Field logs of Paleogene sediments in Sakito-Oshima and Amakusa-Shimoshima areas, northwestern Kyushu, Southwest Japan

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Abstract

This article reports field observation of Paleogene clastic successions in two areas in northwestern Kyushu and provides a preliminary interpretation of their sedimentary environments on the basis of lithological facies. In the sections from Sakito-Oshima Island, the Ichigoshima, Sakito, Maze and Tokuman Formations were logged. They are, except their basal part, interpreted to represent an overall transgression from fluvial, estuarine, shelf, and then to deep marine environments during the latest Eocene to Early Oligocene. A sedimentary cycle of a Middle Eocene age from nonmarine, to deep marine, and then to shallow marine environments was able to be reconstructed from the observation in the sections from the Amakusa-Shimoshima area, where the Fukuregi, Shikiyama and Toishi Formations were examined. These evidence will be adapted in the interpretation of fossil dinoflagellate cysts and molluscs which is the principal intent of the present project.

Key words: Amakusa Coal-Field, environment, estuary, fluvial, northwestern Kyushu, Sakito-Matsushima Coal-Field, sedimentary facies, shallow marine, turbidites

Introduction

This article records field observation of outcrops of the Paleogene sediments in the northwestern Kyushu region, which two of the authors, H.K. and T.M., visited during a field work in October 2002 to collect samples for studies on fossil dinoflagellate cysts and molluscs. The outcrops include formally-designated type localities and reference localities of the established chronostratigraphic stages. The field logs are followed by a short note on sedimentary envi-

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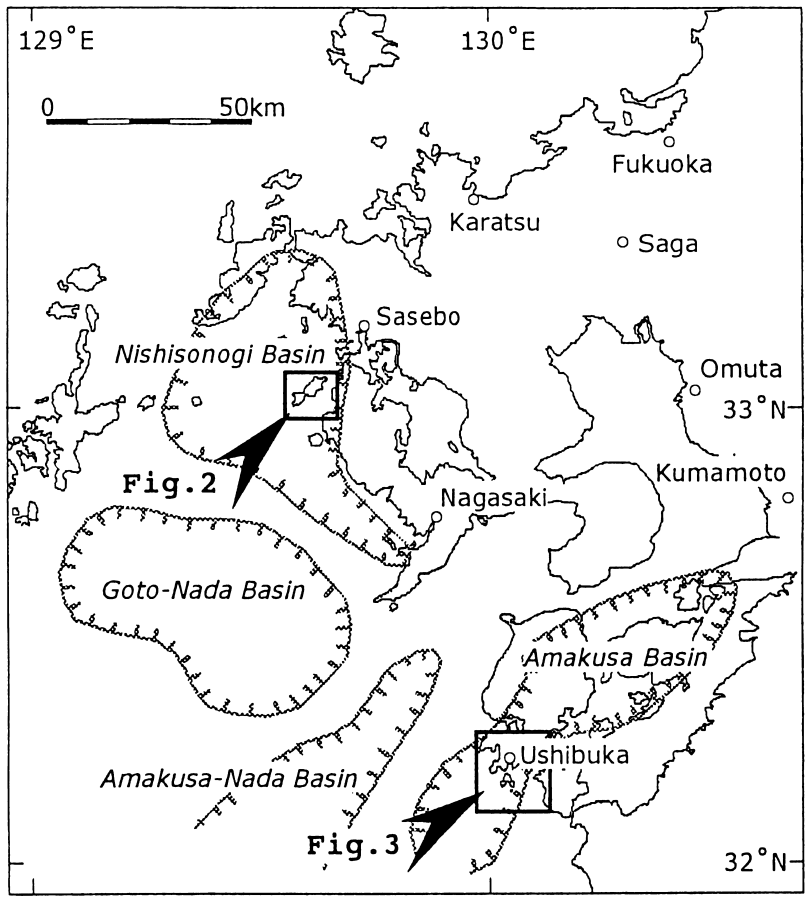

Fig. 1. Index map. Paleogene basin configuration after Iwata and Kameo (2001).

ronments that are inferred from lithological facies.

In the northwestern Kyushu region within the Inner Zone of Southwest Japan, Paleogene sediments mostly of shallow-marine origin are widely exposed. According to the subsurface and offshore data from coal mining and oil exploration industries, these Paleogene sediments are segmented into several basins that are delineated by basement uplifts (Fig. 1; Ito et al., 1999; Iwata and Kameo, 2001). For intra- and inter-regional correlation of these sediments, a chronostratigraphic framework was presented on the basis of molluscan biostratigraphy (Mizuno, 1962–1963, 1964), which has been accepted without major modifications. Geochronology of the chronostratigraphic subdivision was provided by biostratigraphy of calcareous nannofossils (Tashiro et al., 1980; Saito and Okada, 1984; Okada, 1992), radiolarians (Yasuda, 1984; Aita et al., 1997) and planktonic foraminifers (Murata, 1961; Yasuda, 1984; Tsuchi et al., 1987) as well as by radiometric dating (Miyachi and Sakai, 1991; Ozaki and

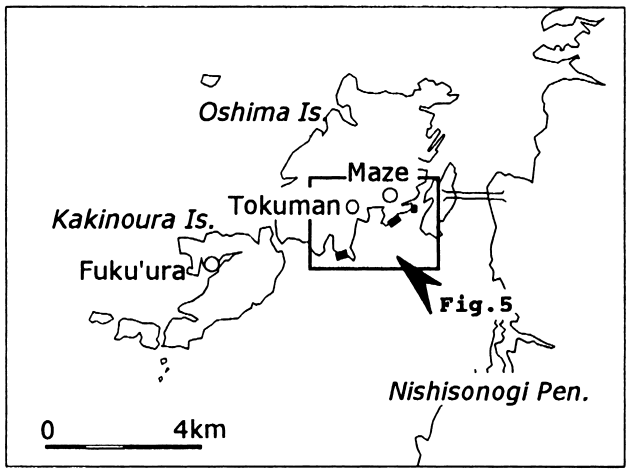

Fig. 2. Locations of sections (thick lines) from Sakito-Oshima Island.

Hamasaki, 1991), although these age constraints are based on limited number of localities only.

On the other hand, organic-walled fossil dinoflagellate cysts from the Paleogene have been reported from various areas in Northeast Honshu, Hokkaido and Sakhalin during the last decade and their biostratigraphy has solved local and regional Paleogene stratigraphic problems (e.g., Kurita et al., 1992; Kurita and Obuse, 1994, 1997; Kurita and Kusunoki, 1997). Recently Paleogene dinoflagellate cysts have been reported from several localities in the eastern Setouchi region within the Inner Zone of Southwest Japan (e.g., Yamamoto et al., 2000). In addition, diverse dinoflagellate cyst assemblages were documented from offshore basins in the East China Sea (Yu, 1989). These previous studies drew our intensive attention to the Paleogene of the northwestern Kyushu region, because Paleogene dinoflagellate cysts have not yet been reported from the region that should have one of the most significant stratigraphic records of the Paleogene in the northwestern Pacific.

Localities and background

The outcrops described here were selected from the two areas; Sakito-Oshima Island in the Nishisonogi Coal-Field and the Amakusa-Shimoshima area in the Amakusa Coal-Field (Figs. 1–3). Lithostratigraphy, chronostratigraphy and geochronology for the studied sections are compiled from previous studies in Fig. 4.

Sakito-Oshima Island, about 16 km southwest of Sasebo City, is located at the northwestern edge of the Nishisonogi Peninsula (Figs. 1, 2). Constituting part of the northeastern extremity of the Nishisonogi sedimentary basin (Fig. 1; Iwata and Kameo, 2001), this island has the type

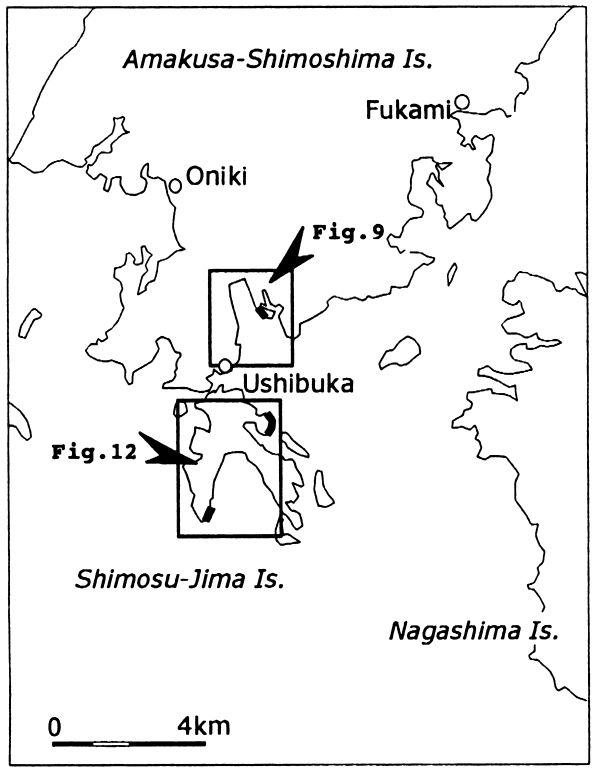

Fig. 3. Locations of sections (thick lines) from Amakusa-Shimoshima area.

localities of the Maze and Nishisonogi Stages (Mizuno, 1964). According to the calcareous nannofossil biostratigraphy, which was based on samples from the northern coast of the island and an offshore borehole 20 km south of the island, the geologic age of the stages was given as the latest Eocene to Early Oligocene (Fig. 4; Okada, 1992).

The present study logged three coastal sections in the southeastern part of Sakito-Oshima Island (Fig. 2). The three sections are present 0.5 km to 1.2 km apart to each other. The Ichigoshima section encompasses the upper part of the Ichigoshima Formation (Nagahama and Matsui, 1958) and the lower part of the Sakito Formation (Matsushita, 1949). These formations constitute the Matsushima Group (Nagao, 1927) and belong to the Funazu Stage (Mizuno, 1962–1963, 1964). In the Maze section, the uppermost part of the Sakito Formation and the type section of the Maze Formation (Nagahama and Matsui, 1958; originally described as Mase Formation) were examined. These correspond to the upper part of the Funazu Stage and the Maze Stage, respectively (Mizuno, 1962–1963, 1964). The Hamaguri section near Tokuman allowed to measure the uppermost part of the Maze Formation and the lower part of the Tokuman Formation (Nagahama and Matsui, 1958). The boundary between the Maze and Nishisonogi Stages is placed at the base of the Tokuman Formation (Mizuno, 1962–1963, 1964).

