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Depositional Systems and Sequence Stratigraphy of the Upper Pleistocene Paleo-Tokyo Bay Deposits

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Abstract Depositional systems including drowned valley, beach–shoreface, tidal delta and inlet, birdfoot delta and meandering river are recognizable in the Kioroshi and Joso Formations of the upper part of the upper Pleistocene Shimosa Group. They crop out in southern Ibaraki and northern Chiba Prefectures, eastern Kanto, central Japan. The Shimosa Group, deposited in Paleo-Tokyo Bay, comprises repetitive thick units of sand beds and thin mud and gravel beds and forms sedimentary cycles. Each sedimentary cycle comprises a transgressive and a regressive unit, forming a depositional sequence. The depositional systems of the Kioroshi and Joso Formations present a depositional sequence consisting of lowstand, transgressive and highstand systems tracts. In Paleo-Tokyo Bay, valleys were formed by rivers during the low sea-level stage of a glacial period (ca. 150 Ka). The subaerial unconformity shows a sequence boundary. During the early transgression associated with the subsequent interglacial period, drowned valleys were filled with estuarine and fluvial deposits. The drowned-valley-fill system corresponds to the lowstand systems tract. A transgressive surface related to an abrupt increase in accommodation and a ravinement process overlies of the drowned-valley fill. A barrier-island system, which consists of beach-shoreface, tidal delta and tidal inlet systems, retreated during transgression, and forms the transgressive systems tract (ca. 140–120 Ka). As the rate of sea-level rise slowed, the landward migration of barrier islands ceased and subsequent emergence occurred. Therefore, the maximum flooding surface corresponds to the beach-shoreface slope just before the emergence of barrier islands. During the lowering of sea level, the coastal plain prograded seawards and forms the highstand systems tract. The birdfoot-delta and meandering-river systems then developed successively (ca. 100–60 Ka). These depositional systems of the Kioroshi and Joso Formations form a depositional sequence controlled primarily by glacio-eustatic sea-level change.

Key words: Depositional systems, sequence stratigraphy, upper Pleistocene, Paleo-Tokyo Bay.

The upper Pleistocene Shimosa Group croup out in the eastern Kanto Plain, central Japan (Fig. 1). The Shimosa Group is composed of repetitive thick units of sand and thin mud and gravel beds, deposited in Paleo-Tokyo bay, which was widely distributed over the modern Kanto Plain (Yabe, 1931; Narita Research Group, 1962). The upper part of the Shimosa Group consists of the Kioroshi and Joso Formations which are exposed in southern Ibaraki Prefecture and northern Chiba Prefecture. These formations are composed of shallow marine and fluvial deposits approximately 40 m thick.

Environments of these Formations have been inferred from facies analysis. Meandering river deposits in the Joso Formation, Ibaraki, were reported by Katsura *et al.* (1980). Masuda and Okazaki (1983a) described directional structures observed in the Paleo-Tokyo Bay deposits. The Kioroshi Formation, which is well known for the occurrence of abundant molluscan shell fossils, was interpreted as delta deposits (Masuda and Okazaki, 1983b). Birdfoot-delta and meandering-river systems were recognized in the Joso Formation by Masuda and Okazaki (1983b) and Okazaki and Masuda (1989a). Other important studies were performed on deposits of longshore bars (Masuda and Okazaki, 1985; Okazaki and Masuda, 1990), beach deposits (Masuda and Yokokawa, 1988; Yokokawa and Okzazaki, 1989), wave ripples (Makino *et al.*, 1985; Makino and Masuda, 1986; Masuda and Makino, 1987), tidally influenced deposits (Masuda *et al.*, 1988; Nakayama and Masuda, 1988; Masuda *et al.*, 1989a), washover deposits (Murakoshi, 1989), and a tidal delta system (Murakoshi and Masuda, 1991). Tectonic movements of the Boso–Kashima emergence axis (Kaizuka, 1974) were deduced from that sedimentary record by Masuda and Nakazato (1988), and the existence of barrier islands was suggested (Masuda, 1989b). Okazaki and Masuda (1989b) summarized paleocurrents of Paleo-Tokyo Bay.

In this paper, all the depositional systems of Paleo-Tokyo Bay area are described and interpreted. Depositional systems of a meandering river, birdfoot delta, shoreface-beach, tidal delta, and drowned-valley fill are present in the Paleo-Tokyo Bay area. The repetition of sand, mud and gravel layers in the Shimosa Group indicates depositional cycles; each depositional cycle formed during a transgression and a subsequent regression (Ueda, 1973; Aoki and Baba, 1978; Kikuchi, 1980; Masuda, 1988; Tokuhashi and Kondo, 1989). These transgression and regression cycles reflect global sea-level changes at the time of deposition of the Shimosa Group, 500 Ka to 60 Ka (Kanto Quaternary Research, 1980; Machida *et al.*, 1980; Masuda, 1988). The Kioroshi and Joso Formations, composing the uppermost unit of the depositional cycles of the Shimosa Group, were deposited during the Shimosueyoshi transgression and the subsequent regression. Shifting of the depositional systems during sea-level change was recognized by the lateral and vertical tracing of the depositional systems in Paleo-Tokyo Bay. Tracing depositional systems through time is relatively easy because the dips of the layers in the study area are gentle, and continuous tephra layers are interbedded in the formations, being useful as marker beds. An important conclusion is that the depositional systems of the Kioroshi and Joso Formations form a depositional sequence strongly controlled by glacio-eustatic sea-level changes. The principle paleogeography consisted of a migrating the barrier system in Paleo-Tokyo Bay.

Geologic setting

The study area is situated in southern Ibaraki Prefecture and northern Chiba Prefecture, eastern Kanto (Fig. 1). The upper part of the Shimosa Group underlies the Joso Upland (including the Hitachi Upland, which consists of the Tsukuba, Inashiki, Dejima, Namekata and Kashima Uplands; and the Shimosa Upland), about 20 m to more than 100 m in altitude. The Shimosa Upland tends to be lower in altitude northwestwards and higher southeastwards. The Hitachi Upland becomes lower southwestwards and higher northeastwards. The geomorphic surfaces of these uplands are classified as follows: the Shimosa Upland is divided into the Shimosa Upper Surface, the Shimosa Lower Surface and the Chiba Terrace (Sugihara, 1970), and the Tsukuba and Inashiki Uplands are divided into the Hitachi Surface, the Ryugasaki Middle Surface and the Ryugasaki Lower Surface (Ikeda *et al.*, 1982). These surfaces correspond respectively to the Shimosueyoshi Surface, the Obaradai Surface and the Misaki Surface in southern Kanto (Sugihara, 1970; Ikeda *et al.*, 1982).

Stratigraphic division of the Shimosa Group is based on of depositional cycles (Kojima, 1959; Ueda, 1969; Aoki and Baba, 1973; Kikuchi, 1974). In this paper, the division is made on the basis results of facies analysis in terms of depositional cycles and tephrochronology (Sugihara, 1979; Nakazato, 1987MS; Unosawa *et al.*, 1988). This study formed especially on the Kioroshi Formation (ca. 10–30 m thick) and the overlying Joso Formation (ca. 1–10 m thick) (Table 1). These formations comprise the upper part of the Shimosa Group. The uppermost clay beds of the Kioroshi and Joso Formations are regarded as the Joso Clay (Nakamura and Fukuda, 1953). In this paper, the Joso Clay is demonstrated to be conformable with the subjacent, previously defined the Kioroshi and Ryugasaki Formations. The former Ryugasaki Formation and the Joso Clay are collectively redefined as the Joso Formation (Kodama *et al.*, 1981). The "Kanto Loam" (Younger Loam), 4 to 5 m thick, overlaps the upper horizon of the Shimosa Group.

Kioroshi formation. The Kioroshi Formation was named after its type locality at Kioroshi, Inzai Town, Chiba Prefecture (Fig. 1),

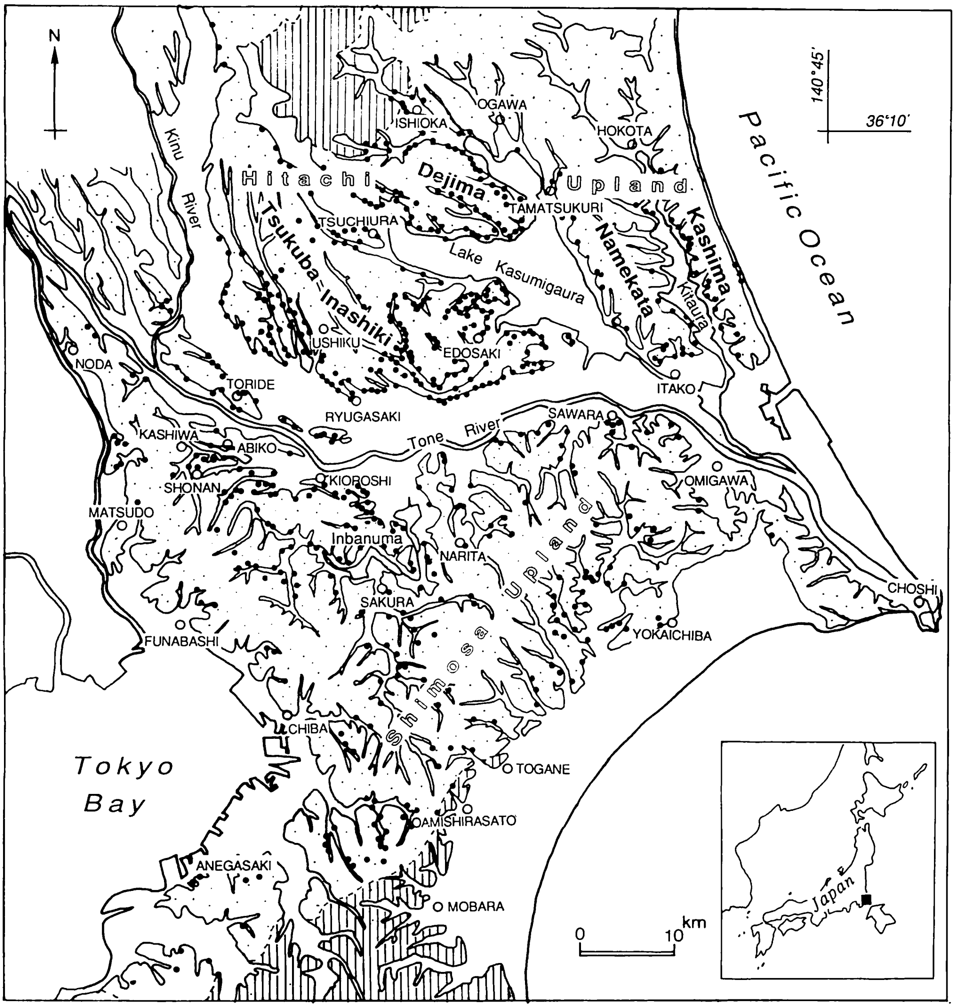

Fig. 1. Index map of the study area, Joso Upland in eastern Kanto. ●: locality for outcrop of the Kioroshi and Joso Formation. The white bold letters show two big uplands, and the black bold letters show local uplands.

Table 1. Stratigraphy of the late Pleistocene in the eastern Kanto Plain.

Nakamura & Fukuda 1953	Sugihara 1970.1979	Aoki & Baba 1979	Kikuchi 1977.1981	Kodama *et al.* 1981	Shimosa-Daichi Reseach Group 1984	Unosawa *et al.* 1988	This Study 1992
Kanto Loam	Tachikawa Loam Musashino Loam Chiba Terrace Gravel	Kanto Loam	Tachikawa / Musashino Loam	Tachikawa Loam Musashino Loam	Tachikawa Loam Musashino Loam Chiba Terrace Gravel	Younger Kanto Loam / Sakuragawa Terrace Deposits & equivalents	Kanto Loam
Joso Clay	Shimosueyoshi Loam / Joso Clay Ryugasaki Sand	Itabashi Formation Ryugasaki Formation	Joso Clay / Shimosueyoshi Loam Anegasaki Formation	Joso Formation	Joso Clay Ryugasaki Sand	Joso Formation	Joso Formation
Ryugasaki Sand Kioroshi Formation	Kioroshi Formation	Narita Formatinon	Narita Formation	Narita Formation	Kioroshi Formaion	Kioroshi Formation	Kioroshi Formation

by Makiyama (1930). In this paper, the definition of the Kioroshi Formation follows that of the Shimosa-Daichi Research Group (1984) in the Shimosa Upland (see also Sugihara, 1979). The formation can be traced to Tsukuba and Inashiki Uplands (Unosawa *et al.*, 1988). It correlates with the Narita Formation defined by Aoki and Baba (1979) in the Namekata and Kashima Uplands, and by Kikuchi (1977) in the Shimosa Upland.

The Kioroshi Formation crops out widely over the study area and rests unconformably on the underlying Kamiiwahashi Formation. The Kioroshi Formation makes up the Hitachi Surface in the Hitachi Upland and the Shimosa Upper Surface in the Shimosa Upland. The Kioroshi Formation can be divided into five units: lower mud, middle sand, upper mud, upper sand and uppermost clay layer in ascending order. However, the facies and thicknesses of the units vary markedly from place to place.

The lower mud unit, 1.5 to 13 m thick, consists of thin alternations of mud and fine grained sand, and fine grained sand with intense bioturbation and plant debris. The plant fossils, including *Menyanthes trifoliata*, *Alnus japonica* and *Trapa* spp., indicate a relatively low-temperature environment. Gravel, muddy gravel, and plant debris are present at the base of the unit.

The middle sand unit is made up of fine to medium grained sand, and is about 0.5 to 15 m thick. Bioturbation is intense. Abundant molluscan shells, including *Mactra sulcataria*, *Anadara subcrenata*, *Glycymeris vestita*, and *Gomphina neastartodes*, are present in the sand unit in the central part of the Shimosa Upland. This is the so-called "Kioroshi shell beds" (Kojima, 1958).

The upper mud unit consists of massive mud, or thin alternations of mud and very fine to fine grained sand. This unit is 1 to 7 m thick. Sand layers show ripples and mud layers contain trace fossils.

The upper sand unit, 3.5 to 7 m thick, are absent in the central part of the Shimosa Upland, where the middle sand unit is well developed. The lower part of the unit is composed of well sorted fine to medium grained sand, and the upper part is composed of medium to coarse grained sand with prominent trace fossils made of the isopod *Excirolana chiltoni japonica* (Kikuchi, 1972).

The uppermost clay unit, called the Joso Clay (Kojima, 1959), consists of tuffaceous clay with plant debris and rootlets. This unit, 3 to 5 m thick, includes the "Klp" and "Kmp" tephras of Kikuchi (1981).

Joso formation. The redefined Joso Formation consists of the abandoned Ryugasaki Formation and the Joso Clay. The Ryugasaki Formation was named for its type locality at Ryugasaki City, Ibaraki Prefecture, by Nakamura and Fukuda (1953). The Joso Formation is divided into three informal members: lower, middle, and upper.

The lower member overlies the Kioroshi Formation. The contact is an erosion surface. The member is composed of medium to very coarse grained tuffaceous sand bearing gravel, and shows cross-stratification. The lower member crops out only in the Tsukuba Upland, and is 5 to 10 m thick at the center of Tsukuba Gakuen City, according to data obtained from shallow cores (Ikeda *et al*., 1982).

The middle member is distributed in the Inashiki and Dejima Uplands, in the eastern part of the Tsukuba Upland, and the northeastern part of the Shimosa Upland. This member is the most widespread within the Joso Formation. The middle member consists of medium grained sand, and is about 3 to 5 m thick. Cross-stratification and channel-shaped erosional bases are predominant in the sand. Clay beds, about 3 m thick, overlie and interfinger with the sands.

