Morpho–dynamic development and facies organization of the Tertiary delta system in the Taishu Group, Tsushima Islands, southwestern Japan

Abstract

The lower formation of the Tertiary Taishu Group in the Tsushima Islands, southwestern Japan, represents repetitive progradation of the bird’s-foot shaped or elongated deltaic system toward the north. Within the deltaic successions, depositional environments include the basin floor, prodelta, channel-mouth bar, lower distributary-channel, upper distributary-channel and interdistributary environments. The Taishu deltaic successions demonstrates that the active distributary channels deeply incised into channel-mouth bars in the delta front due to inertia-dominated river-mouth regime and tidal processes. These channelized mouth-bars grew as a narrow and elongated protrusions in the transitional zone of the delta. As a result, coarse-grained bird’s-foot shaped delta was generated. The interaction of fluvial inertia force and tidal processes was the major controlling factor in morpho–dynamic development and facies organization of the Taishu delta.

Key words: deltaic succession, river-mouth regime, basinal processes, facies organization, morpho–dynamic development, Taishu Group

Introduction

Deltas and deltaic successions have been classified according to dominated physical processes which control depositional geometries and lithofacies organization. The commonly used tripartite classification is based on the relative importance of fluvial, wave and tidal processes (Galloway, 1975). These processes control morphology, constituent environments, and sedimentary facies of a deltaic system. The tripartite classification of the process framework of delta systems by Galloway (1975) is widely used to describe variability of many ancient deltaic successions (e.g., Elliott, 1976; Chan and Dott, 1986; Pulham, 1989; Ramos and Galloway, 1990).

Dynamic condition of the river mouth of deltas rules morphology and depositional patterns of a deltaic system due to the interaction of relative intensity between fluvial and basinal processes such as wave and tidal processes. Coleman (1976) and Wright (1977) stated that sediment dispersal and accumulation patterns at the river mouth are governed by three basic effluent forces and by basinal processes. Neglecting modifications by basinal processes, effluent behavior and consequent depositional patterns depend on the relative dominance of (1) outflow inertia, (2) turbulent bed friction seaward of the mouth, and (3) outflow buoyancy (Wright, 1977). Some studies have also attempted to distinguish the relative importance of dominated effluent forces in classifying ancient river mouth deposits (e.g., Farquharson, 1982; Haszeldine, 1984; Martinsen, 1990). However, these studies have mainly concerned with fluvial-dominated, lacustrine deltas without incorporation of modifications by basinal processes. The relationship between the depositional processes, specifically basinal processes and processes governed by effluent forces, and morpho–dynamics of deltas have not fully documented in ancient deltaic deposits.

This paper concerns with the progradational deltaic successions in the lower formation of the Tertiary Taishu Group, Tsushima Islands, southwestern Japan (Fig. 1). These successions are interpreted to have recorded the interaction of effluent forces from river-mouth and basinal processes in the development of deltaic system and delta morphology. We present the control of these processes on the morpho–dynamic development and facies organization of the delta.
Geologic setting

The Paleogene clastic rocks are widely distributed in northern Kyushu and the adjacent areas in southwestern Japan (Fig. 1). These Paleogene clastic successions are interpreted to have developed in an intra-arc basin which was formed in response to a change in convergent direction of the Pacific Plate from north-northwest to west-northwest (Sakai, 1993). The infills of the intra-arc basin are commonly 1,000 to 3,000 m thick in North Kyushu. These deposits mainly consist of coarse clastic sediments deposited in continental to paralic environments. The successions commonly contain coal-bearing deposits. In contrast, the age-equivalent deposits in the Tsushima and Iki Islands, which are located to the north of Kyushu, are mainly of marine origin, and are dominated by mudstone.