Amakusa-Shimoshima Island, lying between the East China Sea and the Yatsushiro-Kai

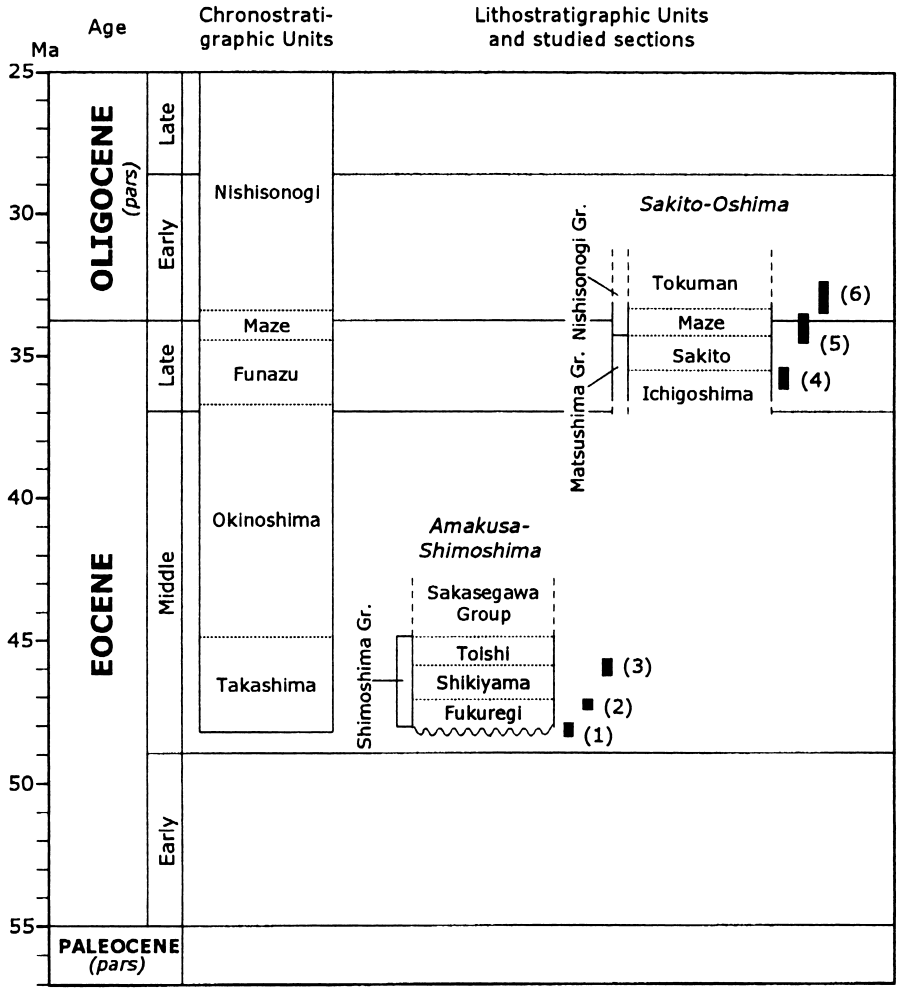

Fig. 4. Summary of stratigraphic subdivision and geochronology of Paleogene formations in studied sections. (1) Akashi section; (2) Biwakubi-Kurosaki section; (3) Komori section; (4) Ichigoshima section; (5) Maze section; (6) Hamaguri section. Stratigraphic subdivision after Matsushita (1949), Takai and Satoh (1982), and Nagahama and Matsui (1958). Chronostratigraphy after Mizuno (1962–1963, 1964). Geochronology after Okada (1992), Tashiro et al. (1980), and Yasuda (1984). Geologic time scale after Berggren et al. (1995).

Sea, constitutes the southern part of the Amakusa sedimentary basin (Fig. 1; Iwata and Kameo, 2001). In the southernmost part of the island, the Ushibuka area, exposed are the Fukuregi, Shikiyama and Toishi Formations in ascending order (Fig. 4; Matsushita, 1949; Takai and Satoh, 1982) which constitute the Shimoshima Group (Hatae, 1960a; Takai and Satoh, 1982) and represent the Takashima Stage (Mizuno, 1962, 1964). Calcareous

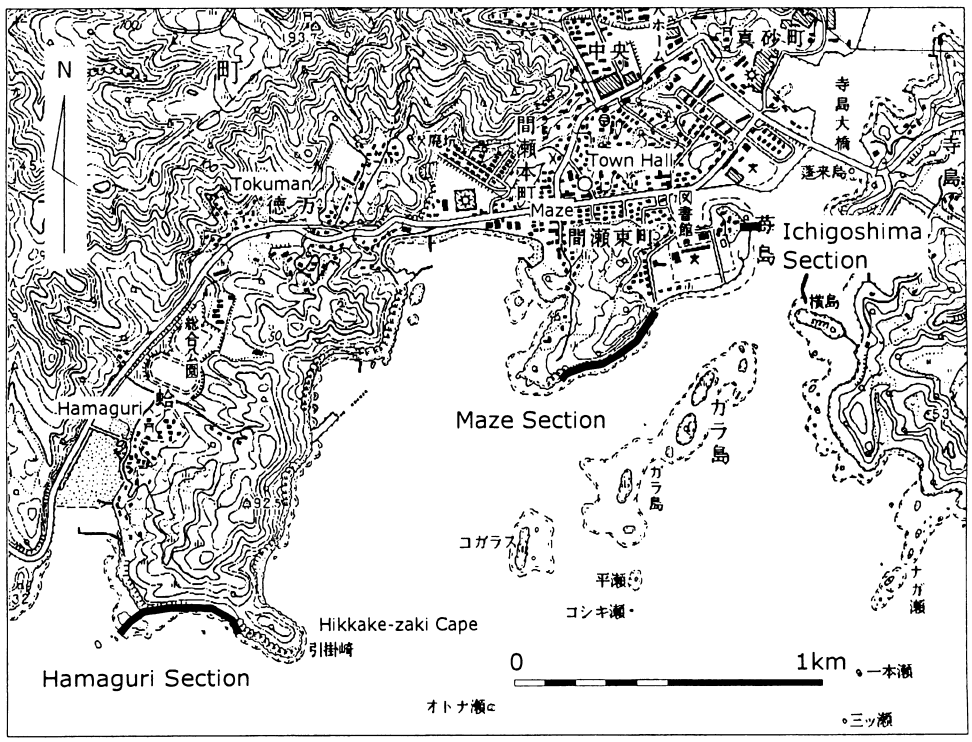

Fig. 5. Map of Ichigoshima, Maze and Hamaguri sections in Sakito-Oshima. Using topographic maps "Omodaka" and "Kakinoura", scale 1: 25,000, published by Geographical Survey Institute.

nannofossils from the basal part of the Fukuregi Formation (Tashiro et al., 1980) and planktonic foraminifers and radiolarians from the Sakasegawa Group (Yasuda, 1984) overlying the Toishi Formation indicated that the age of the Takashima Stage in the Amakusa Islands should fall within the Middle Eocene (Fig. 4).

Three sections in the Amakusa-Shimoshima areas are reported in the present study (Fig. 3). At Akashi, the basal part of the Fukuregi Formation is exposed. Along the coast near Biwakubi, the upper part of the Fukuregi Formation and the lower part of the Shikiyama Formation were examined. The Komori section provided exposures of the upper part of the Shikiyama Formation and the basal part of the Toishi Formation.

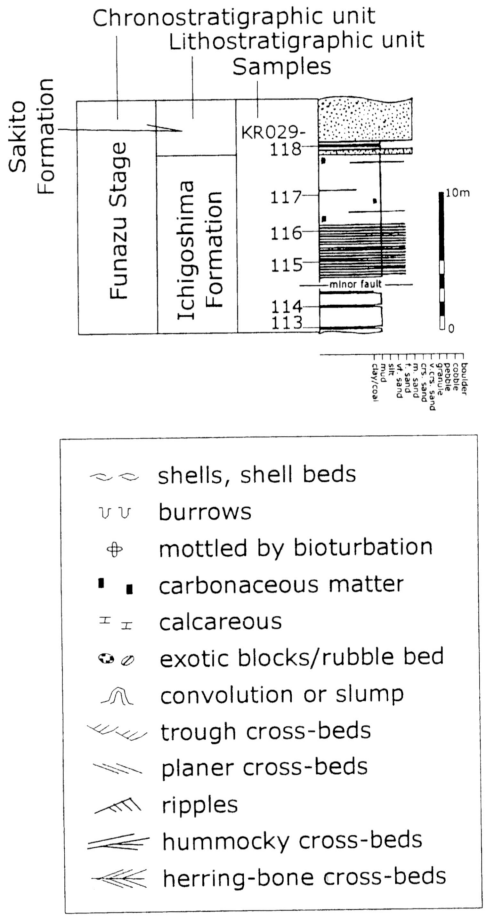

Fig. 6. Columnar section of Ichigoshima section.

Field description

1. Sections from Sakito-Oshima Island

The locality of the three sections from Sakito-Oshima Island is indicated in Fig. 5. Geologic columnar sections are presented in Figs. 6-8.

1-1. Ichigoshima section

Locality and previous studies

The Ichigoshima section, the type locality of the Ichigoshima Formation, lies at the coast immediately east of a public swimming pool at Ichigoshima, Oshima Town, Nishisonogi County, Nagasaki Prefecture (Fig. 6). This section, which provides exposures of the upper part of the Ichigoshima Formation and the lower part of the Sakito Formation, was described

formerly by Sakai et al. (1997). A 16 m-thick section was logged at this locality (Fig. 7).

Lithologic description

The lower part of the section, i.e., the upper part of the Ichigoshima Formation, is basically rich in fine-grained sediments such as siltstone and claystone. The basal 3m of the section consists of alternation of medium-grained sandstone and coal or coaly mudstone. This basal part is in a fault contact with 4 m-thick rhythmic, centimeter-scale alternation of dark gray mudstone and fine-grained sandstone, which shows slumping in part. Judging from general dip and strike in the exposures, the thin alternation overlies the basal part. The alternation is overlain by 5m-thick, gray, thin-laminated claystone-siltstone with common carbonaceous matters.

The 5 m-thick claystone - siltstone bed is overlain by a 4 m-thick section that is contrastingly rich in sandstone. This makes up the basal part of the Sakito Formation (Plate 1, Fig. 1). The very contact between the formations seems to be parallel, sharp and planer. This sandstone-rich sequence consists mostly of massive, blocky medium-grained sandstone with an intercalation of siltstone and coal beds a few meters above the formation contact. The sandstone is characteristically grayish yellow in color when weathered.

1-2. Maze section

Locality and previous studies

The Maze section is the type locality of the Maze Formation, located at the coast 500m south-southeast of the Town Hall, Oshima Town, Nishisonogi County, Nagasaki Prefecture (Fig. 5). This section provides exposures of the uppermost part of the Sakito Formation and the lower to middle part of the Maze Formation (Fig. 7).

Lithologic description

The lower part of this section, which is 30 m-thick, is composed mainly of granule conglomerate and very coarse-grained sandstone, which is characterized by trough-type cross stratification, by upward-fining beds and by dominance of black micaceous grains derived from crystalline schist with minor presence of whitish grains of aplite (Plate 1, Fig. 2). They are intercalated with decimeter-scale alternation of very fine- and medium-grained sandstones that show parallel lamination and occasional cross lamination, and contains carbonaceous matter commonly. Part of the granule conglomerate and very coarse-grained sandstone beds shows slumping or convolution structures. Within this interval, medium-grained sandstone that is seemingly mottled by bioturbation was observed at 10 m above the base of the section.

Judging from the general lithology and contrast against the overlying strata, this lower part of the section represents the uppermost part of the Sakito Formation.