The upper member is exposed in the western part of the Tsukuba Upland. It is 4 to 5 m thick, and consists of tuffaceous, fine to coarse grained sand and clay, showing a fining-upward sequence. Erosive channel-shaped bases are present at the base of the member. The "Pm-1" tephra is intercalated between the middle and upper members of the Joso Formation (Unosawa and Endo, 1984).

The clay layers in the middle and upper members of the Joso formation have been called the Joso Clay (Nakamura and Fukuda, 1953).

Gravel-bearing sand approximately 1 m thick, the so-called Ichikawa Sand Member, crops out in the southern part of the Shimosa Upland, facing Tokyo Bay. The member rests on the Shimosa Lower Surface (Sugihara, 1970), and is contemporaneous with the Joso Formation.

Methods

Facies analysis was applied in order to study the depositional environments of the Kioroshi and Joso Formations. Facies discrimination was made on the basis of several aspects detectable in the field, such as lithology, grain size, bed base type, sedimentary structures, fabric, color, fossils, and paleocurrents. Typical facies sequences were determined from the character of facies succession and the frequency of facies occurrence in the study area. The depositional environments for each facies were inferred not only from the aspects mentioned above, especially sedimentary structures from which the depositional processes or hydrological conditions can be specified, but also by analogy with recent sediments.

Assemblages of laterally adjacent process-related facies, in turn, constitute depositional systems. In fact the facies models proposed by previous workers (e.g. Walker, 1971) are a powerful tool for the identification of depositional systems. The sedimentary and stratigraphic characteristics of Paleo-Tokyo Bay were therefore summarized in terms of the depositional systems.

Next, a depositional sequence was clearly discriminated in the Kioroshi and Joso Formations by facies analysis on the basis of sequence stratigraphy (Vail *et al.*, 1977; Van Wagoner *et al.*, 1988), in particular by recognizing the architecture of depositional systems and their bounding surfaces. Correlation between the depositional sequences and glacio-eustatic sea-level changes was made on the basis of interbedded tephras with the help of ESR dating and identification of the geomorphic surfaces.

Results of facies analysis and discussion

Depositional systems

By applying facies analysis to the Kioroshi and Joso Formations, depositional systems of a meandering river, birdfoot delta, shoreface–beach, tidal delta, and drowned valley fill have been recognized in the study area. The facies characteristics of each depositional system are described in detail below.

1. Meandering-river system (FL)

Facies sequence. Three facies, FL(a), FL(b), and FL(c), as shown in Fig. 2, are distinguishable from the base to the top of the upper member of the Joso Formation in the southwestern part of the Tsukuba Upland. The succession in Fig. 2 is well observed at Mase, Tsukuba City (Loc. 1), Azumadai, Tsukuba City (Loc. 2), Rokuto, Tsukuba City (Loc. 3), Kokashinden, Ryugasaki City (Loc. 4), Nobori, Ryugasaki City (Loc. 5), Mukohara, Ryugasaki City (Loc. 6), Inarishinden, Ryugasaki City (Loc. 7), and Nareuma, Ryugasaki

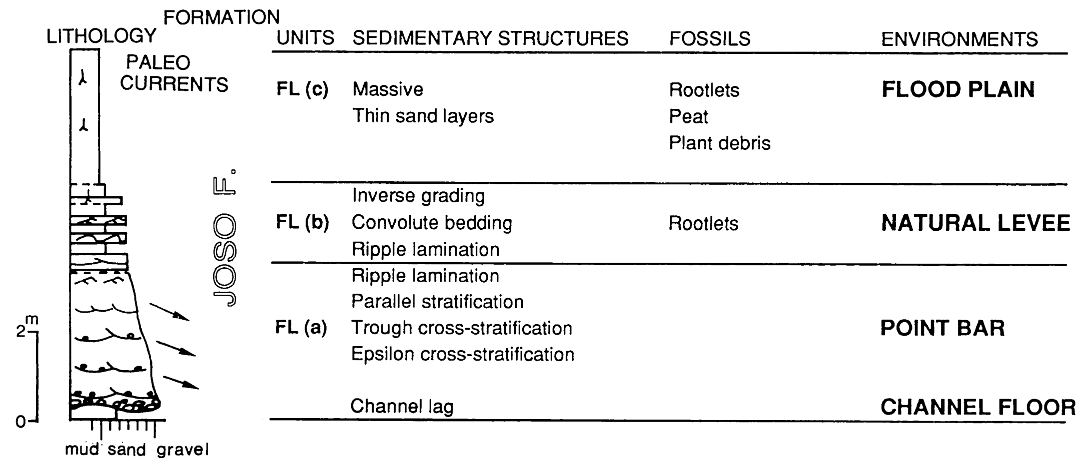

Fig. 2. Generalized facies succession of a meandering river system in the Joso Formation in the Tsukuba Upland, after Okazaki and Masuda (1992). Symbols used in the columnar section are defined in Fig. 10.

City (Loc. 8), as shown in Fig. 3. Columnar lithologic sections from these localities are shown in Fig. 4.

Facies FL(a) consists of fine grained to very coarse grained sand, and is 3 to 5 m thick. Trough cross-stratification and and epsilon cross-stratification are the predominant sedimentary structures. The grain size fines and the scale of the cross-stratification decreases upward (Fig. 5a). Channel-shaped erosional bases (2 to 3 m deep and several meters to 10 m wide) are observed (Fig. 6). Coarse grained deposits, containing bedrock pebbles and locally derived mud pebbles, are present above the erosional surfaces.

Facies FL(b) consists of fine grained sand with thin mud layers, and is 1 to 2 m thick. Local inverse grading, climbing ripple lamination, convolute structures and rootlets are present.

Facies FL(c) is present above or lateral to facies FL(a) and FL(b); the vertical or lateral passage is gradational. The facies is 3 m thick, and consists of mud containing abundant plant fragments and roots. Wedge-

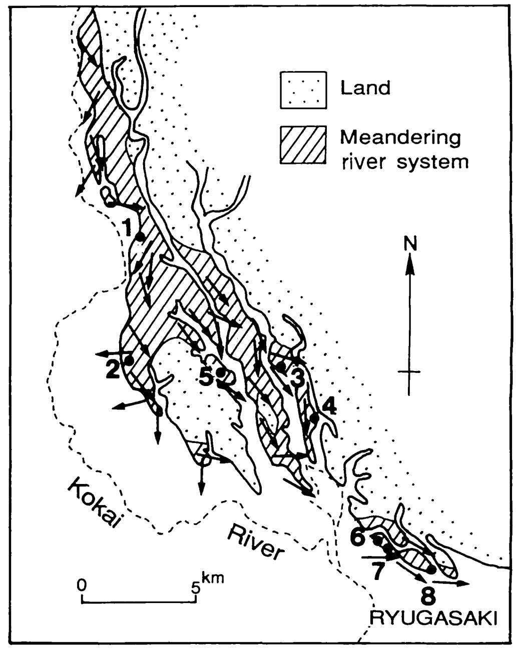

Fig. 3. Distribution of a meandering river system in the Tsukuba Upland, after Okazaki and Masuda (1992). Numbers indicate localities for the columnar sections in Fig. 4. →: paleocurrent direction of a meandering river.

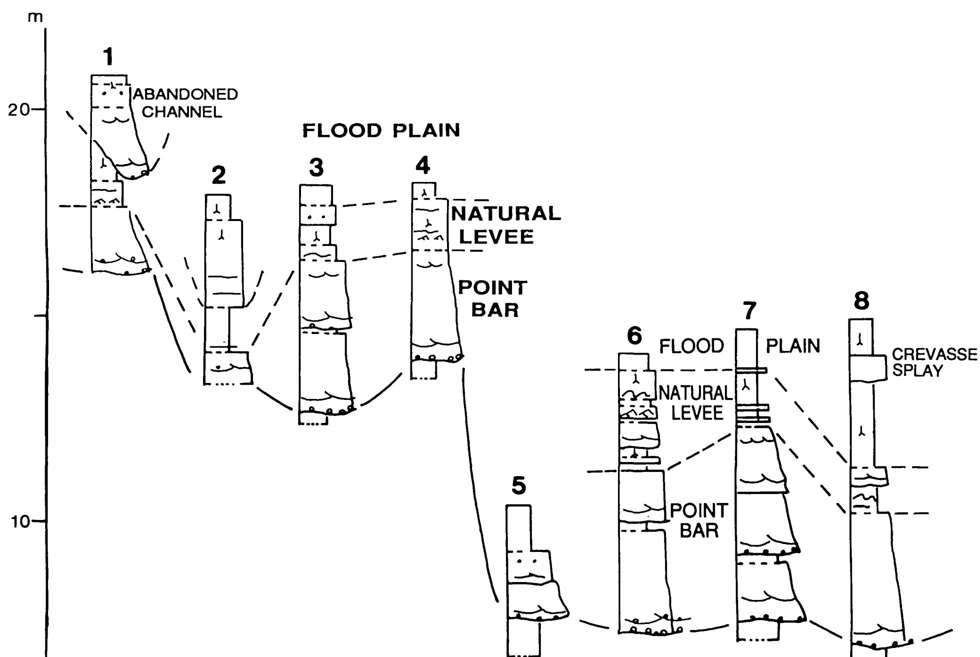

Fig. 4. Examples of typical columnar lithologic sections showing a meandering river system in the Joso Formation, after Okazaki and Masuda(1992). 1: Yatsu, 2: Azumadai, 3: Rokuto, 4: Kokashinden, 5: Nobori, 6: Mukouhara, 7: Inarishinden, 8: Nareuma. The localities are shown in Fig. 3.

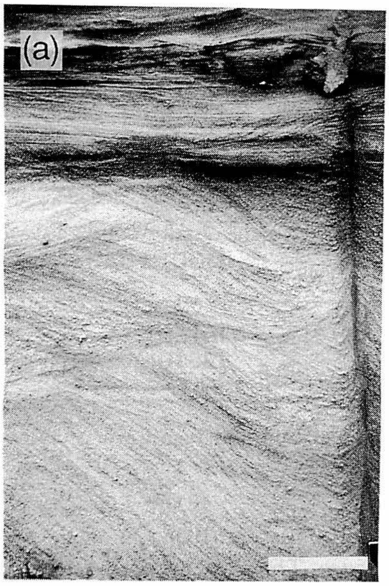

Fig. 5. Meandering river deposits. (a) Trough cross-stratification of coarse-grained sands showing fining- and thinning-upward sequences of point-bar deposits at Loc. 7, Inarishinden, Ryugasaki City. Scale is 10 cm long. (b) Abandoned channel, 5 m wide and 3 m deep, composed of peaty muddy sands at Yatabe, Tsukuba City.

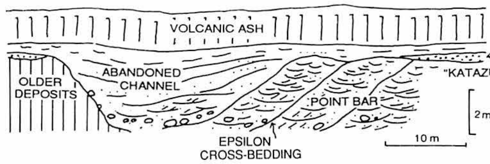

Fig. 6. Outcrop showing an abandoned channel and epsilon cross-stratification of a meandering river system at Loc. 1, Yatsu, Tsukuba City, after Okazaki and Masuda (1992). Left is North.

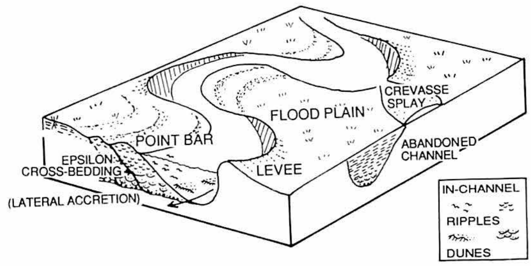

Fig. 7. Schematic block diagram showing morphological elements of a meandering river system, modified after Walker (1979, Fig. 1).

shaped sand layers are rarely intercalated in the mud.

Depositional environments. The depositional environments of these facies are explained by a depositional model of a meandering river (Fig. 7).

Cross-stratification in facies FL(a) was formed by migration bedforms beneath unidirectional currents. The fining-upward and thinning-upward cross-beds are characteristic features within point bars of a meandering river. The upward transition from dunes to small ripples corresponds to an upward decrease of water depth and velocity on a slipoff slope of a point bar. All the bedforms are preserved by the lateral and downstream accretion of the point bars. Epsilon cross-stratification reflecting the shape of the channel floor is formed by migration of the point bars. Coarse deposits in the lowest part of the succession are lag deposits on the channel floor. Mud clasts in the lag deposits were originally flood-plain deposits, which were dried and brought to the bottom of the channel by collapse of the undercut slope. Accordingly, facies FL(a) represents point-bar deposits of a meandering river.

The alternated sand mud in facies FL(b) are considered to be the deposits of a natural levee. Inverse grading is a distinctive indicator of flood deposits (Masuda and Iseya, 1985). Climbing ripple laminations were formed as flood waters, carrying suspended sand from a channel, decelerated and dropped their sediments load on the proximal floodplain. convolute structures were produced by slumping at the natural levee.

Facies FL(c), changing gradually upwards

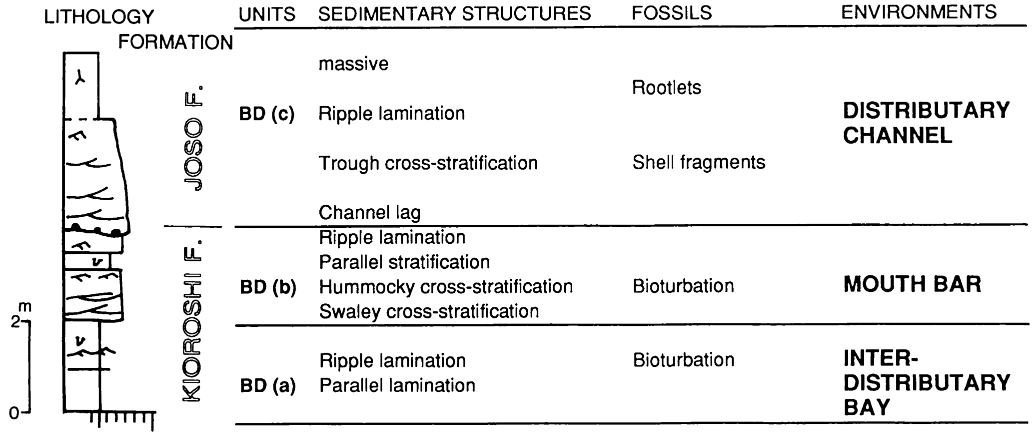

Fig. 8. Generalized facies succession of a birdfoot delta system in the Kioroshi and Joso Formations in the Tsukuba and Dejima Uplands, after Okazaki and Masuda (1992).

and laterally from facies FL(b), is interpreted as deposits of a floodplain beyond natural levees. In the floodplain, muddy deposits intercalate with local thin sand layers, and contain plants that were growing there. The wedge-shaped sand beds are interpreted as overbank deposits of crevasse splays.

Gray, fine grained sand layer called the "Katazuna" Bed consists almost of volcanic fragments, and is locally associated with facies FL(c). This is interpreted as eolian dune deposits on the floodplain, judging from its sorting, distribution, content of eolian loam and traces of plants.

Channels filled with muddy deposits may be abandoned ones (Fig. 5b). Gray, fine to medium grained sands with abundant volcanic fragments, similar to grains in the "Katazuna", form point bar deposits in the Joso Formation at Mase, Tsukuba City (Loc. 1), where a buried abandoned channel is also present. This unusual channel fill may have occurred due to disruption of the fluvial system by large influx of volcanic ejecta into the river (Ito and Masuda, 1988).