Tsushima Islands are chiefly underlain by the Tertiary Taishu Group intruded by the Miocene igneous rocks (Fig. 2A). Takahashi (1969) studied stratigraphy of the Taishu Group and subdivided it into six formations. Later, Ministry of International Trade and Industry (MITI; 1972, 1973, 1974) revised the Taishu stratigraphy, and proposed subdivision into three informal formations: the lower, middle and upper formations, in ascending order. This stratigraphic scheme has been widely accepted by subsequent researchers (e.g., Takahashi and Nishida, 1975; Sakai and Nishi, 1990; Takahashi, 1992; Sakai, 1993; Nakajo and Funakawa, 1996). The Taishu Group is more than 5,400 m thick, and is mainly of marine origin (Sakai, 1993). Its lower and upper contact do not crop out. The predominant lithology is black to dark-gray mudstone with subordinated sandstone.

The framework geologic structure of the Taishu Group is controlled by folding. Major folding axes run en echelon in NE–SW direction, plunging gently northeastward. The Taishu Group yields marine molluscan fossils (Kanno, 1955; Takahashi and Nishida, 1975) and planktonic microfossils (Ibaraki, 1994; Nakajo and Funakawa, 1996), and has been interpreted to be entirely of marine origin. Some sedimentological studies have revealed that the lower and upper formations include deltaic deposits (Okada, 1970; Okada and Fujiiyama, 1970; Koga et al., 1988). Planktonic microfossils suggest the geologic ages of the lower and upper formations are Early Eocene (Nakajo and Funakawa, 1996) and Early Miocene (Ibaraki, 1994), respectively.

In Shimo-jima Island, the Taishu Group is intruded by the Miocene igneous rocks (Fig. 2A), which include plagiophyre, quartz porphyry, rhyolite, dolerite, granophyre, and granite (MITI: 1972, 1973, 1974; Matsumoto and Takahashi, 1987). Takahashi and Hayashi (1983, 1987) estimated fission-track ages of these rocks, at 16–18 Ma for the plagiophyre and at 14–15 Ma for other rocks.

The deposits of the present study belong to the lower part of the lower formation of the Taishu Group. Sections were measured along the coastal outcrops to the north of Kunehama port in Shimo-jima Island (Fig. 2B). Okada (1970) reported coarsening–upward successions in the lower part of the lower formation of the Group near the present study area, and suggested that these successions were originated as a result of deltaic progradation to the northeast.

Sedimentary facies associations

The studied succession mainly consists of mudstone and interbedded sandstone and mudstone with subordinated thick–bedded sandstone. The succession comprises six sedimentary facies associations (facies associations I to IV), which represent their own characteristic recurring combinations of facies defined on the basis of texture and sedimentary structures. Stacking patterns of these facies associations have several coarsening–upward successions reflecting repetitive delta progradation. The vertical relationships of these facies associations are shown in Fig. 4. Facies association 1: Basin floor

Description: This association is represented by massive, black mudstone, 4 to 9 m thick, occupying
the basal part of the individual coarsening-upward successions (Fig. 4). The mudstone is argillaceous and contains no silt and sand grains. The mudstones locally yield abundant planktonic microfossils (e.g., Nakajo and Funakawa, 1996).

**Interpretation:** The massive mudstone of this facies association represents deposition from suspension in a low energy environment subject to little or no influence of currents and waves. The mudstones containing planktonic microfossils are suggestive of low rate of suspension sedimentation on a sea floor. This facies association is thus attributed to deposition in a basin floor beyond an active deltaic body. The basin floor interpretation is supported by the occurrence of this facies association in the basal part of the individual progradational deltaic successions.

**Facies association II: Prodelta**

**Description:** Facies association II forms 3 to 12 m thick units, which gradationally rest on the facies association I (Fig. 4). The predominant lithology of this facies association is dark gray, silty mudstone with occasional intercalations of silty to very fine-grained sandstone. Mudstones are generally massive and mottled due to intensive bioturbation. Sandstone intercalations are most commonly 0.5 to 5 cm thick, and locally show lenticular bedding. Internally, sandstones are graded and parallel or current-ripple cross-laminated. Most of these beds are disrupted by intensive bioturbation.