Above an 8 m-thick stratigraphic gap due to poor exposure, the Maze Formation begins with a 2 m-thick conglomerate bed which grades upward from boulder to pebble. Most of the gravels are from quartzite. This conglomerate bed further grades upward into a 2 m-thick medium- to fine-grained sandstone that is evidently mottled by bioturbation with presence of

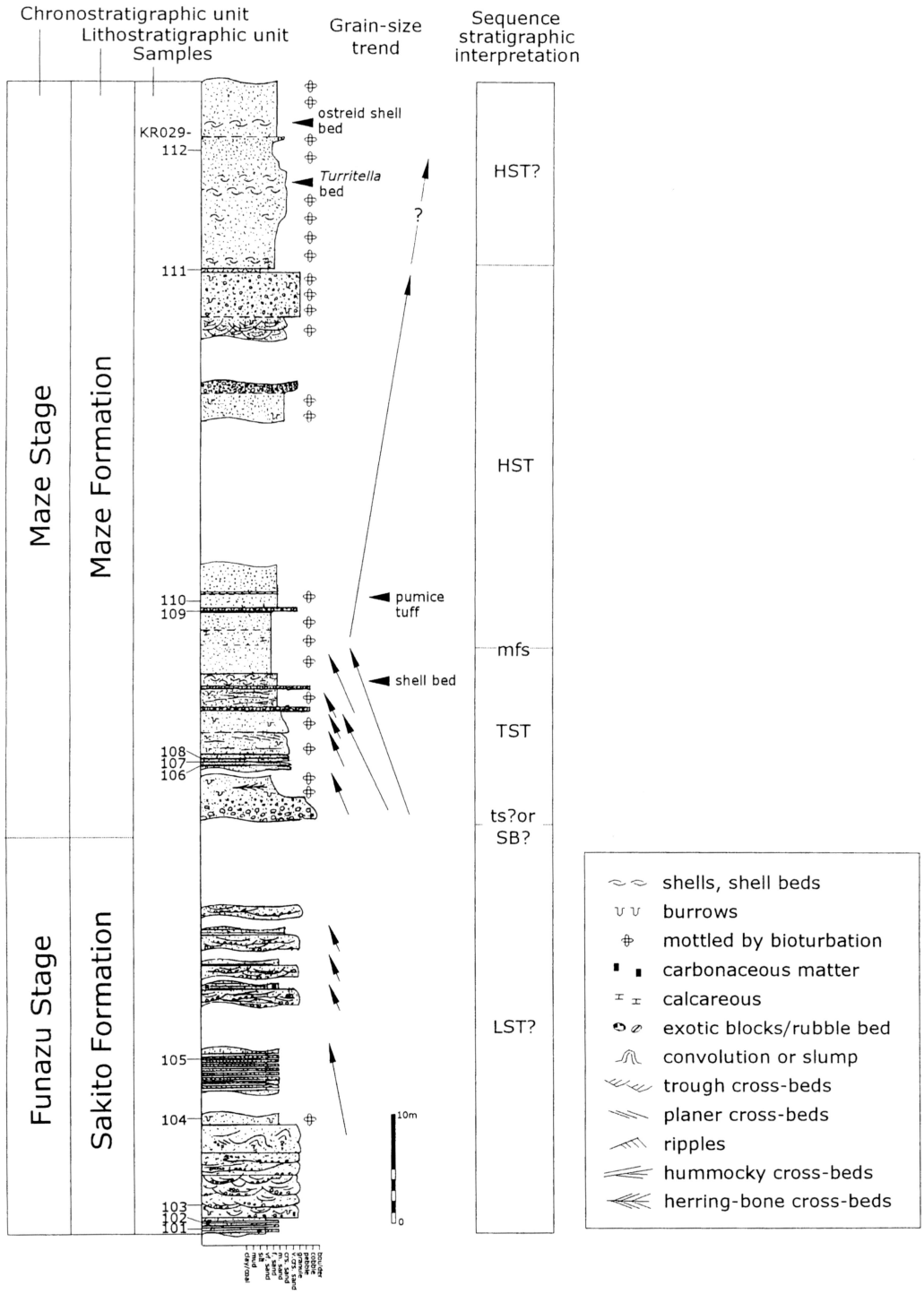

Fig. 7. Columnar section of Maze section. LST=lowstand systems tract, ts=transgressive surface, SB=sequence boundary, TST=transgressive systems tract, mfs=maximum flooding surface, HST=highstand systems tract.

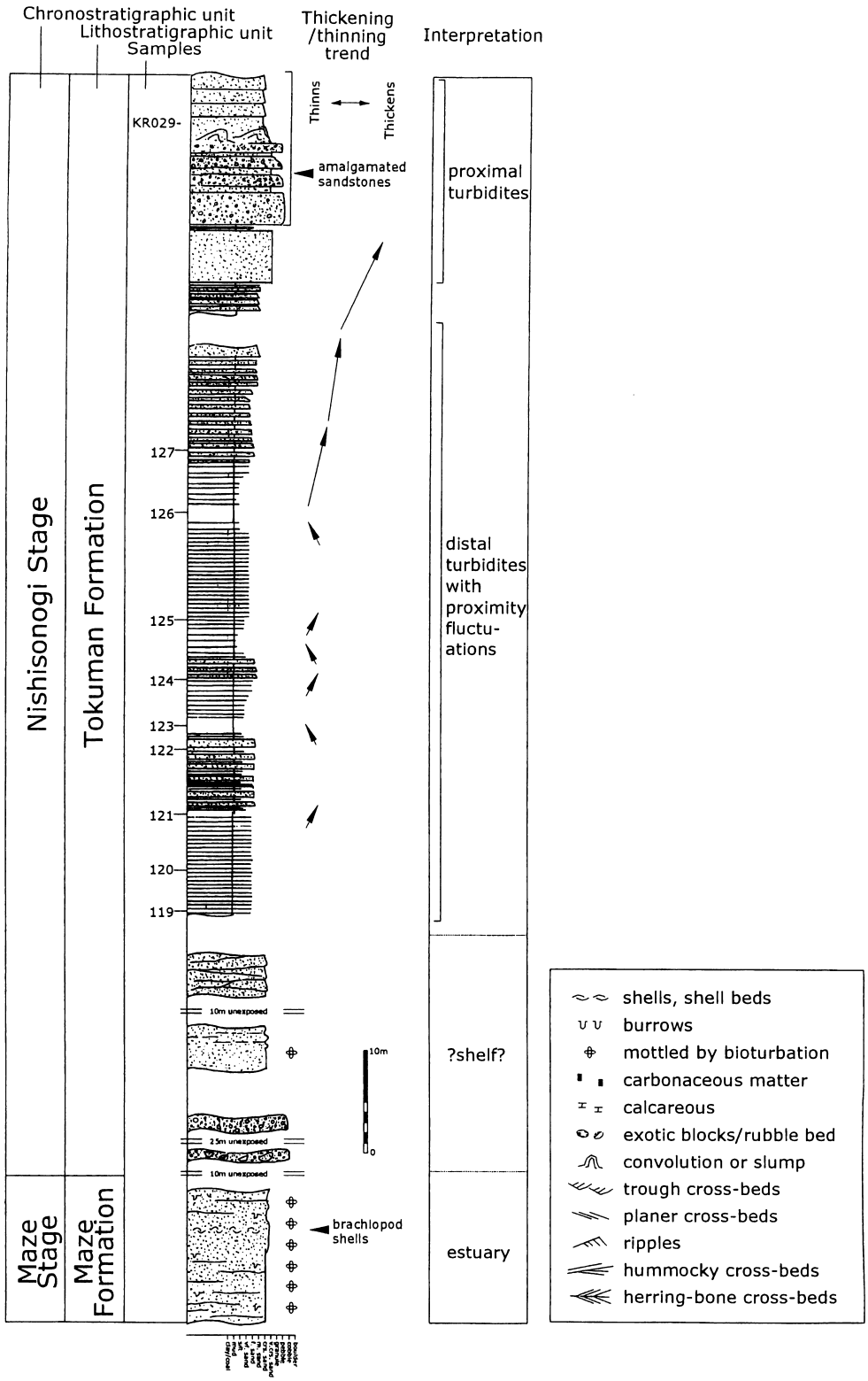

Fig. 8. Columnar section of Hamaguri section.

Ophiomorpha sp. and with probable herringbone cross stratification.

Above this basal part overlies a 7.5 m-thick section of overall upward-fining from very coarse- to fine-grained sandstone. The lower part of this interval has frequent intercalation by fissile shale with plant leaf fossils, and by pebble (partly cobble) conglomerate beds of 0.2 to 0.3 m thick (Plate 2, Fig. 1). At the middle of this interval, 6 m above the exposed formation base, a shell bed of 0.7 m thickness is present where this interval finally grades into fine, massive, mottled sandstone of 3 m thickness. The fine-grained sandstone bed is overlain by a 0.1 m-thick granule conglomerate bed and then by a 2 m-thick silty, fine- to medium-grained sandstone bed.

Again above an 8 m-thick stratigraphic gap due to poor exposure, the upper part of this section is dominated at first by coarse-grained sandstones and granule conglomerates and then by medium- to fine-grained sandstones. The coarse-grained sandstones and granule conglomerates, totally 7 m-thick, are mottled by bioturbation, in part with weak low-angled cross stratifications. The conglomerates are very poorly sorted. The medium- to fine-grained sandstones that make up the uppermost part of this section are also intensively mottled by bioturbation, lacking clear sedimentary structures. This interval yields molluscan shells abundantly, which occur occasionally as shell beds. Most common forms in this interval are those from the genus *Turritella*, although ostreid shells are dominant particularly in the uppermost part of the section.

The lower to middle part of the Maze Formation described here at its type locality shows an overall sedimentary cycle that is represented by a package of an upward-fining section and overlying upward-coarsening section. Between them, the massive, mottled, fine-grained sandstone of 3 m thick is the finest sediments within the whole section.

1-3. Hamaguri section near Tokuman

Locality and previous studies

The Hamaguri section, the type locality of the Tokuman Formation, is located at the coast between the Hamaguri village and the Hikkake-zaki Cape, Oshima Town, Nishisonogi County, Nagasaki Prefecture (Fig. 5). This section provides exposures of the uppermost part of the Maze Formation and the lower to middle part of the Tokuman Formation (Fig. 8).

Lithologic description

This section begins with a large coastal cliff of 13 m-thick, mottled fine- to coarse-grained sandstones of the uppermost part of the Maze Formation (Plate 2, Fig. 2). Their lithological characteristics include abundant mica grains and intensive bioturbation that obscures the original sedimentary structures, although weak parallel bedding planes are easily recognized. These characteristics were found mutually in the uppermost part of the Maze section.

Above an 10 m-thick stratigraphic gap due to poor exposure, a 1 m-thick, poorly-sorted cobble conglomerate is exposed. This rubble bed forms the basal part of the Tokuman Formation. Above this exposure, a 43 m-thick interval of poor exposure is present. Within this interval

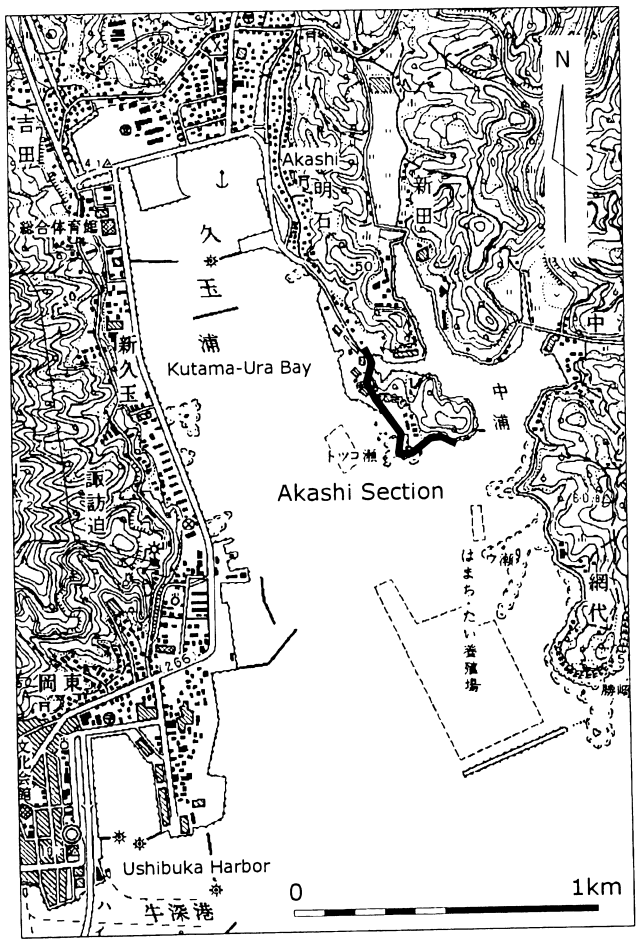

Fig. 9. Map of Akashi section in Amakusa-Shimoshima. Using topographic map "Ushibuka", scale 1: 25,000, published by Geographical Survey Institute.

including the rubble bed, the lithology shows a trend of upward-fining from cobble conglomerate, to poorly-sorted pebble conglomerate, then to coarse or very coarse-grained sandstone. The sandstone beds show parallel bedding or low-angle cross bedding. This interval which consists of conglomerates and sandstones is the basal part of the Tokuman Formation.