Distribution and paleocurrents. The distribution of the meandering river system is shown in Fig. 3. The arrows in Fig. 3 show the average paleocurrents inferred from the cross-stratification of facies FL(a) (Masuda and Okazaki, 1983a). The general direction of flow was from northwest to southeast, parallel to that of the recent Kinu River.

2. Birdfoot-delta system (BD)

Facies sequence. Three facies, BD(a), BD(b), and BD (c) as shown in Fig. 8, are distinguished from the base to the top of the Kioroshi Formation and from the middle members of the Joso Formation in the Tsukuba, Inashiki, and Dejima Uplands. The localities where the generalized succession in Fig. 8 is developed well are Takegaki, Akeno-cho, Makabe-gun (Loc. 9), Oosone, Tsukuba City (Loc. 10), Kamihirooka, Tsukuba City (Loc. 11), Yatabe, Tsukuba City (Loc. 12), Okami, Ami-machi, Inashiki-gun (Loc. 13), Bessho, Ryugasaki City (Loc. 14) and Umamiyama, Miho-machi, Inashiki-gun (Loc. 15), as shown in Fig. 9. Columnar lithologic sections measured at these localities are shown in Fig. 10.

Facies BD (a) consists of alternations of fine to very fine grained sand and mud, and is 1 to 5 m thick. Small-scale wave ripples and parallel lamination are the dominant structures in the sand layers. Small burrows are present. Fecal pellets and plant debris are common. Marine diatoms (e.g., *Melosira sulcata*, *Cyclotella stylorum* and *Coscinodiscus* spp.), and fresh water diatoms (e.g., *Stephanodiscus niagarae* and *Cyclotella comta*) are abundant in the mud layers.

Facies BD(b) consists of fine grained sand and mud layers, and is 1 to 4 m thick. Wave ripples, parallel lamination, trough and tabular cross-stratification, and swaley and hummocky cross-stratification are the dominant

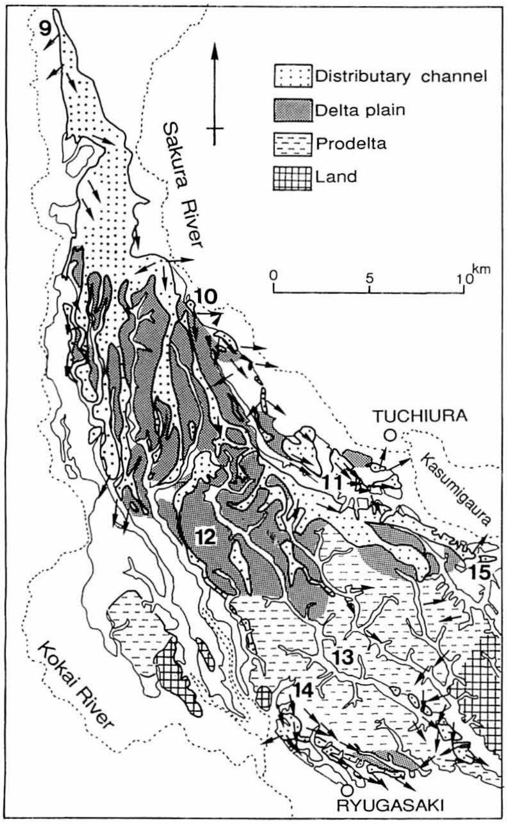

Fig. 9. Distribution of a birdfoot delta system in the Tsukuba Upland, after Okazaki and Masuda (1989). Numbers indicate localities for the columnar lithologic sections in Fig. 10. →: paleocurrent direction on the birdfoot delta plain.

structures in the sand layers (Fig. 11a). Bidirectional paleocurrents with opposing flow directions are present. The mud layers are burrowed.

Facies BD(c) shows a typical fining-upward sequence, consists mainly of fine to medium grained sand, and is 0.5 to 4 m thick. The basal part of the facies is composed of granule-bearing, coarse grained sand. Trough cross-stratification, epsilon cross-stratification and channel-shaped erosional bases are the dominant structures (Fig. 11b). A unidirectional palaeocurrent pattern typifies this facies. The upper part of the facies commonly contains sand and mud beds with inverse grading. The uppermost part consists of muddy layers with roots and plant debris, and is 0.5 to 1.5 m thick. Thin beds of very fine grained sand and sand-streaked laminated mud are common.

Depositional environments. On the basis of detailed topographical analysis, a birdfoot delta plain landform has been identified on the surface of the Tsukuba Upland (Ikeda *et al.*, 1982) (Fig. 9). The facies at the upper reaches of the delta comprises a fining-upward sequence from gravelly sand to mud (Fig. 10, Locs. 9 and 10). In contrast, the facies at the lower reaches forms a fining-upward sequence of sand (Fig. 10, Loc. 15) and thick mud (Fig. 10, Loc. 12). The thick mud includes plant roots, peat layers, driftwood and fresh- and brackish-water diatoms, such as *Melosira granulata*, *Eunotia* sp., *Pinnularia* sp., *Cymbella* sp., *Gomphonema* sp., *Diploneis interrupta*, and *Rhopalodia gibberula*. The depositional environment of the sandy facies corresponds to a distributary channel and the muddy facies to an interdistributary channel area, such as a floodplain and/or a distributary bay.

Facies BD (a) suggests a relatively low-energy environment. Coarse clasts of this facies were deposited under the interaction of sand-laden tractional river currents, wave reworking, and storm-generated currents, with the fine grained clasts settling from suspension (Katsura *et al.*, 1985). The depositional environment of this unit is interpreted to have been a bay or a lake on a delta plain.

Facies BD (b) is characterized by wave-formed structures, such as wave ripples, swaley and hummocky cross-stratification, and trough cross-stratification. This facies comprises deposits at mouth bars in front of distributary channels. Trough cross-stratificatioin, with bidirectional current patterns was formed by the migration of ripples and dunes beneath river currents and oscillatory flow at a delta front.

Facies BD(c) consists of delta plain deposits. Sandy deposits of the facies were deposited under unidirectional currents on point bars of fluvial distributary channels. Fine grained deposits settled from suspension in a marsh or a floodplain environment. The height of the delta front was 1 to 4 m, estimated by the thickness of the delta-front

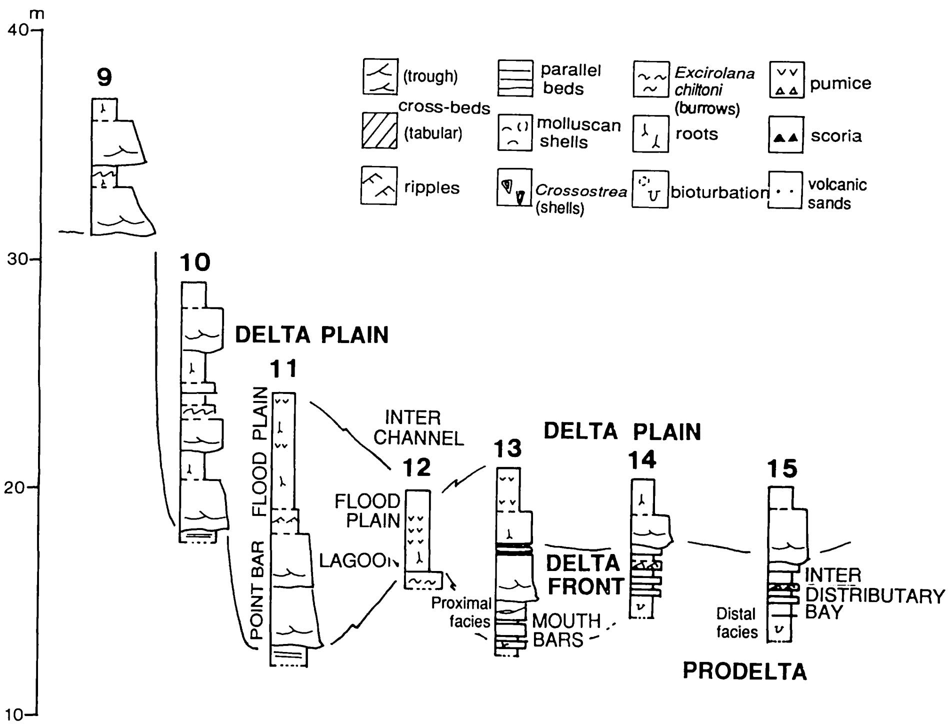

Fig. 10. Examples of typical columnar lithologic sections of a birdfoot delta system, after Okazaki and Masuda (1992). 9: Takegaki, 10: Ozone, 11: Hirooka, 12: Yatabe, 13: Okami, 14: Besho, 15: Koya. The localities are shown in Fig. 9.

facies BD(b).

Distribution and Paleocurrents. The paleocurrent pattern on this birdfoot delta (Fig. 9) is based on measurements of cross-stratification of facies BD(c) (Masuda and Okazaki, 1983a).

The thickness of the sand layers and sand/mud ratio of beds of facies BD(a) indicate a variation from a thick sand bed with thin mud layers to a sand-laminated mud bed. This variation is interpreted to correspond to a change in storm-generated sand layers from the proximal to the distal facies in the down-current direction (Fig. 10, Locs. 13–15). Facies BD (a) is widely distributed from Ushiku to Dejima in southern Ibaraki (Okazaki *et al.*, 1984; Masuda and Makino, 1987). Paleocurrents and proximal to distal trend indicate that the birdfoot delta system advanced into the shallow bay from northwest to southeast.

3. Shoreface–beach system (SB)

Facies sequence. Six facies, SB(a), SB(b), SB (c), SB(d), SB(e) and SB(f) (Fig. 12), are distinguishable from the base to the top of the upper sand member of the Kioroshi Formation in the Kashima and Namekata Uplands, around Togane–Mobara and Chiba–Matsudo in the Shimosa Upland, and around Edosaki in the Inashiki Upland. The localities where the succession in Fig. 12 is well developed are Kanahorityo, Funabashi City (Loc. 16), Amato-cho, Chiba City (Loc. 17), Yoshida, Inbamura, Inba-gun (Loc. 18), Yatotyo, Chiba City (Loc. 19), Hirayama-cho, Chiba City (Loc. 20), and Kabagayama, Edosaki-machi, Inashiki-gun (Loc. 23), Minami, Aso-machi, Manekata-gun (Loc. 22), and Tachihara, Oono-mura, Kashima-gun (Loc. 24), as shown in figs. 13 and 14.

Facies SB(a) is 3 to 5 m thick and is composed of an alternation of fine grained sand and mud, or very fine grained to fine grained sand. An erosional surface defines the base of

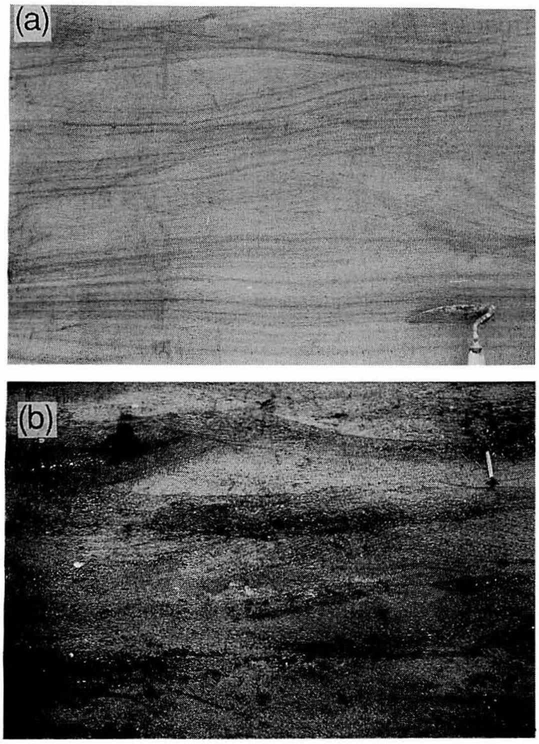

Fig. 11. Birdfoot delta deposits. (a) Swaley and hummocky cross-stratifications of mouth-bar deposits composed of well-sorted fine grained sand at Loc. 13, Okami, Amimachi, Inashikigun. The trowel is 15 cm long. (b) Trough cross-stratification of the distributary channel deposits at Yamaki, Tsukuba city. The locality is 2 km to the north of Loc. 10. The trowel is 30 cm long.

the facies. Granules, mud pebbles, and molluscan shell fragments occur immediately above the surface. Wave dunes, parallel lamination, low-angle, wedge-shaped cross-stratification, and hummocky cross-stratification are present in the sand. The trace fossil of *Cylindrichnus* sp. and marine diatoms of *Melosira sulcata*, *Coscinodiscus* spp., *Stephanopyxis* sp., *Actinocyclus ingens*, and *Thalassiosira* spp. are contained in the mud.

Facies SB(b) is 3 to 5 m thick, and is made up of well sorted very fine to fine grained sand with minor thin intercalation of silt, each less than 20 cm thick. The facies exhibits parallel stratification, low-angle, wedge-shaped cross-stratification, swaley and hummocky cross-stratification, ripple lamination. Intercalated in the sand are wave dunes (wave length: several decimeters to 1 m, wave height: several decimeters) of very coarse grained sand to granules (Fig. 15a) (Makino *et al.*, 1985; Makino and Masuda, 1986; Masuda and Makino, 1987), and coarse grained sand layers less than several tens of centimeters thick, that contain abundant shell fragments, are intercalated in the sand. The wave dunes and shell layers are commonly draped by mud. Trace fossils are rare.

Facies SB(c) is composed of well sorted medium to coarse grained sand, and is 1 to 2 m thick. Molluscan remains and mud pebbles are present sporaddically. Shallow trough cross-stratification (wave length: 4–10 m, wave height: 20–60 cm) and tabular cross-stratification are dominant structures. The trace fossils of *Excirolana chiltoni japonica* and *Ophiomorpha* sp. are present in this facies.

Facies SB(d), 1 to 2 m thick, consists of well sorted fine to medium grained sand. Shallowly dipping parallel lamination is defined by heavy mineral (Fig. 15b). The trace fossil of *Excirolana chiltoni japonica* is prominent. The upper part of the facies contains more limonite, with small tabular and trough cross-laminations (height: less than 1 cm). Plant rootlets and small burrows are common in the uppermost part.

Facies SB(e), 1 to 2 m thick, is composed of very well sorted fine- to medium grained sand. Dish and convolute structures are present.

Facies SB(f), 1 to 2 m thick, consists of poorly sorted, massive sandy silt, and mud intercalated with very fine grained sand layers. Ripple lamination, parallel lamination, or convolute structure are rare. Plant debris is abundant. Peaty mud are rare.

Depositional environments. The depositional environments of these facies are explained by a model of a shoreface–beach (Fig. 16).