**Interpretation:** High silt content in mudstone and intercalations of sandstone indicate that this facies association originated in shallow water than a basin floor environment of the facies association I. However, the muddy lithology and intensive bioturbation represent deposition still in a low energy environment subject to little influence of currents and waves. Thick accumulation of silty mud is suggestive of high rate of sedimentation of suspended fine materials, which were probably debouched from a flood river and further transported basinward as a surface plume (Reading and Collinson, 1996). Thus, in the progradational deltaic setting, the silty mudstone of this facies association is interpreted as the prodelta deposit. The sandstone intercalations indicate intermittent inputs of sand into a prodeltaic environment. The sandstone intercalations may be described as Tce or Tde turbidites, and represent deposition of fine materials from slowly moving, dilute suspension.
Fig. 4. Detailed measured sections, showing the vertical relationship of the sedimentary facies associations. Location of each section is shown in Fig. 2. See Fig. 3 for legend. Facies association numbers (I to VI) are given at the right of each column.
Fig. 4. continued.
cloud. Sand transport presumably occurred either due to strong outflows extended from a distributary channel down into a prodelta during extreme floods (Wright and Coleman, 1974; Wright et al., 1988) or due to distal representatives of storm-induced, offshore-directed currents (Chan and Dott, 1986; Prave et al., 1996).

**Facies association III : Channel-mouth bar**

_**Description**_ : This association forms 3 to 12 m thick units, which gradationally overlie the facies association II (Fig. 4). The succession of this facies association is represented by 2 to 10 m thick, coarsening- and thickening-upward sequences of interbedded sandstone and mudstone (Figs. 4; 5). The lower part of the sequences of this facies association is dominated by mudstone with intercalations of 3 to 10 cm thick sandstones, whereas the upper part is represented by 30 to 40 cm thick beds of sandstone separated by thin (0.5 to 3 cm thick) mud beds.

The sandstones are classified into three component units: asymmetrical-ripple cross-laminated sandstone, hummocky cross-stratified sandstone and planar-stratified sandstone. Asymmetrical-ripple laminated sandstones are very fine- to medium-grained, and occur in beds 10 to 40 cm thick. Some beds of asymmetrical-ripple cross-laminated sandstone locally show climbing-ripple cross-lamination. The basal surface of the beds is sharp and flat. Paleocurrent azimuths determined from ripple-lamination are generally unidirectional, and indicate predominantly northward- to northeastward-flowing currents (Fig. 6). Hummocky cross-stratified and planar-stratified sandstones are very fine- to fine-grained and occur in beds 3 to 30 cm thick. The hummocky cross-stratified and planar-stratified sandstone beds have sharp and broadly undulating, erosional bases. Some beds of hummocky cross-stratified and planar-stratified sandstone contain rip-up mud clasts in their basal part. The top of some beds of the hummocky cross-stratified and planar-stratified sandstone has symmetrical ripples.

Mudstone is commonly silty to sandy, and occurs in 1 to 20 cm thick units. Mudstone beds are mottled and massive due to intensive bioturbation. In places, however, lenticular beds or thin lamination are intercalated.

The minor constituents of this facies association include slumps beds, coarse- to very coarse-grained sandstone, and pebbly mudstone. The sandstones are 20 to 45 cm thick, and internally either graded or inverse-to-normally graded. Abundant rip-up mud clasts are contained in the graded sandstone. The pebbly mudstone comprises pebbles, sand grains, and abundant intraclasts randomly distributed in muddy matrix, and is internally ungraded and unstratified.

**Interpretation** : This facies association represents deposition due to an interaction of fluvial and storm-wave processes, and is interpreted as the storm-influenced channel-mouth bar deposit in a delta front environment. Coarsening- and thickening-upward sequences imply upward increase in sand accumulation as a result of delta progradation.