The basal part is overlain by a 50 m-thick section of rhythmic alternation, generally in decimeter scales, of sandstone and mudstone. The sandstone/mudstone ratio in the alternation is generally equal, although slight fluctuation occurs (Fig. 8; Plate 3, Fig. 1). In the uppermost part of this alternation interval, in particular, the sandstone/mudstone ratio is augmented.

The uppermost part of the Hamaguri section, which is 20 m thick, consists of sandstones and conglomerates (Plate 3, Fig. 2). They are generally very poorly sorted and their grain size varies from fine to granule or pebble. Thickness of some layers in this interval is in meter scale, reaching 3 to 5 m.

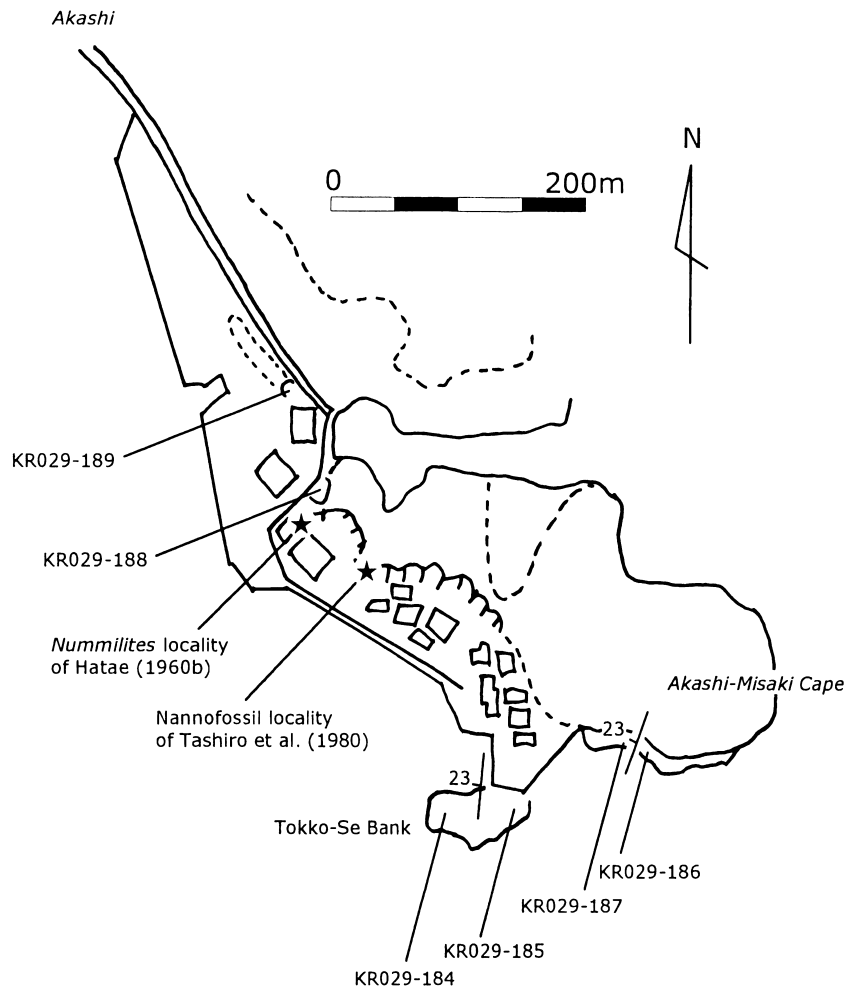

Fig. 10. Geologic sketch map of Akashi section.

2. Sections from Amakusa-Shimoshima area

The locality of the three sections from the Amakusa-Shimoshima area is shown in Figs. 9 and 12. A geologic sketch map and columnar section of the Akashi section are presented in Figs. 10 and 11 respectively. Geologic columnar sections are presented in Figs. 6–8. A geologic sketch map of the Biwakubi - Kurosaki section is shown in Fig. 13. Fig. 14 provides a columnar section of the Komori section.

2-1. Akashi section

Locality and previous studies

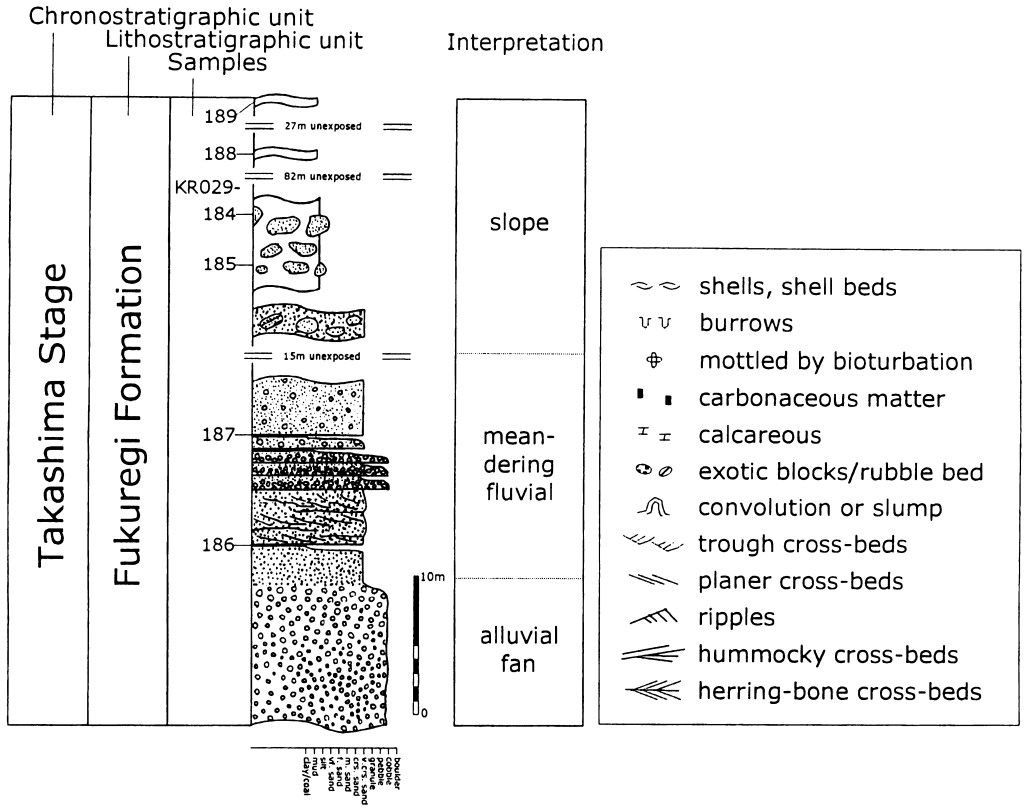

Fig. 11. Columnar section of Akashi section.

The Akashi section is located at the coast of the Kutama-Ura Bay, east of the city center of Ushibuka City, Kumamoto Prefecture (Fig. 9). This section provides exposures of the basal part of the Fukuregi Formation that has the contact with the Cretaceous basement (Figs. 10 and 11). Hatae (1960b) and Takai and Satoh (1982) reported larger foraminifers and molluscs from this section. Tashiro et al. (1980) reported calcareous nannofossils indicating an early Middle Eocene age from an exposure within this section. However, these previous fossil localities are presently not accessible due to land development.

Lithologic description

This section begins with a 10 m-thick or more, cobble, partly boulder, conglomerate that has no evident sedimentary structures. This conglomerate grades upward into 7 m-thick very coarse-grained sandstone beds that are intercalated with thin coaly mudstone layers. This basal 17 m-thick section of overall upward-fining is overlain by another upward-fining interval of 8 m thickness that consist of alternation of pebble conglomerates and coarse-grained sandstones and then coarse-grained sandstones with pebbles and granules scattered and with few siltstone and coaly mudstone layers.

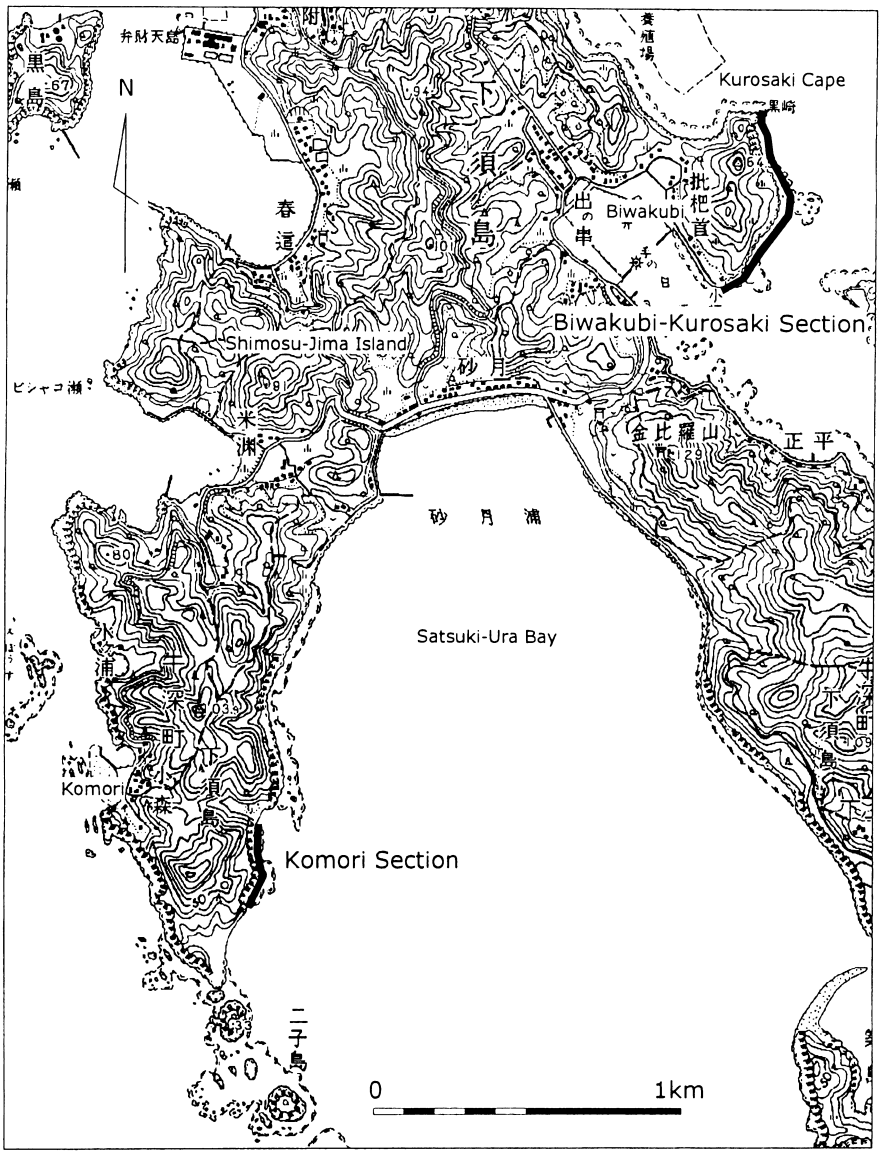

Fig. 12. Map of Biwakubi-Kurosaki and Komori sections in Amakusa-Shimoshima. Using topographic maps "Ushibuka" and "Sasue", scale 1: 25,000, published by Geographical Survey Institute.

Above a 15 m-thick stratigraphic gap due to poor exposure, a 2 m-thick, coarse-grained sandstone bed with pebbles and granules scattered is again exposed. This bed contains exotic sandstone blocks probably derived by slumping. This is overlain by a muddy interval that in part contains numerous slumped blocks irregularly. Otherwise the mudstone is massive. This interval is well exposed at the Tokko-Se Bank.