An upward secession of sedimentary structures from swaley and hummocky cross-stratification, through parallel lamination, to wave-ripple lamination characterizes facies SB(a). This is a diagnostics characteristic of

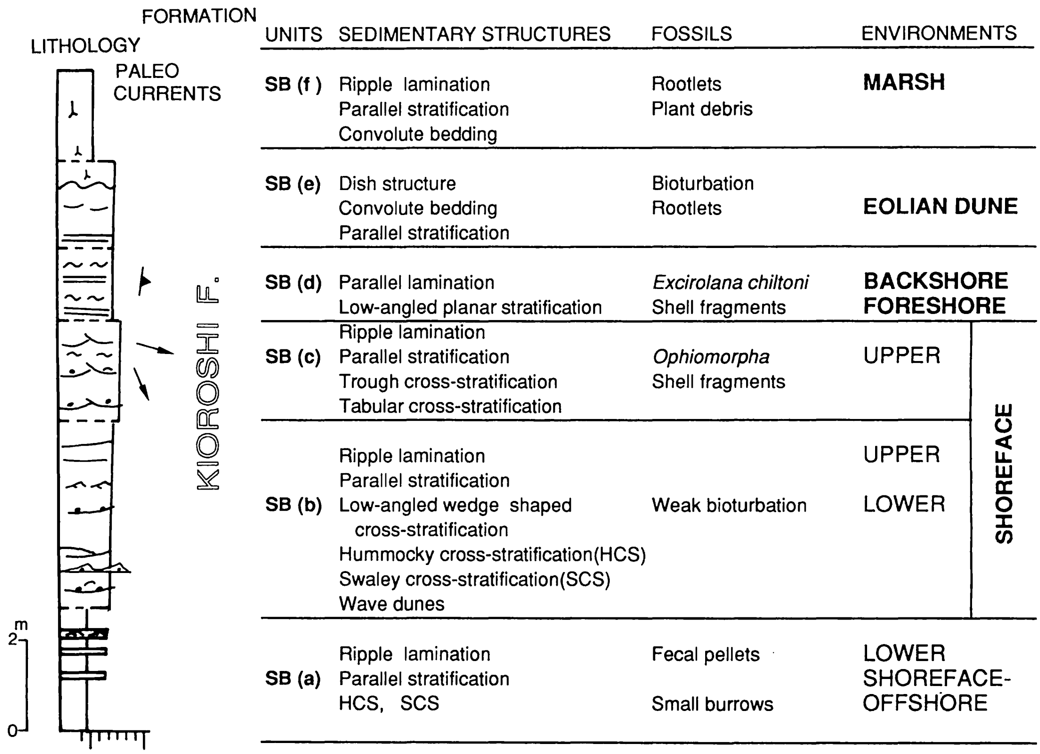

Fig. 12. Generalized facies succession of a shoreface–beach system in the Kioroshi Formation, after Okazaki and Masuda (1992).

"storm-generated sheet sand" (Makino *et al.*, 1985; Katsura *et al.*, 1985). Swaley and hummocky cross-stratification are formed by orbital wave motion and/or seaward-directed geostrophic currents during storms (Hunter and Clifton, 1982; Nottvelt and Kreisa, 1987). The interbedded mud and sand in facies SB(a) are interpreted to reflect alternations of fair weather and storm conditions on the offshore to lower shoreface.

Facies SB(b) is characterized by sand-dominated, amalgamated hummocky and swaley cross-stratification. Wave dunes and shell layers are identical to "Wave-formed, coarse grained ripples" (Leckie, 1988). They form during storm wave conditions, similar to those which would form hummocky cross-stratification. Low-angle, wedge-shaped cross-stratification, parallel bedding, and ripple lamination are also the main sedimentary structures produced by migration of longshore bars during fair-weather conditions (Davidson-Arnott and Greenwood, 1976). Alternated beds of mud and very fine grained sand are present within or lateral to the longshore bar sand. Trough facies intercalated in the bar-sand deposits may be a products of rip currents (Masuda and Okazaki, 1985; Okazaki and Masuda, 1990). Therefore, facies SB(b) is considered to have formed in response to storms and fair weather condition on a lower to upper shoreface.

Trough and tabular cross-stratification in facies SB(c) was formed by migration of asymmetric ripples and dunes along the upper shoreface (Clifton *et al.*, 1971). The cross-beds indicate multidirectional flow, that might be formed by breakers, shoaling waves, and rip or longshore currents on the upper shoreface. The trace fossil, *Ophiomorpha* sp., observed in facies SB(c), probably penetrated downward the overlying lagoonal facies.

Facies SB(d) is characterized by (1) abundant trace fossils of a small isopod *Excirolana chiltoni japonica*, which now lives in the

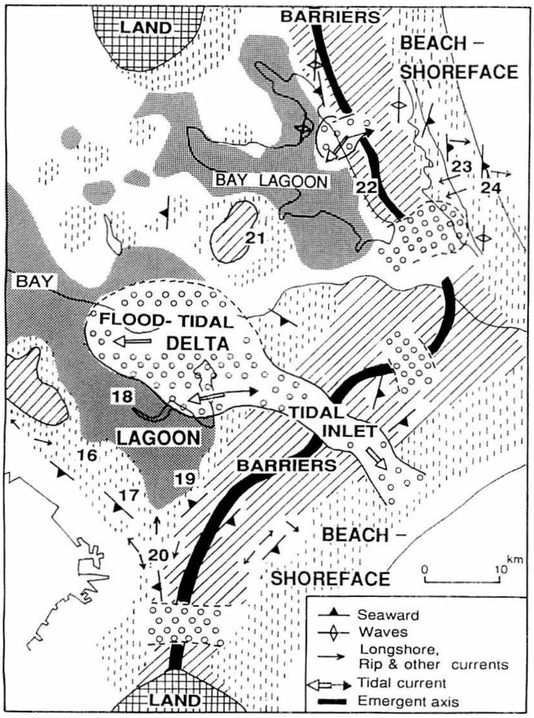

Fig. 13. Reconstruction of the depositional systems and paleocurrents in the "Barrier period", the Shimosueyoshi high-stand in sea level, during 130–110 thousand years ago, after Okazaki and Masuda (1992). Numbers indicate localities for the columnar lithologic sections in Fig. 14.

intertidal zone of sandy coasts, and (2) distinct subparallel to shallowly dipping planar lamination that occurs as wedge-shaped sets. These are characteristic of beach deposits (Masuda and Okazaki, 1983a; Masuda and Yokokawa, 1988; Yokokawa and Masuda, 1988). On the foreshore, separation of heavy minerals from lighter grains occurs with each swash and backwash, resulting in formation of planar lamination that is inclined sewards, roughly parallel to the foreshore surface. In the backshore area, sediment is transported to the berm crest by high spring tides or storms and is distributed by winds and washover. Subhorizontal to landward-dipping plane beds characterize backshore deposits and may be interbedded or overlain by small to medium scale trough cross-stratification formed in a runnel along the backshore.

Facies SB(e) may be eolian dune deposits based on its good sorting and wavy and contorted stratification; dune beds are commonly disturbed by fluctuating ground water and root growth.

Facies SB(f) consists of massive mud with abundant rootlets and plant debris, and was probably deposited in a backshore lagoon or salt marsh and in the troughs of dunes.

Distribution and paleocurrents. Strikes and dips of parallel laminations in facies SB(d) indicate both the orientation of the coastline and seward (or landward) direction, because the seaward or landward dippling stratification corresponds to the surface of the foreshore and backshore, respectively (Masuda and Okazaki, 1983a; Masuda and Yokokawa, 1988). Seaward directions inferred from the beach deposits in the eastern part of the Joso Upland are separated into two direction (Fig. 13). In the Namekata Upland, the seaward direction is westward in the western part, and eastward in the eastern part. The seaward directions in the eastern part of Shimosa Upland are similar to those in the Namekata Upland. It is believed that emergence was initiated near the center of both areas, so that they formed geomorphic highs at the time of the Shimosueyoshi period. These geomorphic highs were probably chains of barrier islands that separated an open sea from an enclosed lagoon. Inlets connected this lagoon to the open sea.

In Paleo-Tokyo Bay, different shoreface–beach systems are observed between the open-sea side and the bay side of the barrier islands (Fig. 17). When the system of an open-sea type is compared to that of a bay type, the following differences are noted: (1) On the whole, the materials and beds of the open-sea type are coarser and thicker than those of the bay type. (2) Shoreface deposits (i.e., facies SB(a), Sb(b) and SB(c)) of the open-sea type are thick and sandy, whereas facies SB(a) of the bay type is muddy. (3) Parallel laminated foreshore facies (facies SB(e)) of the bay type are not well developed. Instead, in some places, poorly sorted medium to coarse grained sand with trough cross-stratification is observed in this position. this is probably washover deposits of the backshore. (4)

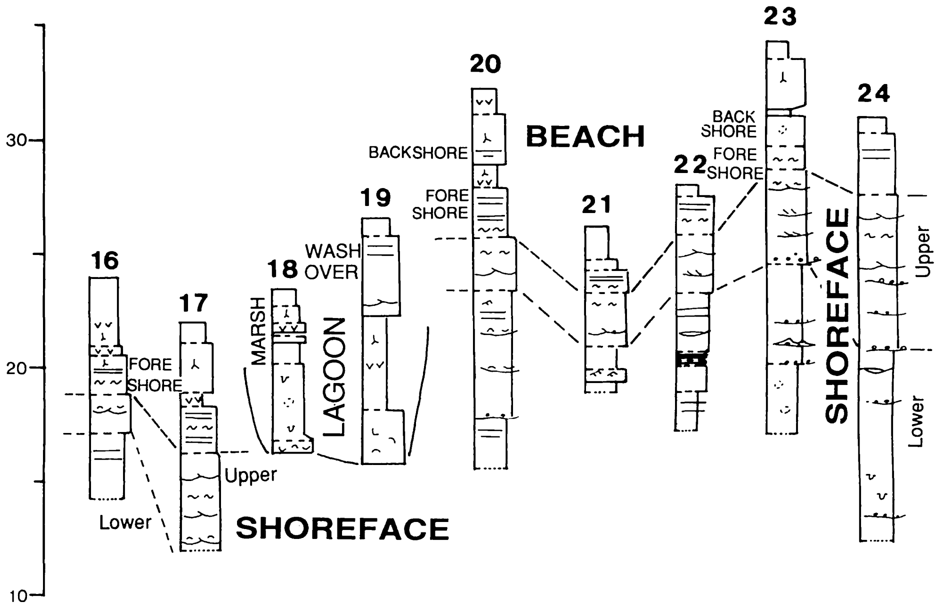

Fig. 14. Examples of typical columnar lithologic sections showing a shoreface–beach system in the Kioroshi Formation, after Okazaki and Masuda (1992). 16: Kanahori-cho, 17: Amato-cho, 18: Yoshida, 19: Yatomachi, 20: Hirayama-cho, 21: Kabagayama, 22: Minami, 23: Tachihara, 24: Kono. The localities are shown in Fig. 13.

There are no, or only thin deposits of tidal flats or salt marsh of the backshore facies SB(d) and (f) in the open-sea type.

The factors controlling these differences are thought to be as follows: on the open-sea side, environments from offshore to shoreface were developed widely because the influence of waves on the upper shoreface and foreshore were stronger than that on the bay side. On the other hand, on the bay side, quieter condition favored mud deposition and the tidal range was sufficiently high that tidal flats and salt marsh were widespread.

4. Tidal-delta system (TD)

Facies sequence. Three facies, TD(a), TD(b), and TD(c) (Fig. 18), are distinguished from the base to the top in the middle sand of the Kioroshi Formation in the Shimosa Upland. The localities where these facies are well developed (Fig. 19) are Kizaki, Higashikatsushika-gun (Loc. 25), Funato, Inzai-machi, Inba-gun (Loc. 26), Waizumi, Inzai-machi, Inba-gun (Loc. 27), Kioroshi Inzai-machi, Inba-gun (Loc. 28), Mukouhenda, Inba-mura, Inba-gun (Loc. 29), Sunaoshi, Inba-mura, Inba-gun (Loc. 30), Ootake, Inba-mura, Inba-gun (Loc. 31), Funato, Inba-mura, Inba-gun (Loc. 32), Kabuwada, Inba-mura, Inba-gun (Loc. 33), and Simokata, Inba-mura, Inba-gun (Loc. 34). Columnar lithologic sections measured at these localities are shown in Fig. 20.

Facies TD(a) consists of mud with thin sheet-sand layers, and is more than 3 m thick. The sand layers show current ripple lamination in lenticular beds. Bioturbation is intense. *In situ* shells of *Theola lubrica* and *Raeta yokohamensis* occur rarely in the mud. The facies also includes the marine diatoms *Melosira sulcata* and *Triceratium favus.* Around Kabuwada (Fig. 20, Locs. 32 and 33), poorly sorted sandy mud, about 5 m thick, is developed below this facies. The mud is burrowed and includes mud clasts, gravel, floated-in pumice grains, plant debris and shells.

Facies TD(b) is divided into two subfacies, TD(b)-a and TD(b)-b. The lower subfacies TD (b)-a, 3 to 6 m thick, consists of well sorted fine- to very fine grained sand with molluscan shells. Parallel lamination and trough cross-stratification are present. *In situ* molluscan shells of *Fluvia mutica*, *Raeta yokohamen-*

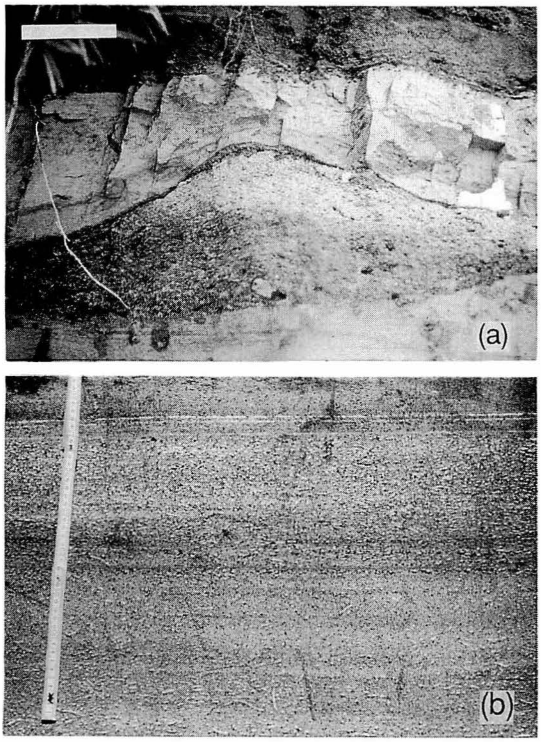

Fig. 15. Beach–shoreface deposits. (a) Wave dunes composed of coarse-grained sand and mud at Yamada, Kitauramura. The locality is 3 km from Loc. 17 in the west of Kitaura. The scale is 10 cm long. (b) Parallel lamination of beach deposits with *Excirolana chiltoni* burrows at Owada, Chiba City. The locality is 10 km to the east of Loc. 20. The scale is 40 cm long.

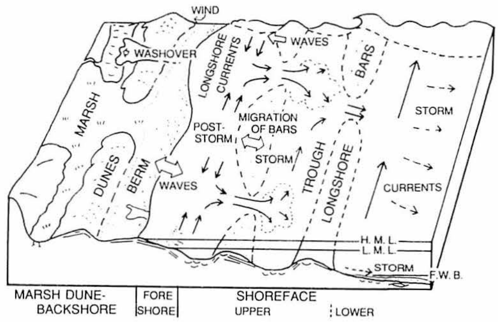

Fig. 16. Schematic block diagram for a shoreface–beach system illustrates topographic features and current systems, after Okazaki and Masuda (1992).

sis, *Fabulina nitidula*, *Siliqua pulchella* and *Solen krusensterni*, and transported shells of *Mactra sulcataria* are dominant. Bioturbation is common. The upper subfacies TD(b)-b, 3 to 6 m thick, consists of medium grained sand with very abundant molluscan shells. This subfacies shows nearly parallel stratification or large-scale, low-angle, tabular cross-stratification (Fig. 21a and b). Molluscan shells of *Mactra sulcataria*, *Tapes variegata*, *Gomphina neastartoides* and *Glycymeris vestita* are dominant. Vertical burrows of *Ophiomorpha* type are abundant in the shell beds.