Asymmetrical-ripple cross-laminated sandstones represent deposition due to fluvial activity. Uni-directional paleocurrent pattern is suggestive of a fluvial-dominated environment. Interbedding of sandstones and mudstones suggests sand deposition during fluvial flood stage in a channel mouth environ-
The occurrence of climbing-ripple cross-lamination suggests abundant temporarily-suspended sand-supply in flood events. An unchannelized flat basal surface of these sandstones indicates that they are channel effluent-derived deposits (channel-mouth bars) rather than distributary-channel fills (Farquharson, 1982). Storm-wave processes are documented by hummocky cross-stratified and planar-stratified sandstones. Hummocky cross-stratification is indicative of deposition under strong oscillatory wave surge (Dott and Bourgeois, 1982; Walker et al., 1983). Planar stratification indicates deposition in a plane-bed regime, which is probably attributed to strong oscillatory wave surge producing sheet flow conditions (Clifton, 1976; Myrow and Southard, 1991). Symmetrical-ripples at the top of the beds suggest deposition under the influence of wave activity during waning storms.

Mudstones represent deposition from suspension of terrigenous fine materials with occasional influences of weak currents during fair-weather periods, and subsequent disturbance by biological activity.

The coarse- to very coarse-grained, graded sandstone and inverse-to-normally graded sandstone are identical to the deposits of a high-density turbidity current (Lowe, 1982) and a density-modified grain flow (Lowe, 1976, 1982), respectively. The pebbly mudstone is interpreted as a cohesive debris flow deposit (Lowe, 1982). These beds, along with slumped beds, represent subaqueous gravity transport on the delta front. Gravity transport are common in a delta front environments of modern and ancient deltas resulting from high sedimentation rates (cf. Wright, 1985; Reading and Collinson, 1996).

**Fig. 7.** Facies association IV. (A) Boundary between the facies associations III (FA III) and IV (FA IV) having remarkable erosional surface at the base of thick-bedded sandstone (arrowed), section B in Fig. 4. (B) Thick-bedded sandstone having internal scours (arrowed), section A in Fig. 4. (C) Lateral transition of mud-draped foresets on the sandstone into very thinly interbedded sandstone and mudstone, interpreted as being resulting from interaction of fluvial flow and ebb-tidal currents, section B in Fig. 4.

**Facies association IV : Lower distributary-channel**

**Description:** Facies association IV is the coarsest facies association in this deltaic system, and is characterized by thick-bedded sandstone associated with interbedded sandstone and mudstone (Fig. 4). The successions of this facies association are 5 to 20 m thick, and overlie the deposits of facies association III. Boundary between these facies associations is marked by a remarkable erosional surface at the base of a
within thick–bedded sandstones. Sandstone beds are most commonly 5 to 90 cm thick, and locally show flaser or wavy bedding. The sandstone beds generally have sharp and flat basal surfaces. Some sandstone beds have erosional bases, 20 to 30 cm deep, and contain abundant mud clasts. The sandstones are internally planar cross–stratified, asymmetrical–ripple cross–laminated or climbing–ripple cross–laminated. Trough cross–stratification are also locally observed. Thin mud drapes, which cover foresets of cross–stratification, are common. In some cases, cross–stratification with mud drapes grades laterally into interbedding of very thin strata of sandstone (1 to 3 mm) and mudstone (Fig. 7 C). Mudstone interbeds, up to 50 cm thick, are commonly silty to sandy. Mudstones show thin lamination or lenticular bedding.

Paleocurrent azimuths of this facies association determined from cross–stratification and ripple cross–laminations are generally unidirectional, and indicate predominantly northward–flowing currents (Fig. 8).

**Interpretation:** This facies association represents deposition in a lower reach of distributary channel which extended into a subtidal zone of a delta front. In this paper, the term of the lower distributary channel is used for these channels. The fining– and thinning– upward sequences of thick–bedded sandstone with interbedded sandstone and mudstone are attributed to tide–influenced fluvial channel–fill deposits (Smith, 1987, 1988). Decrease in activity of the channel resulted in a fining– and thinning–upward sequences.

