceed 10 km, because the Kanamari Formation is not distributed north of the Uda Fault (Fig. 3). The width is about 6 km, and the thickness is about 0.7 km, as already mentioned. The transport direction is toward the NNW; the displacement is estimated to be about 2 km from the separation of the Minamiasai Formation. The sheet was inevitably folded during sliding on ramps, and these sliding-induced folds are outlined in Fig. 16. It is possible that some of these folds preserve their original forms, or have been growing under regional NNW-trending compressive stress. However, these sliding-induced folds cannot yet be identified from the present folds in Fig. 3.

The submarine sliding occurred after the deposition of the Kanamari Formation and before that of the Toyofusa Group, that is, sometime between 0.9 and 0.65 Ma.

4.4 Tectonic setting of the Chikura submarine sliding

Tilting of the seafloor is absolutely necessary for submarine sliding to take place. For the Chikura Submarine Sliding, the seafloor tilted through the motion of one of the ENE-trending thrusts which occur widely from the So-o Trough to this region (Fig. 1). The fault which triggered the Chikura Submarine Sliding probably runs off the south coast of this region. The strata composed mainly of the Mera and the Hata Formations slid along the

![Diagram of columnar sections below the key tuff layer KO at Locs. C, F, G, H, and J.](image-url)
NNW-dipping back slope of the fault, and produced the Chikura Sheet. The distance of the sliding did not exceed 2 km, because the advance was interrupted by the rather steep cliff along the Uda Fault, which is also one of the ENE-trending thrusts. The cliff is estimated to have been several hundreds meters high from the paleontological study of KOTAKE (1988). The fault along the south coast is still active, because the coastal region of the southernmost Boso Peninsula has been uplifted by repeated fault movements (SUGIMURA and NARUSE, 1954, 1955; YOKOTA, 1978).

These ENE-trending thrusts form an imbricated fault zone verging SSE above the Philippine Sea Plate subducting from the So-o Trough (Fig. 1). The Chikura Sheet is one of those submarine sliding sheets which have frequently occurred on landward-dipping benches (the back slope of an imbricated fault zone). In general, landward submarine slidings are probably usual in similar tectonic situations, although they are rarely reported.

5. Discussion

Imbricated thrusts associated with Neogene submarine sliding have been thoroughly reported at Cape Taitomisaki in the southeast Boso Peninsula (YAMAUCHI, 1969) and at the Chuei Pass in Niigata Prefecture (KODAMA et al., 1971). YAMAUCHI (1969) and KODAMA et al. (1971) estimated that these thrusts bifurcate from a basal fault and reach the upper surface of an individual submarine sheet. Their interpretations are seemingly supported by the evidence that there is a zone of compressional folding and thrusting at the toe of the slumps (LEWIS, 1971). However, their upper surfaces are not recognized in either the Cape Taitomisaki or the Chuei Pass examples. Furthermore, a distinct roof fault runs above the upper terminals of these thrusts at the Chuei Pass, according to KODAMA et al. (1971). These thrusts and the roof fault probably compose a duplex fault zone, together with the unexposed basal fault. It is, therefore, highly probable that these faults compose the basal structures of sliding sheets. If so, these imbricated thrusts can correspond to the basal structures of the Chikura Sheet.

The imbricated thrusts at the Chuei Pass are re-examined in detail here. Many thrusts occur verging toward the transport direction of the sheet at intervals of about 15 m. These
thrusts probably bifurcate from the unexposed basal fault, drag the surrounding strata in a ductile manner, and produce folds similar to the imbricated fault zone of the Chikura Sheet. The zone where the thrusts develop corresponds to the imbricated fault zone of the Chikura Sheet. The thrusts at the Chuei Pass merge into the roof fault. On the other hand, the imbricated fault zone in the Chikura Sheet does not have such a roof fault, and instead shows an imbricate fan. The displacements of the imbricated faults in the Chikura Sheet diverge upward and contribute to the production of the brecciation zone. Therefore, the roof fault at the Chuei Pass corresponds to the brecciation zone of the Chikura Sheet; in other words, the roof fault is regarded as a very thin brecciation zone. Here, the basal structures in the sheet at the Chuei Pass are tentatively designated as being of the duplex type, and those in the Chikura Sheet the imbricate-fan type.

An example of the imbricate-fan type is seen in a Neogene submarine sheet in the Boso Peninsula, as reported by MITSUNASHI and KAKIMI (1964). On a basal fault with no gouge, a disturbed zone about 10 m thick occurs where many minor faults displace and drag the strata. The zone corresponds to the imbricated fault zone of the Chikura Sheet. The disturbed zone is overlain by "fluidized silt" 30 to 40 cm thick, which is composed of siltstone with a secondary, i.e., post-depositional flow structure of sandstone layers. The flow structure was probably associated with the formation of the underlying zone. Therefore, the "fluidized silt" corresponds to the brecciation zone of the Chikura Sheet, where the sandstone matrix was predominantly liquefied. As is the case with the Chikura Sheet, no fault occurs between the "fluidized silt" and the overlying undisturbed strata. This fact also supports the similarity of the two examples.

According to the above discussion, submarine slidings will be grouped into two types on the basis of their basal structures: duplex and imbricate-fan types. In the case of the duplex type, a roof fault occurs between the basal disturbed zone and the overlying undisturbed beds of the sheet. The duplex is composed of imbricated thrusts, drag folds, and roof and basal faults. A typical example of the duplex type is exposed at the Chuei Pass. In the case of the imbricate-fan type, a brecciation zone with fluidization and/or liquefaction replaces the roof fault. A typical example of the imbricate-fan type is the Chikura Sheet. However, this is only a working hypothesis. Further examinations will make clear the variations in the basal structures as well as their causes.

It can be generalized that the fundamental arrangement of the basal structures, in an upward sequence, is the shear zone, the imbricated fault zone, and the brecciation zone, in the imbricate-fan type; the basal structures form a duplex fault zone in the duplex type. In both types, soft-sediment deformation is dominant. If duplex or imbricate-fan structures are observed in an outcrop, together with characteristic structures of soft-sediment deformation, it is highly probable that the base of a submarine sliding sheet occurs nearby. The above combination is a tentative criterion for recognizing a submarine sliding sheet, which further studies should refine.

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