Facies TD(c) is divided into three subfacies: TD(c)-a, TD(c)-b, and TD(c)-c. Subfacies TD(c)-a, 2 to 3 m thick, consists of fine- to medium grained sand. Trough cross-stratification with angular foresets is predominant, and commonly has a herringbone cross-stratification. Transported shells, either intact or as fragments, are contained in the basal part above erosive channel-like scours. The upper part contains some burrows and commonly consists of alternations of sand and mud (0.5–1.5 m thick) with tabular beds of broken *Echinarachnius mirabilis* shells. Subfacies TD(c)-b, 1 to 2 m thick, consists of fine to medium grained sand with silt layers. Wave ripples and parallel lamination are the dominant structures. Convolute bedding and dish structures are also present. Bioturbation is common, dominated by *Ophiomorpha*-type burrows. Casts of *in situ* shells are also present. Subfacies TD(c)-c is 1 to 4 m thick and consists of mud with peaty layers and rootlets. Thin beds of very fine grained sand and laminated mud with inverse grading are also present. Minor burrowing characterizes the lower part.

Depositional environments. The depositional environments of these facies are best interpreted by a tidal delta model.

The mud of facies TD(a) indicates a low-energy prodelta environment, where thin sand layers were introduced by storm-generated currents that included density currents or underflows.

Facies TD(b) corresponds to the delta-front deposits. Based on its molluscan ecology, subfacies TD (b)-a represents deeper water conditions in comparison with than facies TD(b)-b. The large-scale, low-angle, tabular cross-stratification may indicate the original

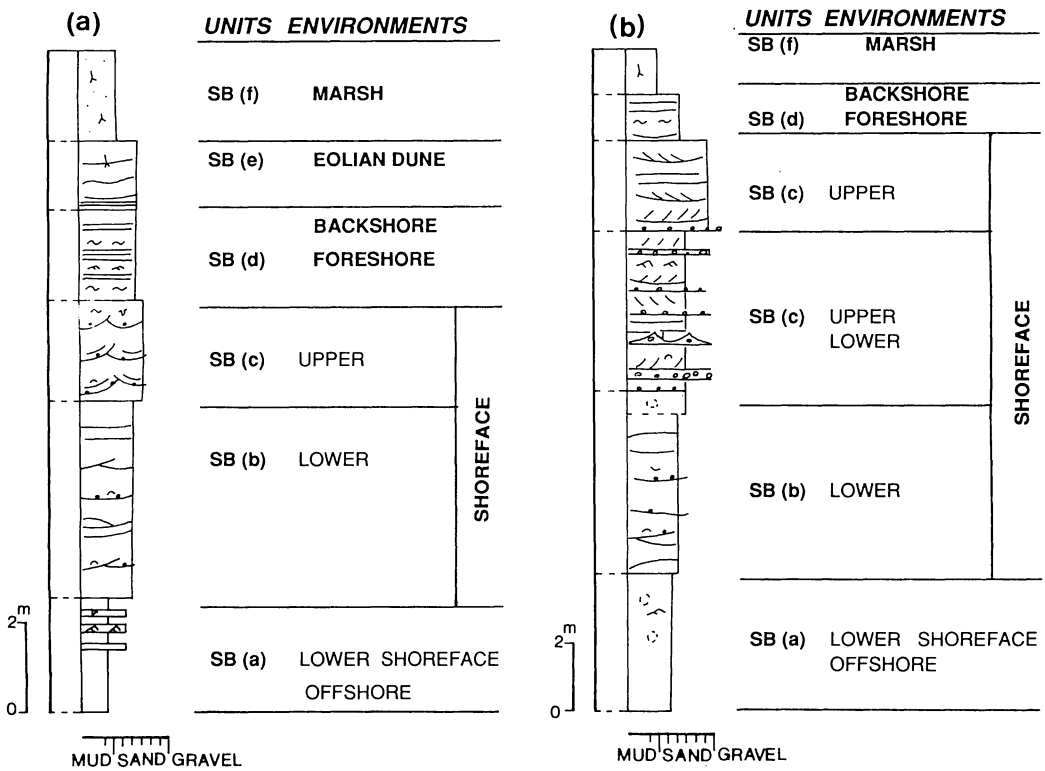

Fig. 17. Two lithologic types of prograding shoreface–beach system, after Okazaki and Masuda (1992). (a) bay type. (b) open-sea type.

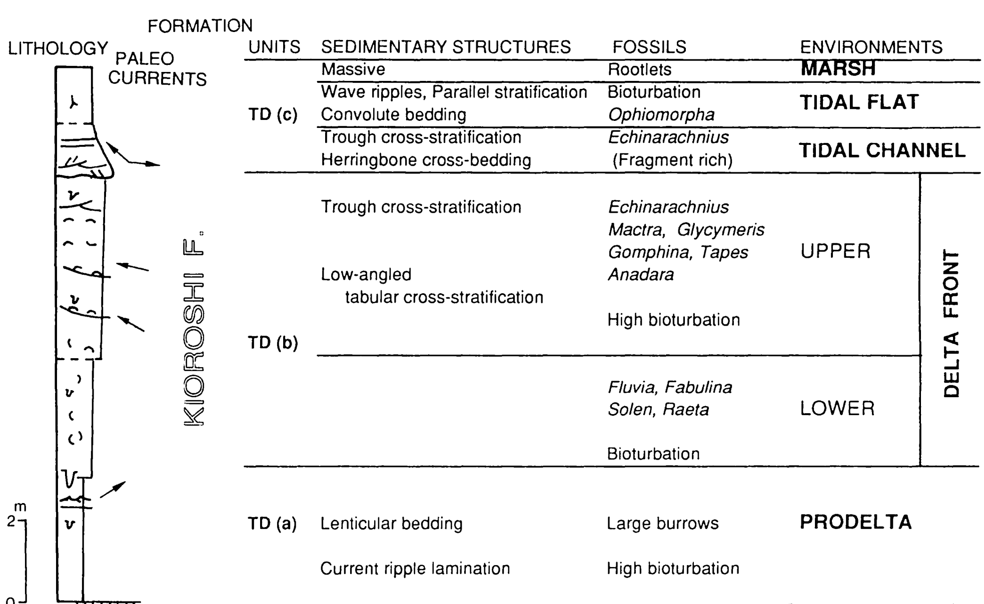

Fig. 18. Generalized facies succession of a tidal delta system in the Kioroshi Formation in the Shimosa Upland, after Okazaki and Masuda (1992).

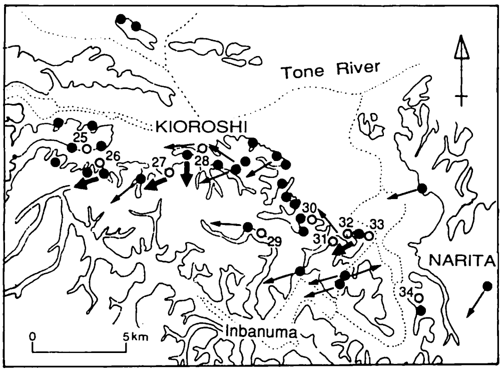

Fig. 19. Distribution of a tidal delta system in the Shimosa Upland. Numbers indicate localities for the columnar lithologic sections, after Okazaki and Masuda (1989) in Fig. 20. →: paleocurrent direction of cross-beds on the delta front. ➡: foreset direction of the delta front.

dip of the deltaic slope. Facies TD(b) was developed by progradation of a delta sandbody.

Facies TD(c) was formed on the delta plain. The sandy deposits of subfacies TD(c)-a and -b are characterized by wave ripples and herringbone cross-stratification with distinct bimodal dispersal patterns formed under the interaction of waves and tides. The wave ripples show the same wave conditions as the ripples formed on the modern tidal flats of Tokyo Bay (Masuda and Makino, 1987). Subfacies TD(c)-a and -b are deposits of tidal channels or tidal creeks, and tidal flats, respectively. The high-energy, coarse grained layer with a unidirectional pattern, intercalated in subfacies TD(c)-b, corresponds to a

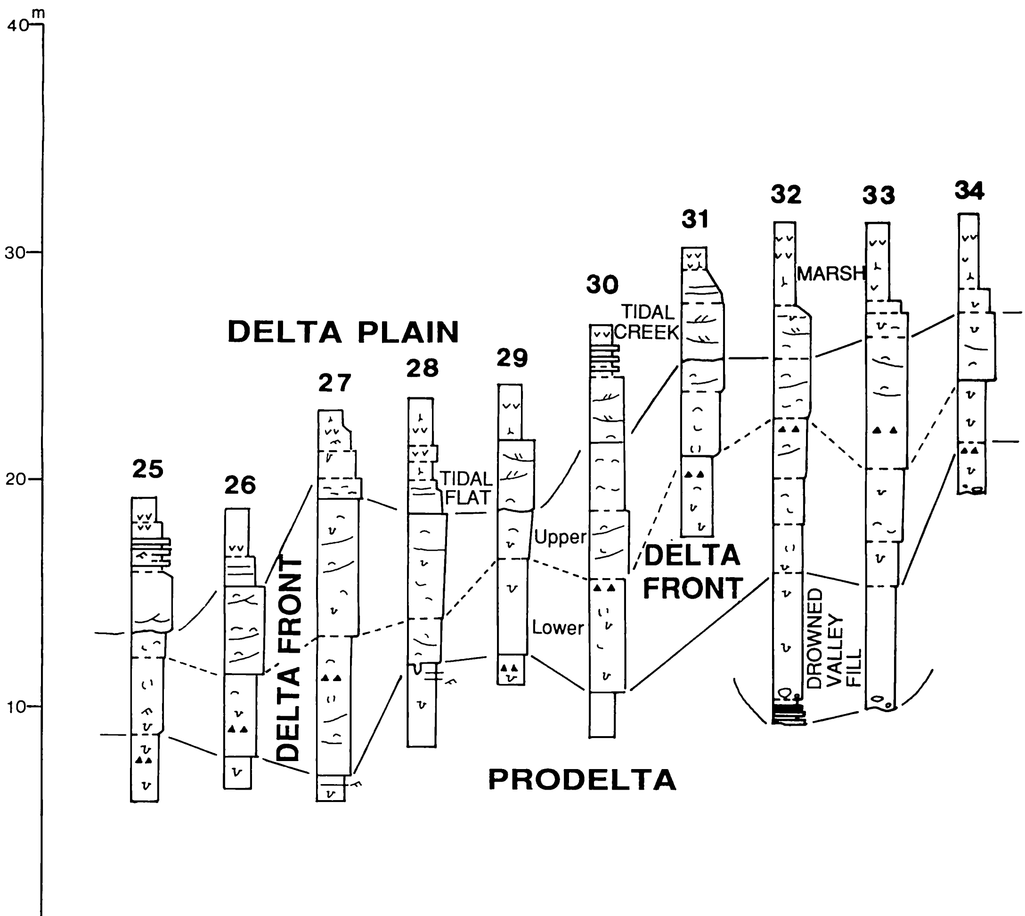

Fig. 20. Examples of typical columnar lithologic sections showing a tidal delta system in the Kioroshi formation, after Okazaki and Masuda (1992). 25: Kizaki, 26: Funato, 27: Izumi, 28: Kioroshi, 29: Tsukuriya, 30: Sunaoshi, 31: Otake, 32: Yoshitaka, 33: Kabuwada, 34: Sogo. The localities are shown in Fig. 19.

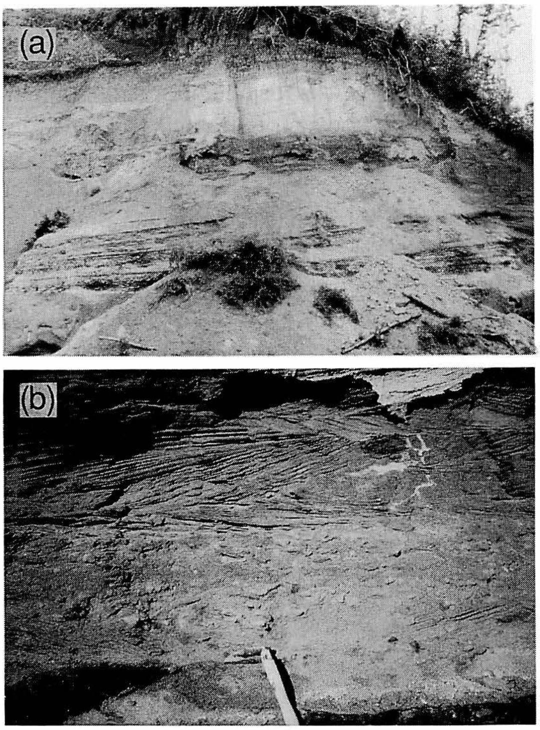

Fig. 21. Tidal delta deposits. (a) Large-scale low-angled tabular cross-stratification of delta-front deposits dips gently to the left in the middle part of the cliff at Loc. 26, Funato, Inzaimachi. The cliff is about 17 m high. (b) Tabular cross-stratification of delta front deposits at Yamada, Inbanuma. Intense bioturbation can be seen in the lower half of the photo. The locality is 2 km to the south of Loc. 33. The trowel is 30 cm long.

washover deposit on a tidal flat. The depositional environment of subfacies TD(c)-c corresponds to a delta marsh. Roots indicate plant colonization in the muddy layers deposited from suspension. Thin sand layers with inverse grading are characteristic of flood deposits.

Distribution and Paleocurrents. The dominant directions of the paleocurrents are from northeast to southwest in the delta-front and from east to west on the delta plain (Fig. 19). Masuda and Okazaki (1983a) discovered that the scoria marker described by Sugihara (1979) occurs in the various units. In the western and southern areas, the tephra layer is intercalated in the prodelta facies of facies TD(a) (Fig. 20, Locs. 25 and 29) or lower delta-front facies of subfacies TD(b)-a (Loc. 26). In the northern Kioroshi area, it lies in the upper part of the lower delta-front facies of subfacies TD(b)-a (Locs. 30–32), and in the eastern area, it occurs in the upper delta front facies of subfacies TD(c)-b (Loc. 33). These observations suggest that there was a difference in water depth of about 10 to 15 m between the northwestern and southeastern areas at that time.

5. Drowned-valley-fill system (DV)

Facies sequence. The Facies, DV(a), DV(b) and TI (Fig. 22) are present in the lower mud of the Kioroshi Formation in the Kashima Upland, the Namekata Upland, the north part of the Inashiki Upland, and around Matsudo–Yokaichiba in the Shimosa Upland. The localities where these facies are well developed (Figs. 23 and 24) are Hiregasaki, Matsudo City (Loc. 35), Iwai, Shonan-machi (Loc. 36), Wakamatsu, Ishioka City (Loc. 37), Hanariko, Ishioka City (Loc. 38), Okishu, Ogawa-machi, Higashiibaragi-gun (Loc. 39), Wagomi, Tamatsukuri-machi, Namekata-gun (Loc. 40), Sakihama, Dejima-mura, Niihari-gun (Loc. 41), Nehori, Aso-cho, Namekata-gun (Loc. 42), Tsuga, Oono-mura, Kashima-gun (Loc. 43), and Nemichi, Oono-mura (Loc. 44).

Facies DV(a), 2 to 4 m thick, consists of massive silt to very fine grained sand, and fine gradually upwards. It contains basal gravel and mud clasts. Bioturbation is intense. *In situ* shells of *Dosinia japonica*, *Macoma tokyoensis*, *Lucinoma annulata*, and *Crassostrea gigas* are present (Locs. 40 and 41).