Subtidal origin of a channel is documented by superimposition of the thick–bedded sandstone with a remarkable erosional base on the channel–mouth bar deposit (facies association III) of a delta front environment. Mud clasts and pebbles concentrated on the scour surface are interpreted as lag deposits on a channel floor. The cross–stratified sandstones with internal scours are indicative of channel–bar development due to vertical accretion of bedload in the form of migrating dunes and sand waves, and of rapid lateral shifting of bars and active tracts in a channel (McCabe, 1977; Pulham, 1989).

The interbedded sandstone and mudstone in this facies association indicate decrease in activity of the channel. A decreased fluvial agency is demonstrated by fining– and thinning–upward and by dominance of planar cross–stratification and ripple lamination rather than trough cross–stratification in thick–bedded sandstones. Mud drapes on forsets indicate pause in migration of dunes and sand waves and suspension settling of mud on them in a slack–water condition. Flaser to lenticular bedding indicate intermittent currents accompanied by slack–water periods. These features are strongly suggestive of regularly fluctuating currents of tidal processes on sedimentation (Dalrymple, 1992; Reading and Collinson, 1998–11).
However, an overall paleocurrent pattern is not bidirectional but unidirectional, and is quite similar to that of the channel-mouth bar deposit (facies association III). It is interpreted that fluvial flows in a channel overpowered the tidal activity. Sand transport in a channel was enhanced during ebb tides and fluvial flood periods due to combined effects of fluvial flows and ebb-tidal currents. On the other hand, flood tides were seldom able to generate reversal currents in a channel against fluvial flows, but were only responsible for producing slack-water conditions and for suspension settling of mud.

Extended channel into the subtidal zone and tidal influences on this channel sedimentation imply that this channel composed the lower reach of distributary channels drained on sea-marginal zone of a delta.

**Facies association V: Upper distributary-channel**

**Description**: The succession of this association is represented by up to 13 m thick, most commonly 3 to 7 m thick, fining-upward sequences, in which medium- to coarse-grained sandstone grades upward into very fine- to fine-grained sandstone with intercalations of mudstone (Fig. 4). These fining-upward sequences of this facies association are enclosed within mud-dominated deposits of the facies association VI.

The fining-upward sequences have an irregular, erosional basal surfaces with up to 50 cm deep scours cutting into underlying deposits. Shallow internal scours are also common in the lower part of the sequence. Mud clasts locally concentrate on the scour surfaces. The sandstones in the lower part of the sequences display medium-scale trough cross-stratification in sets 15 to 30 cm thick. Planar cross-stratification also occurs, but are rare. In the upper part of the sequences, sandstones are characterized by asymmetrical-ripple cross-lamination and minor flaser or wavy bedding. Paleocurrent azimuths determined from cross stratification and ripple cross-lamination are generally unidirectional, and indicate predominantly northward-flowing currents (Fig. 9). The intercalated mudstones are silty to sandy, and commonly less than 10 cm thick. Some mudstones, however, are up to 1 m thick. Mudstones are generally massive, and locally contain abundant plant debris.

**Interpretation**: This facies association represents deposition in distributary channels on a delta plain. In this paper, such channels are called as the upper distributary channel. Presence of plant debris, channel scours, fining-upward sequences and unidirectional paleocurrent patterns are most compatible with a fluvial-dominated channel-fill interpretation (Coleman, 1976; Reading and Collinson, 1996). Fining-upward sequences suggest decelerating flow components due to decrease in activity of such channels. Mud clasts concentrated on the scour surfaces are interpreted as lag deposits on a channel floor. The cross-stratified sandstones in the lower part of the
Mudstones are commonly massive and mottled, and contain abundant plant debris. Rootlets are locally present (Fig. 10 A). Mudstones are commonly intensely bioturbated. Intercalated sandstones are 0.5 to 3 cm thick, and partly show lenticular bedding. The sandstones are very fine- to fine-grained, and are either asymmetrical- or symmetrical-ripple cross-laminated (Fig. 10 B). Locally, enclosed within the mud-dominated deposits are up to 40 cm thick, fine- to medium-grained sandstone. The basal surfaces of these sandstone beds are sharp and flat to undulose with up to 10 cm deep scour. Internally sandstones are either trough cross-stratified or asymmetrical-ripple cross-laminated. Paleo currents azimuths determined from trough cross stratification and ripple cross-lamination are generally unidirectional, and indicate predominantly northward-flowing currents (Fig. 11).