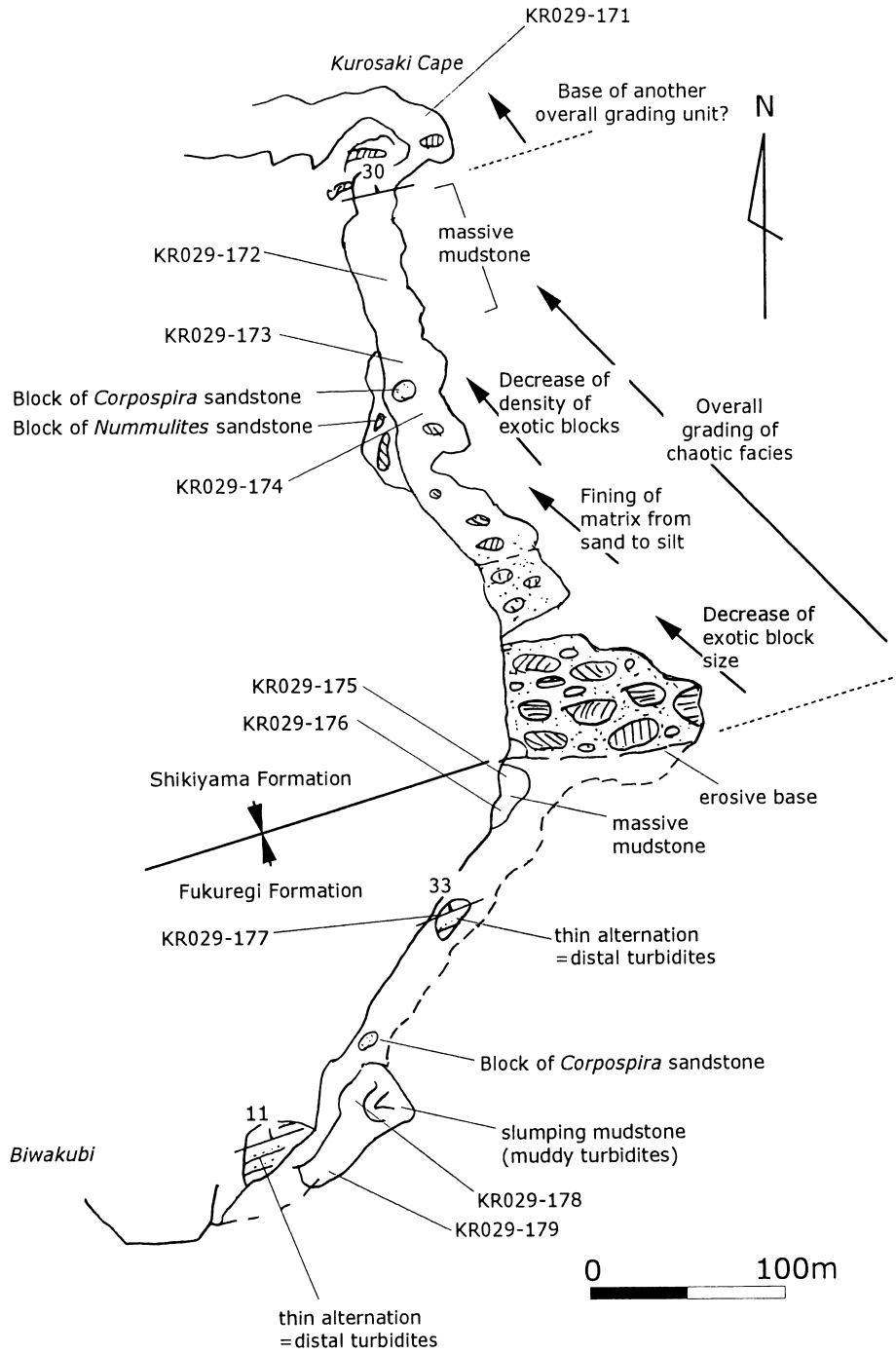

Fig. 13. Sketch map of Biwakubi-Kurosaki section.

Above that, the exposure is very limited because of land development, and only few roadside cuts provided exposures of the main part of the Fukuregi Formation that is composed of dark gray massive mudstone as far as observed.

In summary, the Akashi section shows the lithological change in the basal part of the Fukuregi Formation, the oldest Tertiary sediments in the Amakusa Coal-Field, that is characterized by an overall upward-fining trend from conglomerate to massive mudstone.

2-2. Biwakubi - Kurosaki section

Locality and previous studies

The Biwakubi - Kurosaki section is located at the northeast coast of Shimosu-Jima Island, 1.7 km southeast of the Ushibuka Harbor, Ushibuka City, Kumamoto Prefecture (Fig. 12). This section provides exposures of the uppermost part of the Fukuregi Formation and the basal part of the Shikiyama Formation (Fig. 13). Hatae (1960b) and Takai and Satoh (1982) reported molluscs and larger foraminifers from this section.

Lithologic description

The lower part of this section consists mainly of alternation of fine sandstone and mudstome of centimeter scale (Plate 4, Fig. 1). In addition , alternation of slitstone and mudstone with slumping, and massive mudstone are present. A probable isolated block of bedded sandstones commonly including a turritellid gastropod, *Colpospira*, was observed in this interval, although its host rock and their contact were not exposed (Plate 4, Fig. 2; Plate 5, Fig. 1).

The base of the Shikiyama Formation here is manifested by the erosive base of chaotic slumping beds, about 75 m-thick, which lies on the massive mudstone of the Fukuregi Formation (Plate 5, Fig. 2; Plate 6, Figs. 1 and 2; Plate 7, Figs. 1 and 2). The chaotic beds consist of up to meter-scale exotic blocks of sandstones which are probably of shallow marine origin. Within the 75 m interval, the density of blocks in matrix decreases upward, and the grain size of matrix grades upward from coarse sand to silt. In addition, the average size of the exotic blocks also grade upward smaller within the basal 20 m-thick interval (Fig. 13). This chaotic interval is overlain by 20 m-thick massive mudstone beds without exotic blocks, which means that the chaotic beds and the massive mudstone beds form a large-scale upward-grading succession.

In the uppermost part of the section at the Kurosaki Cape, mudstone containing meter-scale exotic sandstone blocks is exposed. This may be the base of another large-scale upward-grading succession.

Some of the exotic blocks of the Shikiyama Formation yielded molluscs and larger foraminifers.

2-3. Komori section

Locality and previous studies

The Komori section is located along the west coast of the Satsuki-Ura Bay near Komori

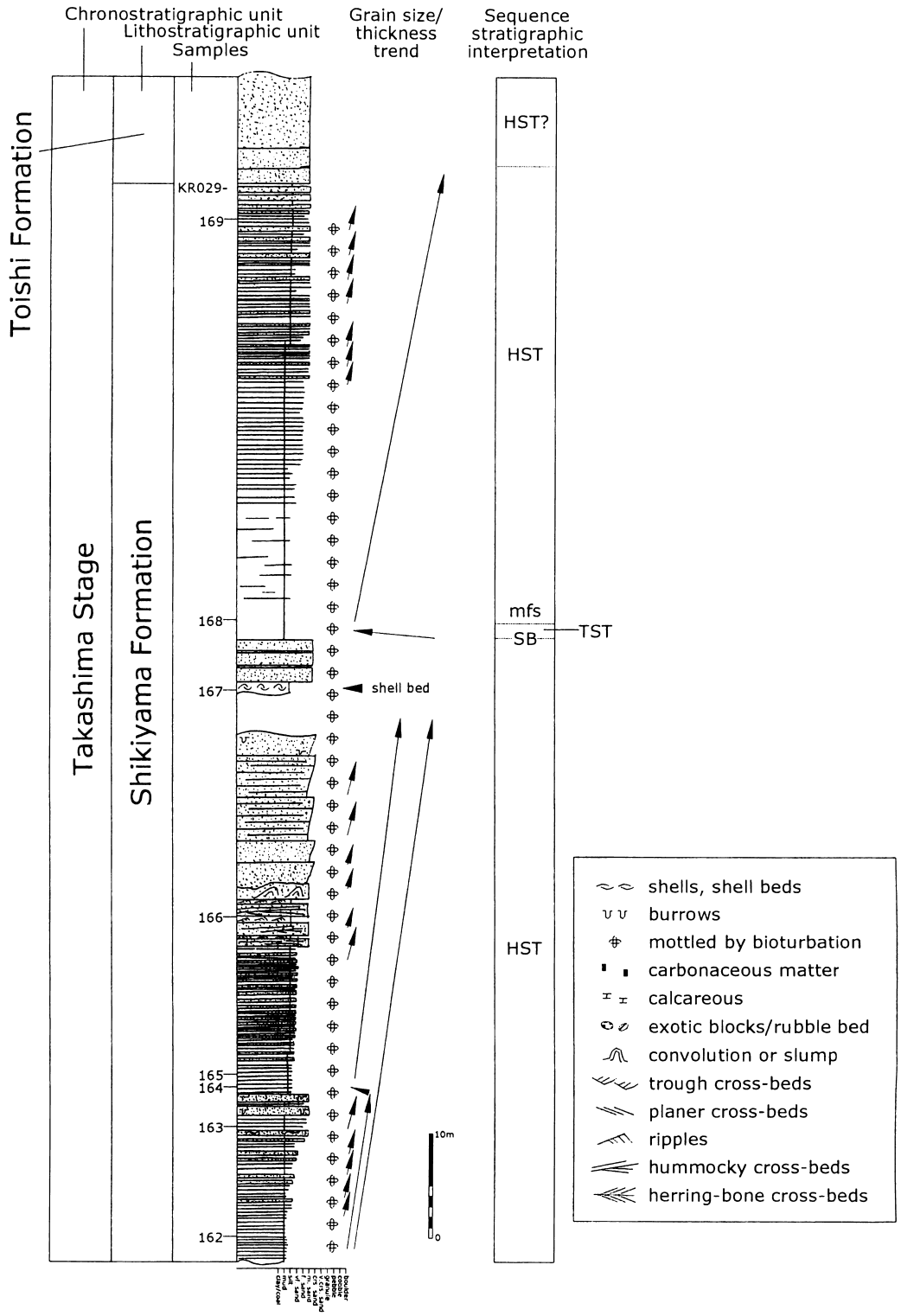

Fig. 14. Columnar section of Komori section. SB=sequence boundary, TST=transgressive systems tract, mfs=maximum flooding surface, HST=highstand systems tract.

village at the southwestern tip of the Shimosu-Jima Island, Ushibuka City, Kumamoto Prefecture (Fig. 12). Walking access to the section is possible through a well-maintained but narrow walkway eastward from the center of the Komori village that crosses over the hill down to the coast on the opposite side. The Komori section provides exposures of the uppermost part of the Shikiyama Formation and the basal part of the Toishi Formation (Fig. 14). Hatae (1960a) and Takai and Satoh (1982) reported occurrences of molluscs from this section.

Lithologic description

This section is characterized by thin alternation of sandstone and mudstone that forms stacking of multiscale upward coarsening succession (Plate 8, Fig. 1).

The lower part of the section begins with alternation of parallel-laminated fine to medium-grained sandstone and dark blackish gray mudstone, and grades up finally to the meter-scale sandstone layers that are mottled by bioturbation. Within this overall upward-coarsening interval, numerous packages of upward-coarsening of meter-scale thickness are stacked (Plate 8, Figs. 1 and 2). In addition, tens of meters scale packages are overprinted in the interval. Sandstone beds in this interval frequently show parallel bedding or otherwise small-scale ripple cross stratification which is commonly draped by mudstone (Plate 10, Fig. 1). Slumping or convolution was observed in the sandstone near the base of the meter-scale sandstone layers. The molluscan fossil horizon reported by Hatae (1960a) and by Takai and Satoh (1982) is located at a few meters below the top of this overall upward-coarsening interval, i.e., at a level 62 m above the base of this section and 43 m below the contact with the Toishi Formation.

The upper part of the section begins with a massive mudstone bed that covers the sandstone layer at the top of the lower part of the section with a sharp contact (Plate 9, Fig. 1). This mudstone immediately grades upward into alternation of fine sandstone and mudstone within a 3 m-thick interval above the base (Plate 9, Fig. 2). Above this, continuous increase in the sandstone ratio against mudstone dominates the upper part of the Komori section, although minor fluctuation, which means smaller-scale upward-coarsening packages, is frequently present. In the uppermost part of the section, the lithofacies is dominated by sandstone of meter scale thickness, that forms the basal part of the Toishi Formation (Plate 10, Fig. 2). The contact between the Shikiyama and Toishi Formations should be placed elsewhere within this gradually-changing interval from sandstone-rich alternation to sandstone-dominated succession.