Facies DV(b) consists of alternations of very fine to fine grained sand and mud, exhibiting lenticular and flaser bedding. Plant fragments are commonly present on the surfaces of the lamination. The upper part is massive mud with intense burrowing.

Facies DV(a) and DV(b) fill erosional valleys, in some places.

Facies TI interfingers with facies DV (Fig. 24). It consists of coarse grained sand bearing granules and pebbles, and is 2 to 5 m thick. Channel-shaped erosional bases are observed. Trough and tabular cross-stratification are

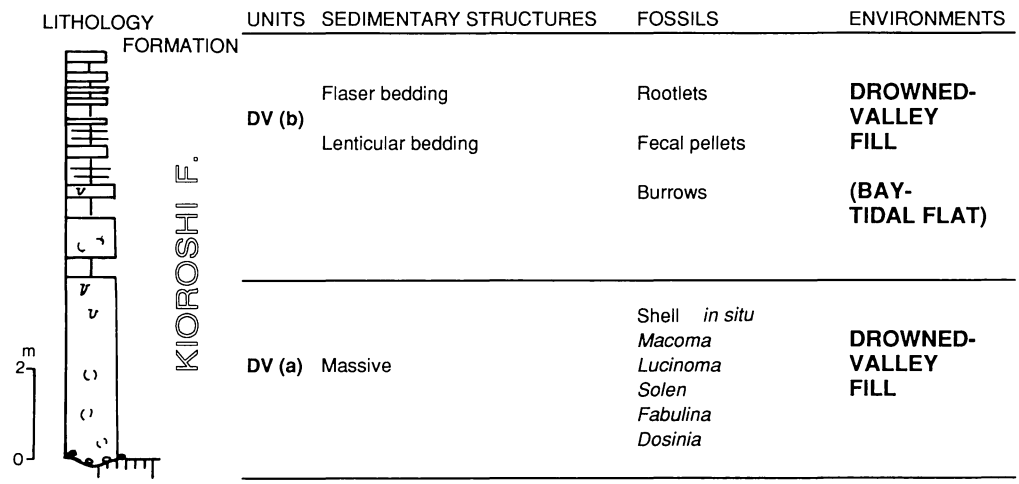

Fig. 22. Generalized facies succession of a drowned-valley fill system in the Kioroshi Formation, after Okazaki and Masuda (1992).

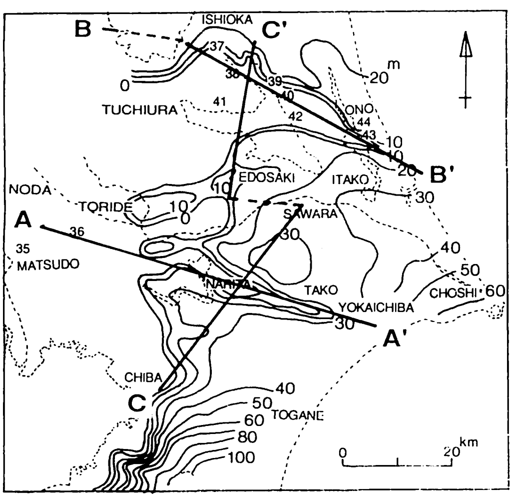

Fig. 23. Contour map of the base of the Kioroshi Formation after Kikuchi (1981). A–A′, B–B′, C–C′ show the cross sections in Figs. 27, 28, and 29.

predominant structures. Herringbone cross-stratification, reactivation surfaces, and mud drapes are also present. Massive mud with large vertical burrows (diameter: 2–3 cm, length: 10–20 cm) overlies facies TI.

Depositional environments. Facies DV(a) was probably deposited in a bay, protected from fluvial and wave action, to account for the presence of *in situ* molluscan fossils and lack of sedimentary structures. Ecological data for molluscs indicate an intertidal to mesoneritic zone with a sandy mud bottom as the deposition environment of facies DV(a).

The lenticular and flaser bedding of facies DV(b) are characteristic features of tidally deposited sand (Reineck and Wunderlich, 1968) (Fig. 25a). Abundant burrows and plant debris indicate that facies DV(b) has deposited under low energy condition with a mixed influence of fluvial currents and tides. Therefore, the facies is estuarine. Most of the sand was probably introduced from the ocean, whereas the mud was contributed primarily by river discharge.

Facies DV(a) and DV(b) deposites resemble alluvial valley deposits, and are interpreted as a drowned valley-fill deposits.

Herringbons cross-stratification, reactivation surfaces, and mud drapes in facies TI indicate tidal influence (Fig. 25b). Herringbone cross-stratification is formed by the reversal of tidal currents. Reactivation surfaces occur in areas where either the ebb or flood flow predominates and the weaker countercurrent erodes some previously deposited foresters. The subsequent flow of predominant current builds foresets over the erosional surface, preserving in the set as a reactivation surface. Mud drapes accumulates from suspension on the foresets during the

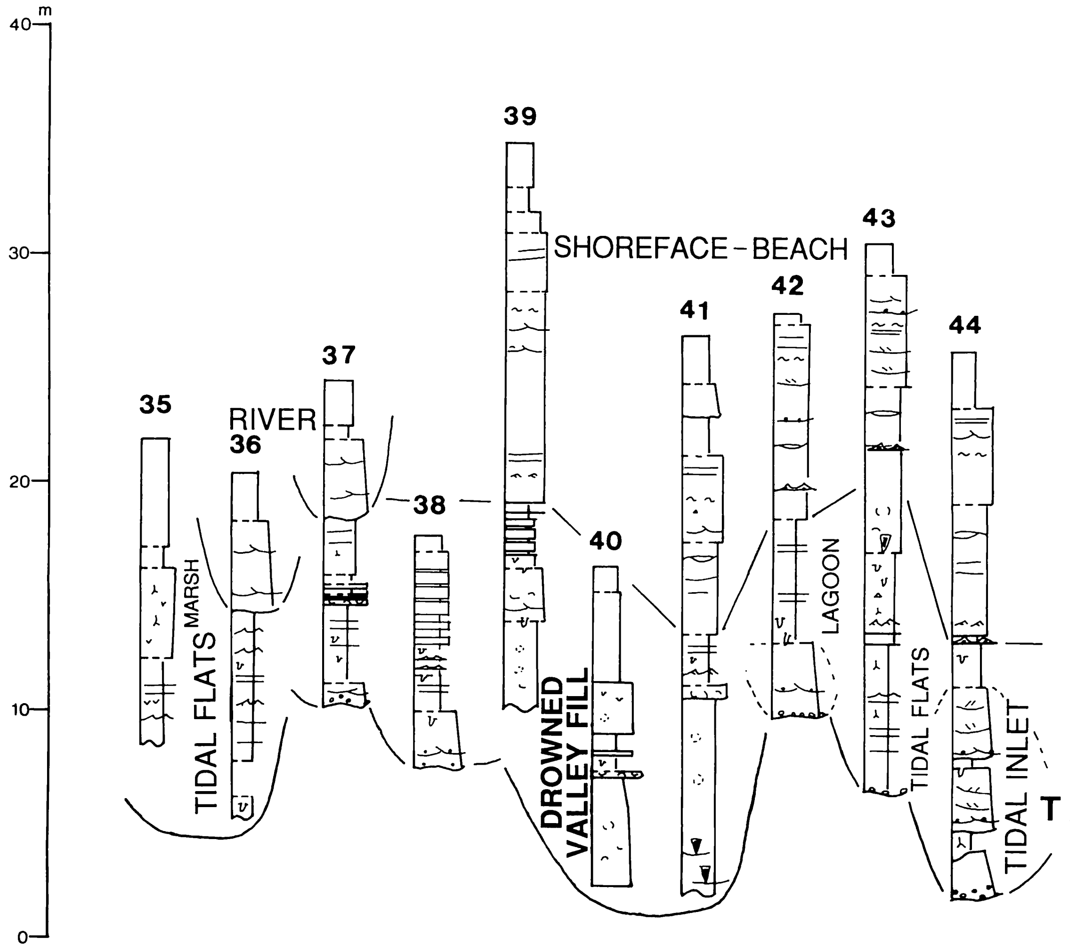

Fig. 24. Examples of typical columnar lithologic sections showing a drowned-valley fill system in the Kioroshi Formation, after Okazaki and Masuda (1992). 35: Hiregasaki, 36: Iwai, 37: Koya, 38: Hanashi, 39: Okisu, 40: Wagomi, 41: Sakihama, 42: Nehori, 43: Tsuga, 44: Nemichi. The localities are shown in Fig. 23.

slack water phase after flow of the subordinate currents (Visser, 1980). Considering its channelised depositional style and textures, facies TI is interpreted as deposits of either tidal channel or tidal inlet.

Distribution and paleocurrents. Facies DV(a), DV(b) and TI found at the base of the Kioroshi Formation are distributed in the geomorphic lowland areas of the Shimosa Upland, Kashima Upland, Namekata Upland, Dejima Upland, and the northern part of the Inashiki Upland (Fig. 23).

The strike of the channel wall of facies TI in the Kashima Upland is approximately east–west. The direction of tidal currents inferred from the cross-stratification is north-west–southeast. Both directions are normal to the elongation direction of the barrier islands (approximately north–south), as inferred from the overlying foreshore facies of SB(d) (Okazaki, 1992). This suggest that the channel was a tidal inlet connecting the bay with the open sea.

6. Depositional systems of Paleo-Tokyo Bay

Figures 13 and 26 show the environmental distribution and associated depositional system geometry at the time of deposition of the Kioroshi and Joso Formations, respectively.

Geomorphology of valley and drowned valley-

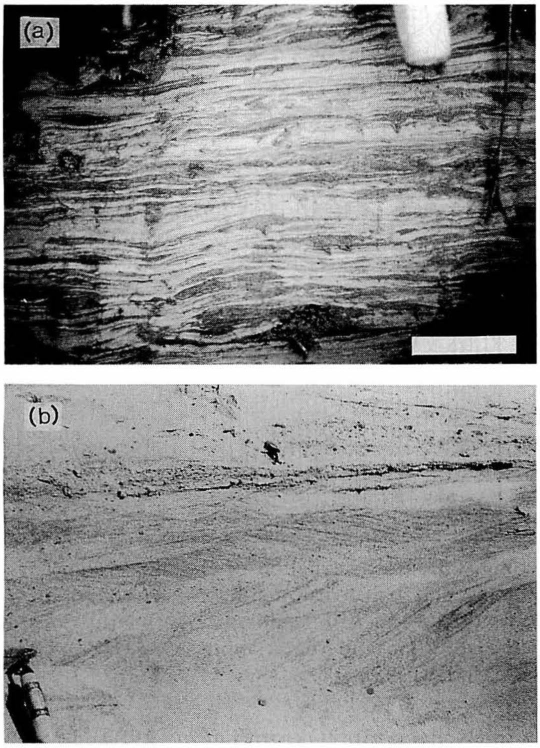

Fig. 25. Drowned-valley fill deposits. (a) Lenticular bedding composed of alternations of fine to very fine grained sand and mud in the tidal flats deposits. Small ripple and parallel laminations in the sand at Loc. 36, Iwai, Shonanmachi. The scale is 5 cm long. (b) Herringbone cross-stratification composed of fine to medium grained sands in the tidal channel deposits at Loc. 44, Nemichi. The scale is 10 cm long.

fill system. At the base of the Kioroshi Formation, there are two large depressions (Fig. 23). One depression, observed in the Shimosa Upland (Shimosa Upland Research Group, 1984; Sugihara, 1979), extends from Yokaichiba to Matsudo (AA′ in Fig. 23), and the other extends from Choshi through Itako (Kawamura and Masuda, 1985) or from the Kashima Upland through the Namekata Upland to lake Kasumigaura (BB′ in Fig. 23). These features were long and narrow valleys at the base of the Kioroshi Formation. They are filled with drowned-valley-fill deposits. A similar buried-valley topography has been reconstructed in the Higashi Ibaraki and Ishioka Uplands by Sakamoto *et al.* (1981).

Shimosueyoshi transgression and barrier-islands system. The Kioroshi Formation was deposited during the Shimosueyoshi transgression (Sugihara *et al.*, 1978). At the stage of the highest sea level during the Shimosueyoshi transgression, the conclusion that the sea covered the area of the present Kanto Plain is supported by the distribution of beach deposits and the wave-cut surfaces in the Kioroshi Formation. Specifically, beach deposits crop out at about 25 m altitude around Mt. Tsukuba, at about 40 m in the Kakioka Basin to the east of the Tsukuba Mountains, and at more than 112 m from Ooami to Togane in the Shimosa Upland due in part to later tectonic uplift (Okazaki and Suzuki, 1990). Moreover, around Omigawa, Yokaichiba and Sahara in Chiba Prefecture (Sato, 1987MS), and around Hokota, Hinuma, Ogawa and Ishioka in Ibaraki Prefecture (Sakamoto *et al.*, 1981), flat erosional surfaces define the base of the Kioroshi Formation, and are interpreted to have been wave-cut surfaces formed during the transgression.

In the central part of the ancient bay, tidal delta deposits are found in the middle sands of the Kioroshi Formation. The deposits from Takomachi to Kioroshi in the Shimosa Upland contain thick fossil beds of molluscan shells (Fig. 13). Generally, barrier islands and their associated tidal deltas develop during the transgression (Moslow and Heron, 1979). This tidal delta contains a tephra layer of the "Klp" group, dated at about 130 to 140 Ka. At this time, barrier islands associated with the Shimosueyoshi transgression existed on the eastern side of the Shimosa Upland.

The tidal delta in the Kioroshi area is different from other deltas in Paleo-Tokyo Bay, in that (1) the shell bearing layers is unusually thick, (2) the tidal delta shape is long and narrow, and (3) a drowned-valley-fill facies forms the delta bottomsets.

Apparently, the drowned valley became shallower due to filling. Barrier islands developed onward the open-sea side, while a shallow bay formed on the landward side. The valley mouth acted as a tidal inlet, and tidal currents flowed into the bay from the open sea through the valley, so that the tidal delta advanced landward into the bay.

Furthermore, before and after this period, in the Namekata Upland along the east-facing shore of the present lake Kasumigaura, there was a chain of barrier islands (Masuda, 1989 b). Coeval tidal deltas and washover deposits are also recognized at Tamatsukuri and Itako in the Namekata Upland (Yokokawa *et al.*, 1989; Murakoshi, 1989; Murakoshi and Masuda, 1991).

Lowering of sea level and emergence of a shoreface-beach system. When the sea level began to drop from the high stand, tidal deltas became inactive and then emergent, and the inland bay changed progressively to a lagoon, then a salt marsh and finally a fresh-water swamp. The area of the shoreface changed into a strand plain. The shoreface-beach system then advanced seaward. The shoreface from Chiba to Matsudo in the Shimosa Upland became emergent on a large scale in this period (Fig. 13), as demonstrated by Kikuchi (1981). In this area, the beachface shifted toward the present Tokyo Bay, leaving emergent ridges parallel to the present shoreline. These ridges are inferred to have been barriers that extended northward from the Boso Peninsula. The area from Sakura to Usui, situated between this beach area and the tidal-delta area, changed from an open bay to a lagoon as the growing barriers blocked water exchange (Okazaki and Masuda, 1989b). The massive mud contained the subaqueous "Pm-1" tephra (Nakazato, 1987MS). Accordingly, this area remained as an area of stagnant water until a later period without inflow of coarse-grained materials. The other areas except for Edozaki, which had emerged during the earlier phase, remained as a bay of muddy sediments composed principally of alternating layers of sand and mud with the "Klp" tephra.