**Interpretation:** Predominance of mudstone, intense bioturbation, abundant plant debris and presence of rootlets suggest that this facies association was originated chiefly in low-energy environments between distributary channels on a delta plain (Wright, 1985; Reading and Collinson, 1996). Abundant plant debris and rootlets represent a marsh or swamp environment. Intensely bioturbated silty mudstones are the deposits influenced by faunal activity in a body of standing water such as bays and lakes. Thin sandstone intercalations show intermittent supply of sand on a delta-plain low land, probably due to overbanking of suspended sand grains from the nearby distributary channels. Symmetrical ripples show modification of some sand beds by wind waves on the surface of ponded water (Wright, 1985; Reading and Collinson, 1996). On the contrary, relatively thick sandstone beds were undoubtedly deposited under a high energy condition, as indicated by a sharp, erosional base and trough cross-stratification. These thick sandstone beds are interpreted as the deposits of small-scale channels and lobes formed by crevasse spray from distributary channel (Elliott, 1974; Fielding, 1984).

**Depositional model**

On the basis of the preceding interpretations of each facies association and of their vertical relationships, it is clear that the succession of the lower formation of the Taishu Group under study records deposition in a deltaic setting and that the basin floor (facies association I), prodelta (facies association II), channel-mouth bar (facies association III), lower distributary-channel (facies association IV), upper distributary-channel (facies association V), and interdistributary deposits (facies association VI) form progradational deltaic successions. Paleocurrents indicate the delta progradation toward the north. This delta system in the lower formation of the Taishu Group is called as the Taishu...
delta system. The depositional model of the Taishu delta system is summarized in Fig. 12.

The Taishu delta system comprised subaerial, transitional, and subaqueous segments. The subaerial segment, the delta plain, is represented by the muddy interdistributary deposits, which originated in marshes, swamps, bays, and lakes. Across the delta plain, the distributary channels flowed and carried coarse materials. Infilling and gradual abandonment of these channels produced the fining-upward sandstone sequences of the upper distributary-channel deposits enclosed within the mud-dominated deposit of an interdistributary origin. The transitional segment of the delta is represented by the lower distributary-channel deposit. The lower reaches of the distributary channels extended out into the subtidal zone, and coarse sediments deposited mostly as subtidal channel fills. Deposition in the sea-marginal zone of a delta is generally affected by marine processes (Coleman, 1976; Wright, 1985; Reading and Collinson, 1996). In the Taishu delta, the lower distributary-channel sequences well record interaction of fluvial and tidal processes. Lack of wave-worked deposits implies a limited role of wave processes, suggesting either a low wave-energy coast or low preservation potential of such deposits in the fluvial-dominated setting (Coleman, 1976). Thus, the fluvial and tidal processes were the principal agents in the development of the transitional zone of the Taishu delta. The subaqueous segment of the delta is represented by the channel-mouth bar and prodelta deposits. Channel mouthbar is commonly characterized by the major sand accumulations in a delta (Coleman, 1976; Wright, 1985). In the Taishu delta, the interbedded sandstone and mudstone of the channel-mouth bar deposit suggests that they are rather distal representatives of mouth-bars. The remarkable erosion at the base of the overlying lower distributary-channel deposit indicates that proximal-bar sands were eroded by channelized flows due to extension of subtidal channel and were redistributed and incorporated within the channel deposit. Storm waves occasionally reworked the channel-mouth bar deposit and produced sheets of hummocky cross-stratified and planar-stratified sandstone. The deposit, however, reveals no evidence of fair-weather wave and wave-induced current activities, further suggesting of limited role of wave processes during fair-weather periods. Suspended fine materials were debauched from river flows and further transported basinward as surface plume. Deposition of these fines produced silty mudstone of the prodelta deposit. The basin floor received little sediments directly from the delta, and massive mudstone was deposited from hemipelagic sedimentation.