Note on sedimentary environments

On the basis of the field observation described above, consideration on sedimentary environments that deposited the Paleogene sediments is intended with general sedimentological models such as Walker and James (1992). It should be noted, however, that this consideration is preliminary because it is based on a single section only, and further comprehensive study using information from neighbouring sections as well as paleontological data and others is required. A summary of sedimentary environments of the studied section is given in Fig. 15.

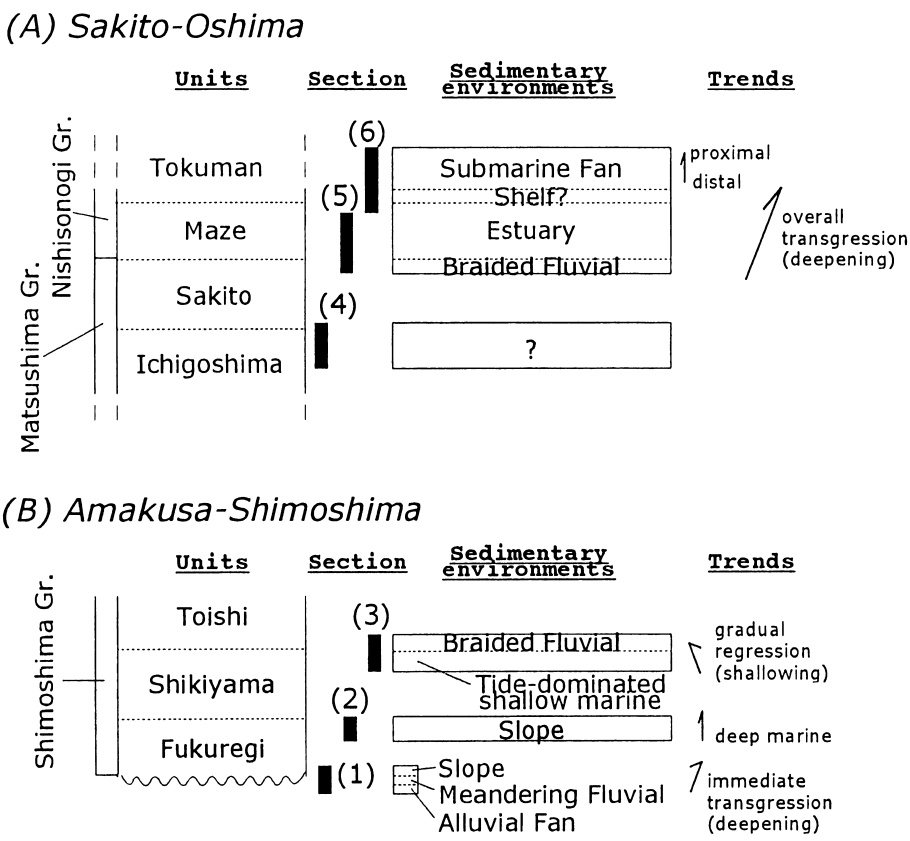

Fig. 15. Summary on sedimentary environments. (1) Akashi section; (2) Biwakubi-Kurosaki section; (3) Komori section; (4) Ichigoshima section; (5) Maze section; (6) Hamaguri section.

1. Sakito-Oshima Island

The three sections from Sakito-Oshima Island as a whole encompass the Ichigoshima, Sakito, Maze and Tokuman Formations in ascending order (Figs. 4 and 15).

The sedimentary environments of the observed section of the Ichigoshima Formation are presently indeterminable, because the rhythmic thin alternation can occur under either marine or nonmarine setting. The presence of a coal bed associated with the alternation suggests that this alternation would be related to a coastal or fluvial environment.

The Sakito Formation, which this study has observed its basal and uppermost parts only, would have deposited under a braided fluvial environment because it is dominated by cross-stratified sandstones with minor intercalation by coal beds, lacking obvious bioturbation and without evidence of marine fossils.

The Maze Formation at the Maze section is interpreted to be deposited under a sandy

estuary environment because of intensive bioturbation, temporary intercalation by shale with plant fossils (Plate 2, Fig. 1), and probable herring-bone crossbeds. When considering the sequence stratigraphic model, the maximum flooding surface (mfs), which divides the Maze Formation into the TST and the HST, can be located within the 3 m-thick, fine, massive, mottled sandstone bed, which lies 6 m above the exposed formation base (Fig. 7).

The Tokuman Formation at the Hamaguri section is composed mainly of turbidites which have deposited under a submarine fan environment. The most part of the turbidites is of distal fan facies with minor fluctuation of proximity within the fan system that was recorded as the fluctuation of sandstone content (Fig. 8; Plate 3, Fig. 1). The uppermost part of the section, however, is evidently of proximal facies, because it is rich in gravels and thick sandstones that are amalgamated. This indicates deposition within, or close to, a distributary channel on the fan (Fig. 8; Plate 3, Fig. 2). The sedimentary environment of the basal part of the Tokuman Formation is not clear because of poor exposure, although it might be related to shelf environments when considering the estuary environment of the underlying Maze Formation and the submarine fan environment of the main part of the Tokuman Formation. The sandstone rich facies of the basal part of the Tokuman Formation does not disclaim this interpretation.

In summary, if the Ichigoshima Formation is excluded, the three sections from Sakito-Oshima Island can be interpreted as a record of an overall transgression from braided fluvial (Sakito Formation), to estuary (Maze Formation), to shelf (the basal part of the Tokuman Formation), and then to submarine fan (the main part of the Tokuman Formation) environments (Fig. 15).

2. Amakusa-Shimoshima area

The three sections from the Amakusa-Shimoshima area recorded parts of the Fukuregi and Shikiyama Formations that constitute one of the oldest sections of the Paleogene in the northwestern Kyushu region (Fig. 4).

The sedimentary record of the basal part of the Fukuregi Formation in the Akashi section is considered to indicate an immediate upward-deepening (Fig. 11). The basal conglomerate may be deposited under an alluvial fan environment, because it consists exclusively of conglomerates and its uniform lithology suggests deposition by grain flow. This conglomerate is overlain by a stack of the units that fine upward from conglomerate, sandstone to coaly mudstone, which is interpreted to be of a meandering fluvial environment. These probable nonmarine succession is covered by an interval that characteristically contains abundant exotic clastic blocks. This lithology was probably formed by slumping on an offshore marine slope setting. An offshore marine environment is indicated by the occurrence of calcareous nannofossils from this facies (Tashiro et al., 1980). This chaotic facies is overlain by massive mudstone that would have been deposited under an offshore environment. As a result, the Akashi section records an immediate environmental change, i.e., deepening from continental to deep marine

within a relatively short range of sediment thickness.

The Biwakubi - Kurosaki section containing the contact between the Fukuregi and Shikiyama Formations can be characterized, as a whole, by frequent influx of eventual gravity flow of various scales. This should have occurred under an offshore setting in which muddy clastics are deposited during non-event intervals. Sediments of each eventual flow may have been deposited within a channel that was formed probably by highly-erosive preceded flows. According to this view, the contact between the Fukuregi and Shikiyama Formations corresponds to the base of a large-scale channel that accommodated thick, chaotic sediments containing vast amount of exotic blocks (Fig. 13; Plate 5, Fig. 2). Within the chaotic interval, upward-grading in the grain size of the matrices, and also possibly in the size and density of the exotic blocks, is apparent. This suggests that the deposition of this chaotic interval would have occurred as a single successive event (Fig. 13).

The depositional environment of the uppermost part of the Shikiyama Formation in the Komori section is contrasting to those in the preceding two sections. The sedimentary facies of this interval is characterized as follows; 1) multi-ordered stacking of upward-coarsening units (Fig. 14; Plate 8, Figs 1 and 2; Plate 9, Fig. 1), i.e., parasequences in a sequence stratigraphic sense, that makes up a single, large-scale upward-coarsening succession; 2) intensive bioturbation throughout the whole section; 3) dominance of small-scale ripple cross-stratification in most sandstone layers; 4) mud drapes over the sandstone layers that frequently develops to the wavy bedding (Plate 10, Fig. 1). These characteristics suggest a tide-influenced shallow marine setting. At the top of the Komori section, this shallow marine setting grades upward into a possible braided fluvial environment that deposited the Toishi Formation, showing the overall shallowing from coastal to nonmarine environments.

Within the multi-ordered stacking in the Komori section, the most conspicuous lithological discontinuity was observed at the middle of the logged interval, dividing the lower part and upper part of the section. This surface can be attributed to a sequence boundary of a certain order (Plate 9, Fig. 1).

In conclusion, the three sections from Amakusa-Shimoshima Island are interpreted to respectively represent a transgressive stage, deep marine stage, and regressive stage of a single large-scale sedimentary cycle (Fig. 15). However, this interpretation is speculative, because the observed sections do not cover the entire succession. The transgression seems to have occurred immediately within a short range of sediment thickness. The deep marine phase here is distinguishing because of intensive gravity-flow deposition. A tide-dominated shallow marine setting would have reigned the regressive phase in this area, which gradually shifted to a fluvial setting that concludes the sedimentary cycle.

Summary

This article has reported field observation of Paleogene clastic successions in two areas in northwestern Kyushu and has provided a preliminary interpretation of their sedimentary environments on the basis of lithological facies interpretation. The sections from the Sakito-Oshima area, except the basal part, is interpreted to represent an overall transgression from fluvial, estuarine, shelf, and then to deep marine environments during the latest Eocene to Early Oligocene. A sedimentary cycle of a Middle Eocene age from nonmarine, to deep marine, and then to shallow marine environments was able to be reconstructed from the observation in the sections from the Amakusa-Shimoshima area. These evidence will be adapted in the interpretation of molluscan and dinoflagellate cyst fossils which is the principal intent of the present project.

Acknowledgments

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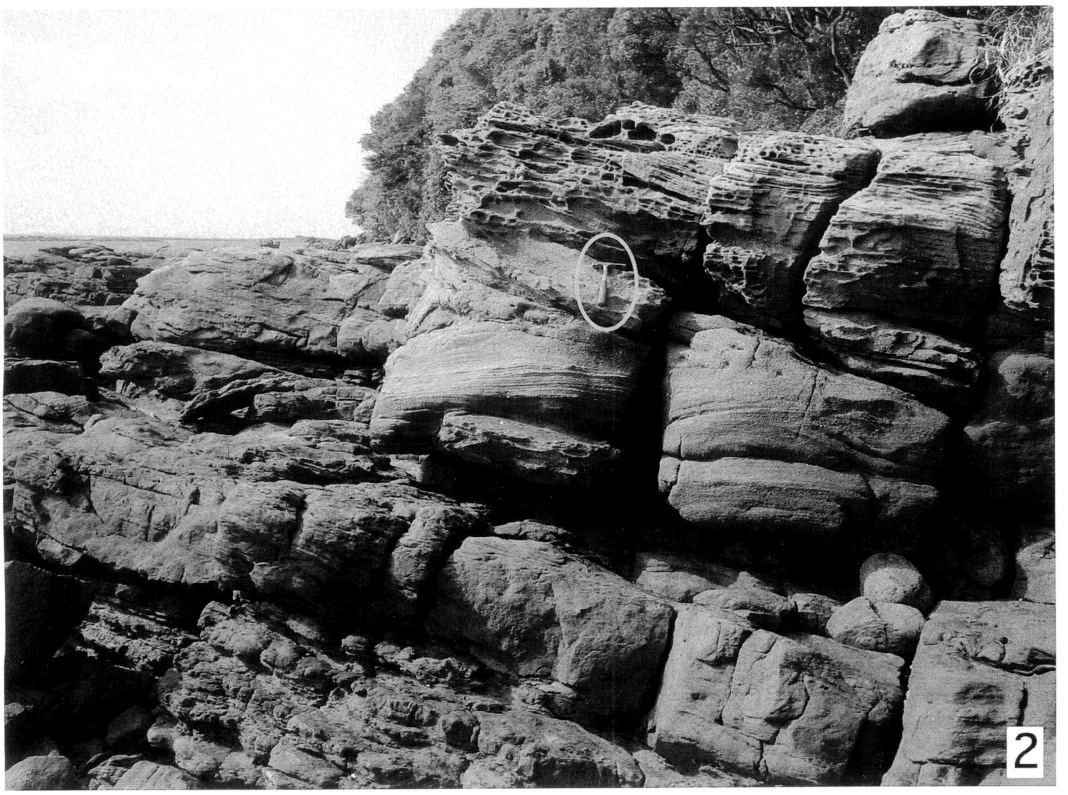
Explanation of Plate 1

Fig. 1. A coastal cliff of the upper part of the Ichigoshima section. Massive mudstone of the upper part of the Ichigoshima section overlain by blocky sandstone beds of the basal part of the Sakito Formation, Sakito-Oshima Island, Nagasaki Prefecture. The formation contact (arrows) relatively sharp and planer. Samples KR092-117 and -118 collected from this exposure.