Reduction of Paleo-Tokyo Bay, and the birdfoot delta-meandering river systems. Following the lowering of sea level, a coastal plain appeared by the emergence of the shallow and flat areas. There after, a small relative rise of sea level is inferred to account for marine washover deposits of a lagoon that spread over the Sakura area. Around lake Kasumigaura, the bay enlarged and persisted as a fairly deep site (Okazaki *et al.*, 1984). Lagoonal deposits for this period are also observed in the area from Yokaichiba to Omigawa (Sato, 1987MS). This rise in sea level suggests the possibility of transgression during the Hikihashi period. As a result of subsequent lowering of sea level again, the birdfoot delta system of the Joso Formation advanced from northeast to southwest (Fig. 26). As brackish-water diatoms and plant fossils are contained in the bottomset beds of the delta, this area is considered to have been a lagoon. The "Pm-1" tephra is observed in the interdistributary bay mud. Following continued lowering of sea level, the Joso Upland became emergent and the meandering-river system of the Joso Formation, the antecedent to the present Kinu River, flowed from the northwest to the southeast. Wave-cut terraces, known as Chiba Terrace, were formed along the present Tokyo Bay side of the Shimosa Upland. The circumstances along the present Pacific Ocean side of the upland are believed to have been the similar, but details are not available.

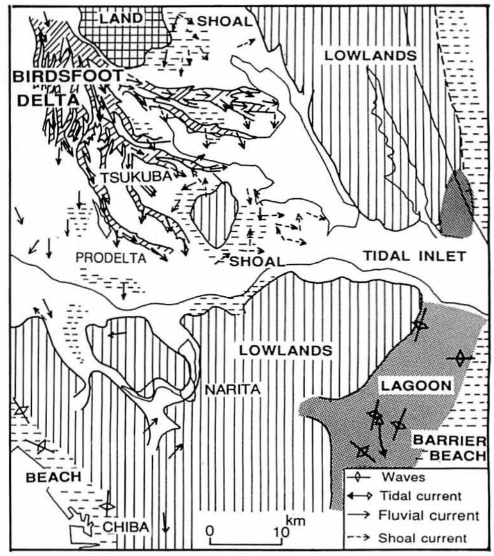

Fig. 26. Reconstruction of the depositional systems and paleocurrents in the "Period of Birdfoot delta", the Hikihashi and Obaradai periods in 100–80 thousand years before, after Okazaki and Masuda (1992).

Results of sequence analysis and discussion

Sequence stratigraphy

The concepts of sequence stratigraphy developed in seismic stratigraphy have been applied to the depositional seequence in the Kioroshi and Joso Formations.

1. Depositional succession

Depositional successions are drawn up in order to discuss the depositional sequence of Paleo-Tokyo Bay (Figs. 27, 28 and 29). The cross-sections shown in Fig. 23 correspond to the valleys filled by the Kioroshi Formation. In the valleys, the thickest deposits in the bay are well preserved and transgressive and regressive deposits are evident.

Yokaichiba–Matsudo cross-section. Five depositional systems are observed in the Yokaichiba–Matsudo area: drowned-valley-fill, tidal-delta, shoreface–beach, birdfoot-delta and meandering-river systems in ascending order (Fig. 27).

The drowned-valley-fill system is found in the lowermost part of the area and is 8 to 16 m thick. The system overlies the subjacent formation with a distinct erosional surface. The drowned-valley-fill facies varies in different portions of the valley. The eastern part corresponding to the valley mouth consists of the sandy tidal channel and muddy tidal flat deposits. The branches of the valley (4–8 m deep) running obliquely to the main valley and present in the central part of the valley, are filled with intensely bioturbated mud. The western part representing the upper reach of the valley consists of muddy deposits, such as flood plain, tidal flat, lagoon and bay floor deposits.

The tidal delta system sharply overlies the drowned-valley-fill systems. The delta foreset, 10 to 15 m thick, is divided into two subunits in this area. The tidal inlet is intercalated with the delta system at Narita.

The beach–shoreface system is observed from the Narita to Yokaichiba over the tidal delta system. This system is 5 to 10 m thick, becoming thicker eastwards. The base of the system shows a sharp surface, and marine shell fragments and coarse grained sand are accumulated on the surface. Alternated mud and sand of the shoreface in the lower part of the system grade upwards to beach sand. The beachfaces decline in opposite directions between Narita and Yokaichiba, suggesting that the barrier islands existed there.

The birdfoot delta system is observed in the Shirai area, covering the underlying systems with erositional surface. The "Kmp" and "Pm-1" tephras are intercalated in the inter-

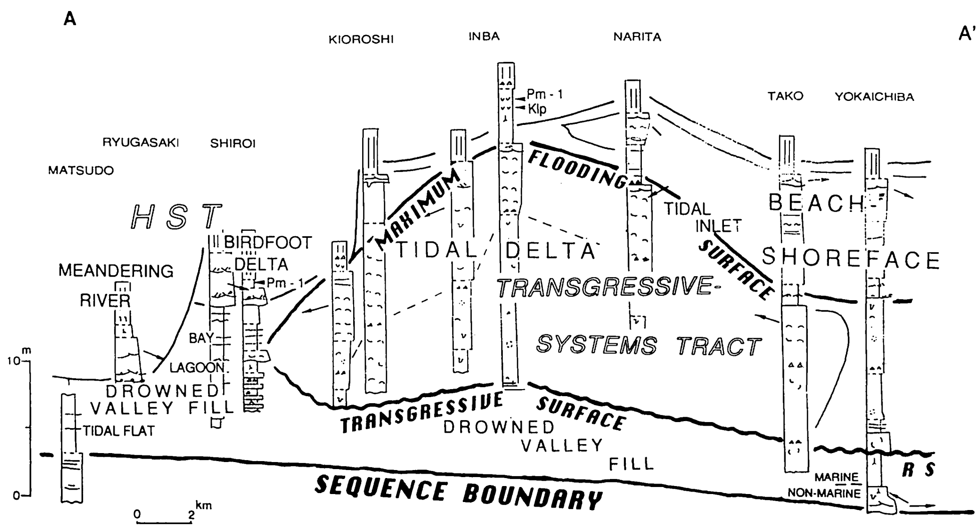

Fig. 27. Depositional sequence of the Kioroshi and Joso Formations showing the sequence stratigraphic relationships. A–A′ is shown in Fig. 23.

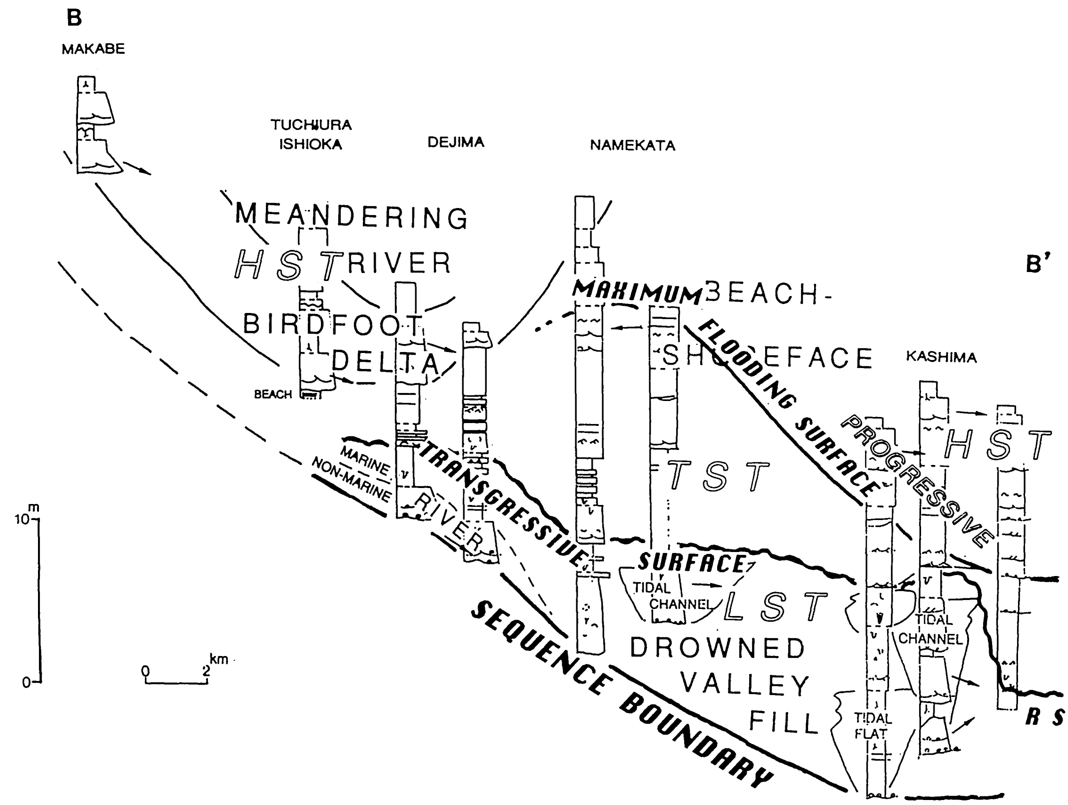

Fig. 28. Depositional sequence of the Kioroshi and Joso Formations showing the sequence stratigraphic relationships. B–B′ is shown in Fig. 23.

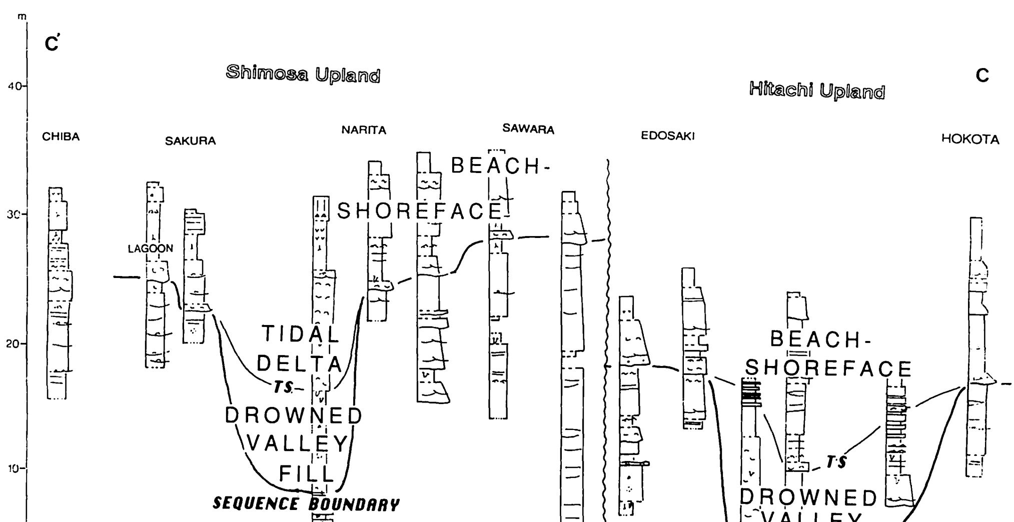

Fig. 29. Depositional sequence of the Kioroshi and Joso Formations showing the sequence stratigraphic relationships. C–C′ is shown in Fig. 23.

distributary bay mud of the birdfoot delta. Furthermore, the meandering river system progrades into Ryugasaki from Takegaki, taking away the birdfoot delta system and eroding the shoreface-beach system.

Kashima–Ishioka cross-section. Four systems are observed in the Kashima–Ishioka area; drowned-valley-fill, shoreface–beach, birdfoot-delta, and meandering-river systems in ascending order (Fig. 28).

The drowned-valley-fill system is observed in the lower part of the whole area. The system is 10 to 15 m thick at the center of the drowned valley, and 4 to 5 m in the marginal area. Estuarine deposits, such as tidal channels, tidal flats, and channel-fill facies, develop in the eastern part of the valley in the Kashima and Namekata Uplands. The tidal channels migrated laterally, and abundant channels were filled with muddy deposits, including swamp plants and brackish-water diatoms, such as *Cymbella* spp., *Pinnularia* spp., *Gomphina* spp., *Diploneis smithii*, *Coscinodiscus lacustris etc.* The tidal channels grade upwards into the tidal inlet. A tidal flats facies is observed in the upper or lateral portions of the tidal channels. Plant debris are contained in the lower part of the tidal flat deposits, and burrows increase in number upwards. The drowned-valley-fill system in this area was discussed by Okazaki (1992). The central part of the valley is deeper and yields *in situ* shell beds of *Crassostrea gigas* or *Dosinia japonica.* In the western part, at Ishioka, the fluvial facies is observed in the basal part of the valley.

The shoreface–beach system, 8 to 14 m thick, is present in the whole area. Further, the beach facies is traceable to Kakioka, 10 km west of Ishioka. The base of the system shows a relatively flat erosional surface. Coarse grained sand layers containing pebbles, granules and shell fragments are found on the surface. Molluscan shell species included in this layer are *Tapes variegatus kioroshiensis*, *Mactra sulcataria*, *Mercenaria stimpsoni*, *Patamocorbula anurensis*, and *Spisula sachalinensis.* The upper part of the beach facies contains the "Klp" tephra. The system is eroded by the overlying birdfoot delta system in the western part of the valley. It appears that the barrier islands were present at the center of the Namekata Upland based on the dip orientations of the beachfaces. At the sites closest to the valley mouth, no drowned-valley system is evident. This may indicate that the coastline at the beginning of the transgression was located there, or eroded by the overlying shoreface–beach system.

The birdfoot-delta and meandering-river systems overlie the shoreface–beach system in the western part of the valley, during 6 to 15 m thick as a whole. The birdfoot delta system eroded the underlying shoreface–beach system. The meandering-river system lies on the birdfoot-delta system without distinct erosion.

2. Depositional sequence

The fundamental unit of sequence stratigraphy is based on the depositional sequence, which is defined as "relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities (Mitchum *et al.*, 1977). It is possible to subdivide the depositional systems of the Kioroshi and Joso Formations into a lowstand, transgressive and highstand systems tracts (Figs. 27 and 28) based on their recognition of their bounding surfaces and stacking patterns. In this chapter, features of the systems tracts are described as consisting of a set of the depositional systems, the bounding surface of the systems tracts, and their relation to glacio-eustatic sea-level changes in Paleo-Tokyo Bay.

Sequence boundary. Significant erosive relieves are evident at the base of the Kioroshi Formation (Fig. 23). They occur as narrow and long depressions which form valleys. The Kioroshi Formation rests on the underlying strata with eroded surfaces in some places, one or two subordinate formations being cut off by the erosion. This unconformity is considered to have been formed by subaerial fluvial erosion owing to fall in sea level. Therefore, this erosional surface is recognized as a sequence boundary. A channel-

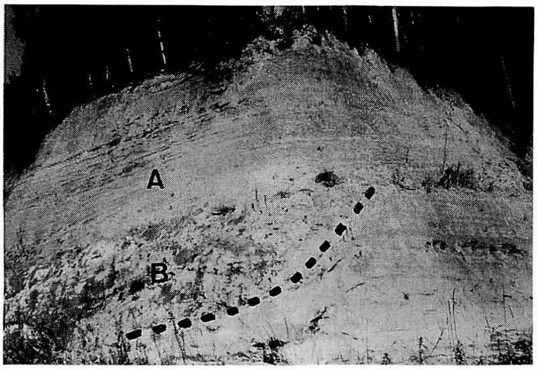

Fig. 30. Deposits of tidal channel, channel-fill and tidal flats, Inashiki area in Fig. 28 (Loc. 44 in Fig. 24). A indicates tidal channel deposits composed of very coarse grained sand and includes medium-scale trough cross-stratification. B is channel-fill deposits composed of massive peaty clay. The channel-erosive base of the tidal channel (---) indicates a channel diastem. The cliff is about 6 m high.