Fig. 2. Coarse-grained sandstone beds of the upper part of the Sakito Formation at the Maze section. Trough cross-beds frequent. Samples KR092-101, -102 and -103 collected from this exposure. Hammer shaft for scale of 30 cm.

Plate 1



Explanation of Plate 2

Fig. 1. Sandstone beds mottled by bioturbation, alternated with fissile mudstones (arrows) that contain plant fossils, of the Maze Formation at the Maze section, Sakito-Oshima Island, Nagasaki Prefecture. Samples KR092-106, -107 and -108 collected from this exposure. Hammer shaft for scale of 30 cm.

Fig. 2. Thick sandstone-rich succession of the uppermost part of the Maze Formation at the base of the Hamaguri section. Planer bedding planes obscured by bioturbation.

Plate 2

Explanation of Plate 3

Fig. 1. Rhythmic alternation of sandstone and mudstone, i.e., distal turbidites, of the Tokuman Formation at the Hamaguri section, Sakito-Oshima Island, Nagasaki Prefecture. Fluctuation of sandstone content frequently observed in this section as seen in this figure that shows upward-thickening packages (arrows). Sample KR092-121 collected from this exposure. Pickax shaft for scale of 75 cm.

Fig. 2. Conglomerate beds with possible slumping structure (A) and amalgamated sandstone beds (B) of the Tokuman Formation at the uppermost part of the Hamaguri section. Interpreted as proximal turbidites. Pickax shaft for scale of 75 cm.

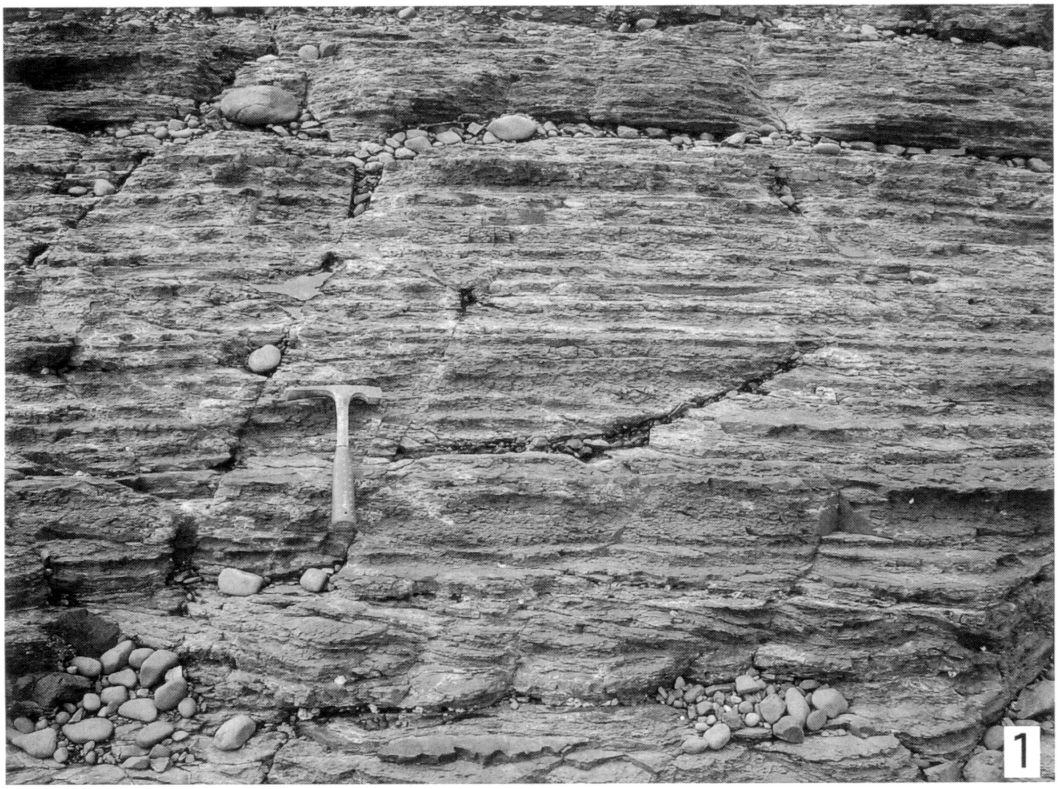
Plate 3

Explanation of Plate 4

Fig. 1. Thin, rhythmic alternation of sandstone and mudstone, i.e., distal turbidites, of the Fukuregi Formation at the base of the Biwakubi - Kurosaki section, Amakusa-Shimoshima Island, Kumamoto Prefecture. Hammer shaft for scale of 30 cm.

Fig. 2. Slumping part of distal, muddy turbidites (front) and a possible exotic sandstone block abundantly containing a turritellid gastropod, *Colpospira* (back, highlit by bordering) of the Fukuregi Formation at the Biwakubi - Kurosaki section. Contact of these not exposed here. Sample KR092-178 collected from the front part of this exposure. Pickax shaft for scale of 75 cm.

Plate 4

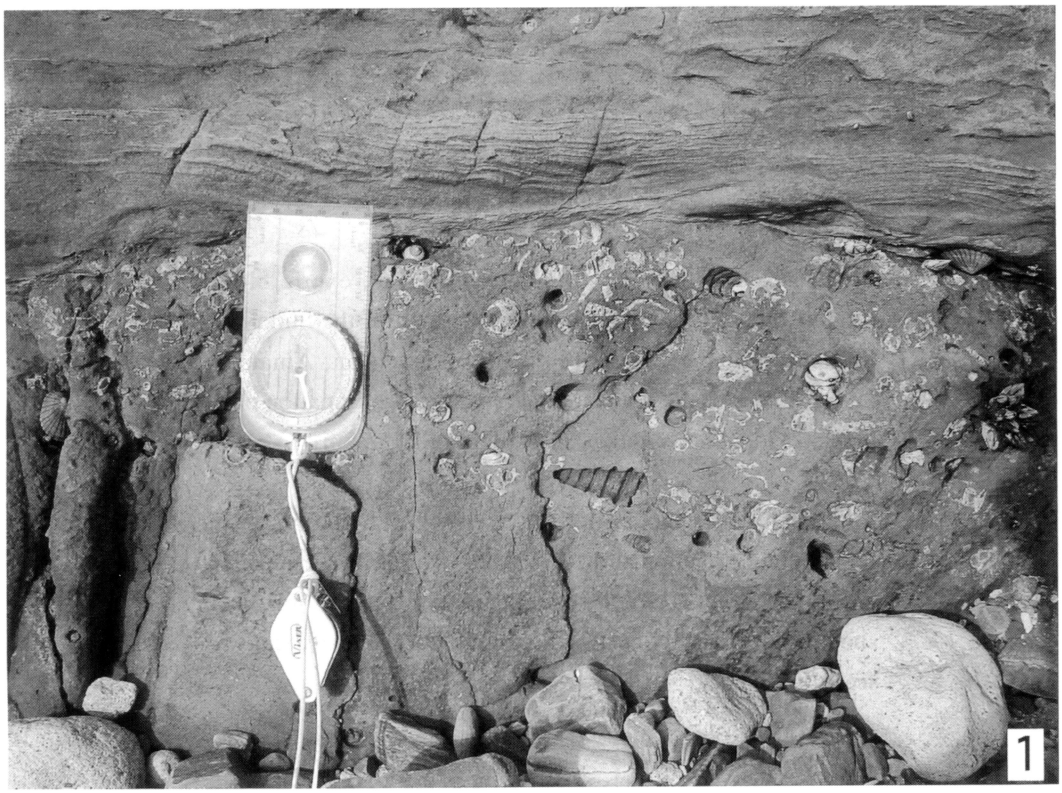


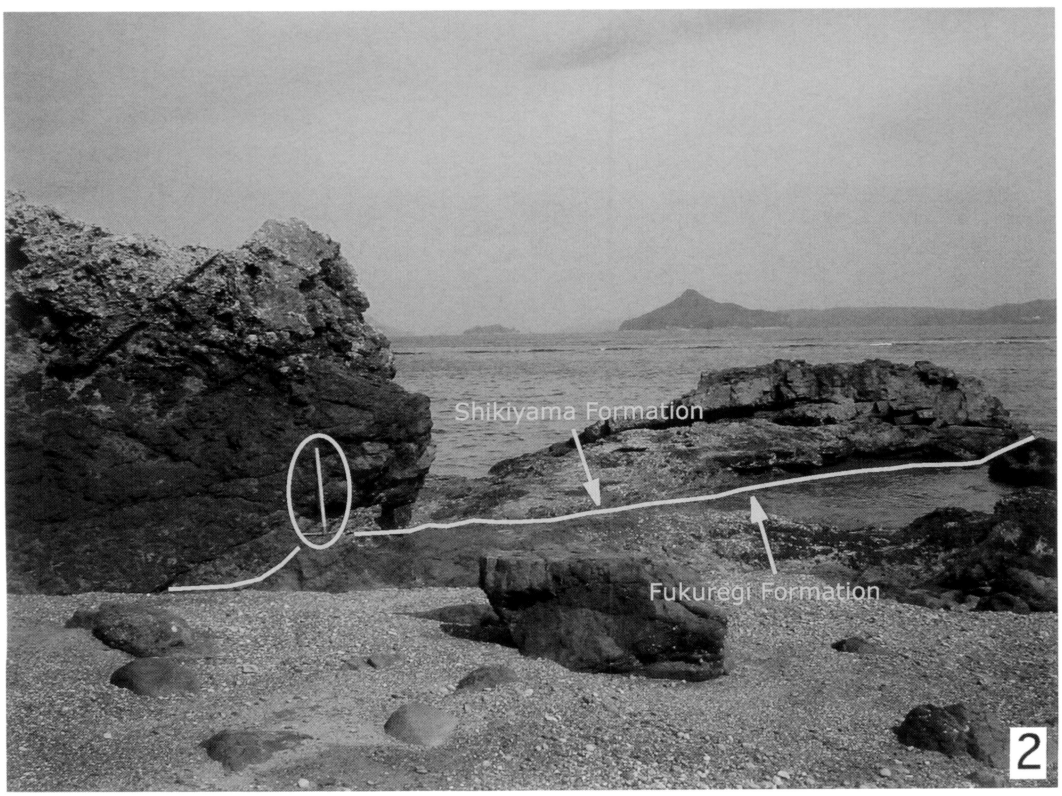
Explanation of Plate 5

Fig. 1. Mode of occurrence of *Colpospira* in a possible exotic sandstone block (Plate 4, Fig. 2) of the Fukuregi Formation at the Biwakubi - Kurosaki section, Amakusa-Shimoshima Island, Kumamoto Prefecture. Compass length for scale of 10 cm.

Fig. 2. Contact between the Fukuregi and Shikiyama Formations at the Biwakubi - Kurosaki section, marked by an erosive surface that divides massive mudstone beds of the Fukuregi Formation and chaotic facies with numerous large, exotic blocks of the basal part of the Shikiyama Formation. Pickax shaft for scale of 75 cm.

Plate 5



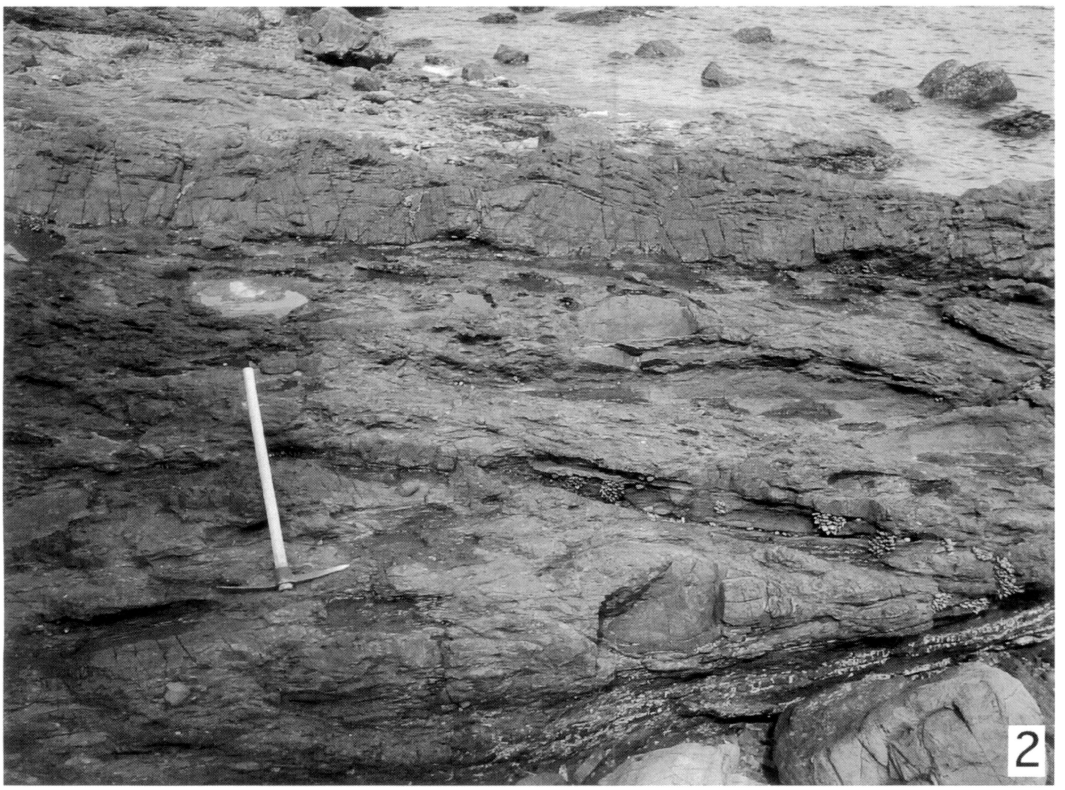


Explanation of Plate 6

Fig. 1. Chaotic facies with numerous large, exotic blocks (highlit by bordering) of the lowermost part of the Shikiyama Formation at the Biwakubi - Kurosaki section, Amakusa-Shimoshima Island, Kumamoto Prefecture. Deformation of the blocks evident here. Pickax shaft for scale of 75 cm.

Fig. 2. Chaotic facies with relatively few exotic blocks of the Shikiyama Formation at the Biwakubi - Kurosaki section. This portion ca. 30 m above the part pictured in Fig. 1 of this Plate, showing decreased density of exotic blocks. Pickax shaft for scale of 75 cm.

Plate 6

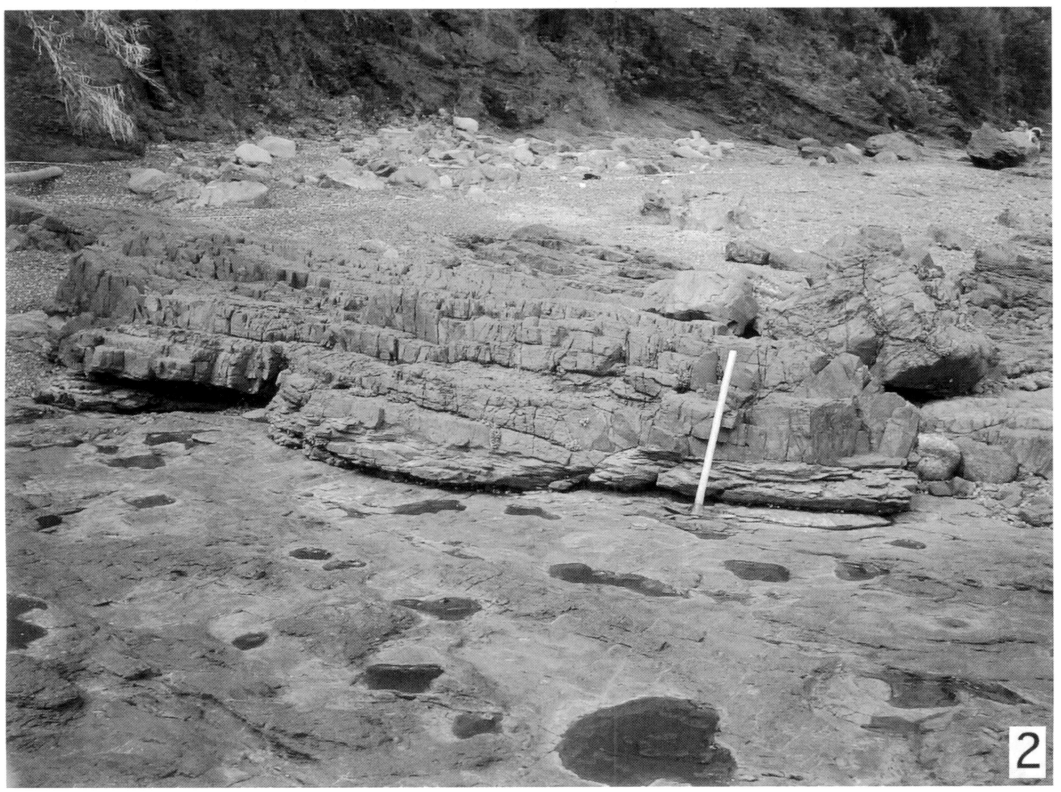


Explanation of Plate 7

Fig. 1. A close-up of the matrix part of the chaotic facies pictured in Plate 6, Fig. 2, of the Shikiyama Formation at the Biwakubi - Kurosaki section, Amakusa-Shimoshima Island, Kumamoto Prefecture. Hammer head for scale of 17 cm.

Fig. 2. A large exotic block of sandstone beds, not heavily deformed, of the Shikiyama Formation at the Biwakubi - Kurosaki section. Sample KR092-174 collected near this site. Pickax shaft for scale of 75 cm.

Plate 7

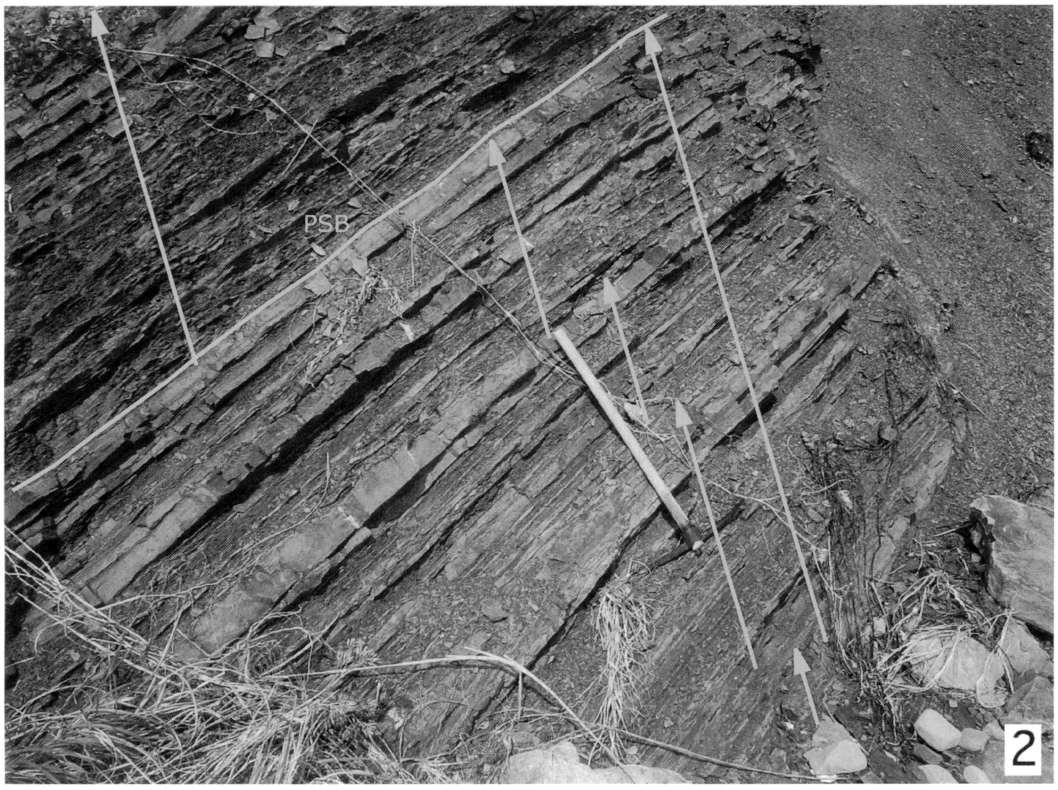


Explanation of Plate 8

Fig. 1. Rhythmic alternation of sandstone and mudstone of the upper part of the Shikiyama Formation at the Komori section, Shimosu-Jima Island at the southernmost tip of Amakusa-Shimoshima Island, Kumamoto Prefecture. Stacking pattern of upward-coarsening/thickening packages (arrows) in few meters scale apparent. Sample KR092-163 collected from this exposure.

Fig. 2. Rhythmic alternation of sandstone and mudstone of the upper part of the Shikiyama Formation at the Komori section. Stacking pattern of upward-coarsening/thickening packages (arrows) of multiple scales apparent. Surface of lithological discontinuity relatively distinctive here, attributable to a parasequence boundary (PSB). Pickax shaft for scale of 75 cm.

Plate 8



Explanation of Plate 9

Fig. 1. A sequence boundary (SB) in the upper part of the Shikiyama Formation at the Komori section, dividing the lower and upper parts of the section. Distinctive lithological contrast between thick sandstone-rich succession of the highstand systems tract (HST) of the underlying sequence and massive mudstone of the lowstand systems tract - transgressive systems tract (LST-TST) of the overlying sequence. Above the maximum flooding surface (mfs), estimated from the finest part of the muddy succession, beginning of another HST manifested by upward-increase of sand content. Shimosu-Jima Island at the southernmost tip of Amakusa-Shimoshima Island, Kumamoto Prefecture. Sample KR092-168 collected from around the mfs. Pickax shaft for scale of 75 cm.

Fig. 2. Thin alternation of sandstone and mudstone of the Shikiyama Formation at the Komori section. This exposure from the HST right above the pictured portion of Fig. 1 of this Plate. Hammer head for scale of 17 cm.

Plate 9

Explanation of Plate 10

Fig. 1. Sandstone with extensive development of small ripples, frequently draped over by muddy layers, of the uppermost part of the Shikiyama Formation at the Komori section, Shimosu-Jima Island at the southernmost tip of Amakusa-Shimoshima Island, Kumamoto Prefecture. Sample KR092-169 collected near this exposure. Compass length for scale of 10 cm.

Fig. 2. Upward-coarsening/thickening succession of the uppermost part of the Shikiyama Formation (below) that finally grades up into the blocky sandstone succession of the lower part of the Toishi Formation (above) at the Komori section.

Plate 10