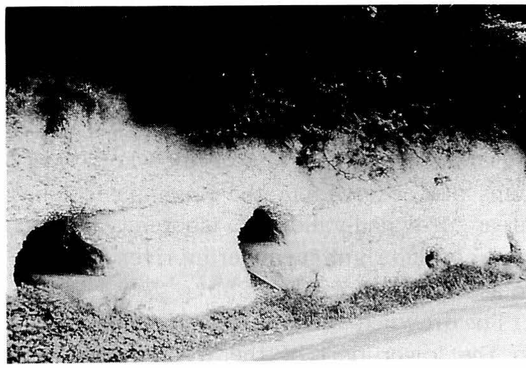

Fig. 31. Trough cross-stratification of drowned valley-fill deposits is composed of oyster shells at Loc. 41, Sakihama, the Dejima Upland. The cliff is about 2 m high.

like diastem is a local expression of a regional subaerial surface that is a sequence boundary, for instance, tidal channels at the mouth of a valley (Fig. 30) (Nummedal and Swift, 1987). At the central part of the valley, the sequence boundary coincides with the floor of the ribs of the valley. Pebbles, mud clasts, plant debris etc. directly overlying the sequence boundary may be lag gravels or rip-up clasts of the underlying beds.

Lowstand systems tract. Valley-fill sediments are characterized by a drowned-valley-fill system of fluvial, esturine, and/or marine sands and muds. Valley-fill deposits of the valley mouth are characterized by estuarine deposits, though fluvial deposits are observed at the basal part of the upper reaches of a valley. Oyster reefs and mounds are formed in the valley margin (Fig. 31) (Okazaki and Masuda, 1989b; Masuda *et al.*, 1990).

Valley-fill sediments consist of a vertical sequence from fluvial or tidal channels and tidal flats, through estuarine-mouth facies, to open-bay muds or oyster reefs. The lower part of the valley deposits is characterized by the point bars of active meandering tidal channels and abandoned channels which grade into an extensive tidal inlet (Okazaki, 1992). In this way, an estuary with lateral-shifting tidal channels and tidal flats may develop during a period of relatively lowstand sea level. Change to the tidal inlet and open bay seems to indicate that upward accretion occurred owing to valley drowning during the early transgression.

Accordingly, the drowned-valley-fill system corresponds to a lowstand systems tract deposited during the late eustatic fall or early eustatic rise. The lowstand systems tract generally consists of a basin-floor fan, slope fan and lowstand wedge in a basin. However, Paleo-Tokyo Bay is located so proximally relative to the positions of these depositional systems that the drowned-valley-fill system may correspond to them. Most of the valley fill represents the deposit laid down in the transgressive stage. Nevertheless, this system is not included in the transgressive systems tract in this study, because it bound the overlying depositional systems with a sharp surface, that is, the transgressive surface, as mentioned later, Therefore, in this paper, the lowstand systems tract is defined as the deposits from the sequence boundary to the transgressive surface. Accordingly, the distribution of the lowstand systems tract is restricted to the valley-shaped base of the Kioroshi Formation. The thickest lowstand depositional systems are formed and preserved in the deepest entrenched valleys.

Transgressive systems tract. The uppermost part of the drowned-valley-fill deposits is re-

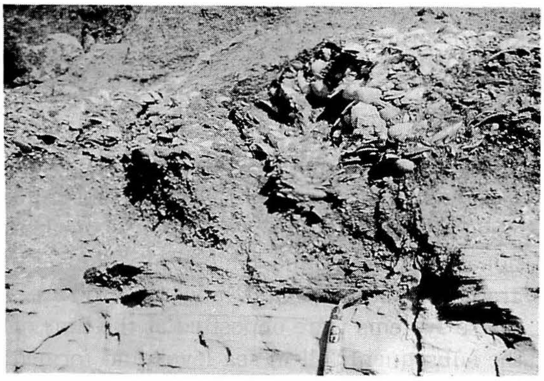

Fig. 32. Shell concentration above an erosional base in the Kioroshi Formation at Shojiki, Amimachi. The locality is 3 km southeast of Loc. 13. It indicates a ravinement surface and corresponds to the sequence boundary out of the valley areas. The trowel is 15 cm long.

Fig. 33. Lag deposits with a sharp bottom surface consist of granule. Shell fragments are shown at the center of the photo. Kashima area in Fig. 28 (Takei, 1 km south of Loc. 44). Above the lag deposits highy bioturbated alternations of mud and very fine grained sand of lower shoreface deposits are observed. The trowel is 30 cm long.

presented by mud with abandoned vertical burrows, which probably indicates a temporarily stable sea level. The surface at the top of the drowned valley is typically burrowed and appears to represent a highly erosional event. Above the surface, at the basal part of the shoreface–beach system, there are coarse deposits containing gravels, mud clasts, and abundant molluscan shells either intact or fragmental (Fig. 32). The surface is most easily recognizable on outcrop because of the lithologic contrast between the muddy valley-fill deposits and coarse sediments. The surface is traceable over the exterior area of the valleys and forms wave-cut terrace of Paleo-Tokyo Bay. Accordingly, the surface is recognized as the transgressive one which is capable of an abrupt increase in accommodation and causing the flooding of sea interfluvial areas, resulting in a ravinement surface. A ravinement surface is a surface of sediment transfer. Sediment eroded from the shoreface by storm currents is commonly redeposited above the ravinement surface further seaward (Swift, 1968; Ryer, 1977; Weimer *et al.*, 1985). Where the transgressive surface truncates previously subaerial interfluves or other coastal headlands, the ravinement diastem replaces the sequence boundary (Fig. 29). The time of the transgression is about 140 Ka according to ESR dating of the shells on the surface (Nakazato *et al.*, 1992).

Above the surface, alternated mud and sand from the offshore-lower shoreface are laterally overspread (Fig. 33). A beach facies contemporaneous with the shoreface facies is observed at the margin of Paleo-Tokyo Bay, as mentioned above. The transgressive surface indicates that the shoreline began to migrate landward and that sediment influx was insufficient to keep pace with increasing accommodation.

In the central part of the bay, the tidal delta system migrated landwards, as inferred from the observation of marker tephra layers of scoria (Fig. 27). The ESR age of the tidal delta is 140–120 Ka (Nakazato *et al.*, 1992). The barrier system intruded into the bay during the Shimosueyoshi transgression.

In Paleo-Tokyo Bay, the transgressive systems tract is characterized by the retreat of the barrier islands system, consisting of tidal delta and shoreface–beach systems.

Highstand systems tract. As the rate of sea-level rise slowed, barrier islands probably ceased their landward migration and might have reached the area of Narita (Fig. 27) and Namekata (Fig. 28), which constitute the emergence axis (Fig. 13). As emergence proceeded, the coastal plain prograded both eastwards and westwards. Consequently, the beach–shoreface slope just before the emergence corresponds to the maximum flooding surface. The initial inclination of the beach–shoreface is obtainable from the modern sandy beachface slope off Kujukurihama or off Wakanoura, and is calculated to be approximately 3/1000 to 5/1000. In Figs. 26 and 27, the columnar sections on the east side, at Yokaichiba and Kashima, respectively, are lowered 15 to 20 m, considering the tectonic rise after the Shimosueyoshi period, when the rate of lifting was 0.1 to 0.5 mm/yr, according to Masuda and Nakazato (1988). If this estimate of the lifting rate is correct, then the shoreface of Yokaichiba and Kashima is contemporaneous with the beach facies of Narita and Namekata, respectively. In other words, most of the beach–shoreface system on the east side of the emergence axis area was formed during the regression. The different types of beach–shoreface system, the bay and the open-sea types, as mentioned before may correspond to the transgressive and regressive stages of the beach–shoreface systems. However, this is only speculative because no differentiable tephra can be identified in the these sections. Above the maximum flooding surface, the beach–shoreface system prograded to the open-sea side and formed the highstand systems tract.

Subaerial deposits, the birdfoot delta and meandering river systems, overlie the tidal delta and the shoreface–beach systems with a distinct channel diastem. The birdfoot delta and meandering river systems are aggradational in the Kashima–Ishioka area, but progradational in the Yokaichiba–Matsudo area. These systems were deposited at the time of the subsequent fall in sea level, and formed the late highstand systems tract. Further, at the top of the sequence, the Kioroshi and Joso Formations are bounded by the sequence boundary formed in the Tachikawa period later than 60 Ka.

3. Depositional sequence and sea-level change

The inferred history of the depositional sequence and sea-level change is as follows (Fig. 34): A sequence boundary is located at the base of the Kioroshi Formation and valleys which were formed by a river (150 Ka). This corresponds to the period of rapid eustatic fall, that is the glacial period at stage 6 of the oxygen isotope curve of Emiliani (1978). During the transgression (Shimosueyoshi transgression) from stage 6 to stage 5, the valleys were filled as drowned valleys with fluvial-esturine deposits. The tops of the valleys represent a transgressive surface (140

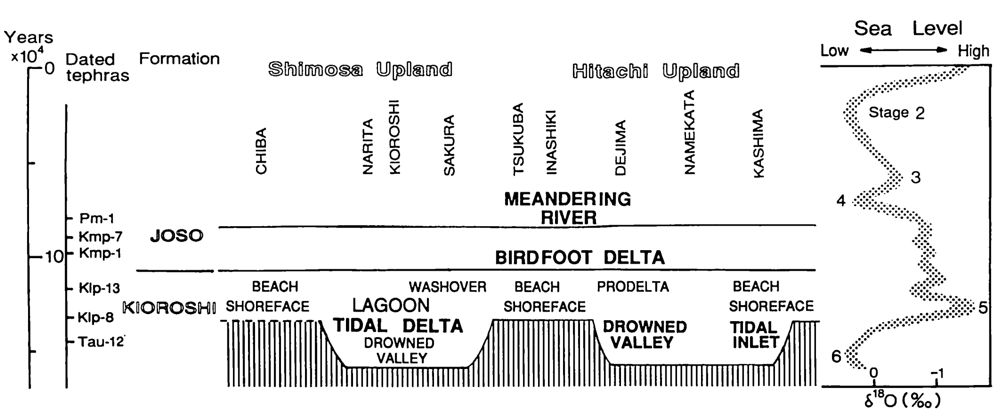

Fig. 34. Chronostratigraphic facies evolution of the Kioroshi and Joso Formations. The marker tephras dated with the fission-track method by Machida and Suzuki (1971) and Sugihara *et al.* (1978). Oxygen isotope curve after Emiliani (1978) shows the global sea-level changes.

Ka), over which rapid transgression took place, and the barrier-island system comprising the shoreface–beach and tidal delta systems retreat and formed a transgressive systems tract (140–120 Ka). The subsequent episode of maximum flooding occurred at stage 5, and was followed by progradation of the coastal plain toward open sea in the highstand systems tract. During the next sea-level lowering (100–60 Ka), birdfoot delta and meandering river systems prograded during the late highstand. Further, at the top of the sequence, the Kioroshi and Joso Formations are bounded by the sequence boundary formed during the Tachikawa period in 60 Ka.

Summary

1) A study of depositional systems and sequence stratigraphy was carried out on the late Pleistocene Kioroshi and Joso Formations deposited in the Paleo-Tokyo Bay area in southern Ibaraki and northern Chiba Prefectures.

2) Depositional systems of drowned-valley fill, beach–shoreface, tidal delta, birdfoot delta and meandering river were recognized in the Kioroshi and Joso Formations in ascending order.

3) The drowned-valley-fill system that consists mainly of alternated sand and mud or bioturbated mud, was observed at the unconformable basal part of the Kioroshi Formation.

4) The beach–shoreface system, that indicates a sandy coarsening-upward sequence, was distributed as a barrier-type landform of Paleo-Tokyo Bay.

5) The tidal delta system, characterized by abundant molluscan shell layers to the east, migrated to Paleo-Tokyo Bay from the open sea.

6) The beach–shoreface and tidal-delta systems comprise the barrier-island system of the Kioroshi Formation.

7) The birdfoot delta system of the Joso Formation, which is a fluvial-dominated coarsening-upward sequence, intruded to the shallower bay from northwest to southeast.

8) The meandering-river system of the Joso Formation, consisting of coarse-grained sand to mud, with a fining-upward sequence, prograded from northeast to southwest. It is an antecedent of the Kinu River.

9) The following systems tracts were clearly discriminated in Paleo-Tokyo Bay by means of paleoenvironmental analysis on the basis of sequence stratigraphic concepts and principles for interpretation of the depositional systems and their bounding surfaces: lowstand systems tract, transgressive-systems tract and highstand systems tract.

10) In Paleo-Tokyo Bay, valleys were formed by fluvial rivers during the low sea-level stage of a glacial period (ca. 150 Ka). The subaerial unconformity shows a sequence boundary.

11) The valleys were drowned and filled with estuarine and fluvial deposits during the early transgression associated with the subsequent inter-glacial period. The drowned valley-fill system corresponds to the lowstand systems tract in Paleo-Tokyo Bay.

12) The transgressive surface related to an abrupt increase in accommodation and a ravinement process at the time of a sea-level flood (ca. 140 Ka) was observed at the top of the drowned valley.

13) In Paleo-Tokyo bay, the transgressive systems tract was characterized by the retreat of a barrier-island system consisting of the beach–shoreface and tidal delta systems accompanying the transgression (the Shimosueyoshi transgression) (140–120 Ka).

14) The maximum flooding surface corresponded to the beach–shoreface slope just before the emergence of the barrier islands.

15) After the maximum flooding, during the early regression associated with the glacial period, a coastal plain prograded sewards and formed the highstand systems tract.

16) During the next sea-level lowering (110–60 Ka), birdfoot delta and meandering river systems developed successively.

17) Unconformity over the top of the Kioroshi and Joso Formations was formed during the Tachikawa period (60–20 Ka), corresponding to the top of the depositional sequence boundary.

18) The depositional systems of the Kio-

roshi and Joso Formations form a depositional sequence. They were strongly controlled by glacio-eustatic sea level changes, and were characterized by the barrier-island system of Paleo-Tokyo Bay.

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上部更新統古東京湾堆積物の堆積システムとシークェンス層序

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茨城県南部から千葉県北部には上部更新統の木下層およびその上位の常総層が広く分布している．この木下層と上総層にみられる，いくつかの特徴的な堆積システムを明らかにした，すなわち，溺れ谷埋積 (drownd valley fill), 外浜–海浜 (shoreface–beach), 潮汐三角州 (tidal delta), 鳥趾状三角州 (birdfoot delta), 蛇行河川 (meandering river) システムである．これらの堆積システムから堆積シークェンスを検討した．木下層の基底の谷の基底面がシークェンス境界である (150 Ka)．この谷は溺れ谷埋積システムで埋積され，このシステムの下部は，低海水準期堆積体 (lowstand systemstract) に相当すると考えられる．この上位にはバリアーシステムを構成する外浜–海浜システムと潮汐三角州システムが重なる．バリアーシステムは海進時に外洋側から内湾側に前進してその後の海退期に海浜平野へと変化し (ca. 140–100 Ka), 海進期堆積体 (transgressive-systems tract) から高海水準期堆積体 (highstand systems tract) を形成している．バリアーシステムの上位には陸成の鳥趾状三角州システムや蛇行河川システムが発達し (ca. 100–80 Ka), 高海水準期堆積体を形成する．これらのシステムの形成後，“沖積の谷”が削られ，この基底が上位のシークェンスで，その形成時期は酸素同位体比曲線のほぼ Stage 6-4 に当たる．