Morphology of a delta is controlled by river-mouth regime and basinal processes around the transitional segment of a delta (Coleman, 1976; Wright, 1977). In the progradational successions of the Taishu delta, the depositional records in such a zone are characterized by the relatively distal mouth-bar deposit and the overlying, deeply incised, lower distributary-channel deposit. These features are highly suggestive of that the distributary mouth-bar sands were principally deposited by channelized flows. The mouth-bars, thus, developed as a channelized bar rather than a depositional lobe. Such processes would have been caused by little deceleration and
diffusion of discharge, hence a limited effluent expansion, in the channel mouth area, suggesting high-velocity fluvial discharge and inertia-dominated river-mouth regime (Coleman, 1976; Wright, 1977). Tidal processes accelerated the development of the subtidal channels and channelized bars. Ebb-tidal currents enhanced acceleration of channelized flows and seaward extension of the subtidal channels. Mud settling, particularly on the levee of the subtidal channels, in a low energy condition during flood tides contributed to stabilization and consequent up-building of the subtidal channels. Consequently, active sedimentation at the mouth of the distributary channels should have resulted in elongated protrusions of subtidal channel–channelized mouth-bar complex oriented approximately normal to the overall coastal trend. The Taishu delta, thus, developed as a kind of bird’s-foot shaped or elongated delta (Fig. 12).

Discussion

The Taishu delta had a bird’s-foot shaped or elongated geometry as a result of interaction of fluvial inertia force and tidal processes. Generally, the bird’s-foot shaped to elongated deltas are regarded as a river-dominated delta characterized by low tidal range, low wave energy, low littoral drift, and relatively high discharge of fine materials as suspended load (cf. Coleman, 1976; Wright, 1985). The Mississippi delta is the best documented modern delta of this type (cf. Coleman, 1976; Wright, 1985). Other modern examples include the Atchafalaya lacustrine delta in North America (Tye and Coleman, 1989a, b) and the Volga delta in the Caspian Sea (Kroonenberg et al., 1997). Numerous examples of similar delta type have been reported in geologic records, including the Bideford Group delta complex in England (Elliott, 1976), the Clare Basin delta complex in western Ireland (Pulham, 1989), the Westphalian B delta complex in England (Haszeldine, 1984), the Perrin delta system in the Canyon Group in North America (Erxleben, 1975), the Corbies Creek Group delta in New Zealand (Retallick and Ryburn, 1982), and the Appalachian Carboniferous deltaic system in North America (Horne et al., 1978). The Taishu deltaic successions also demonstrated high fluvial discharge and low wave energy similar to the modern and ancient river-
dominated deltas. However, the Taishu deltaic suc-
cessions are dissimilar to them in that the deposits are
rich in coarse materials, and in that tidal processes
played important role in sedimentation in the lower
reaches of distributary channels and in organizing
elongated protrusion of a channelized mouth–bars.
Furthermore, the river–mouth regime of the Taishu
delta was inertia–dominated rather than buoyancy-
dominated.

Bird's–foot shaped to elongated deltas rich in coarse
materials have been less well known. As modern
examples of such a delta, may be cited the
Tunsbergdal delta in western Norway (Bogen, 1987)
and the Kezar and Lovewell Pond deltas in North
America (Caldwell and FitzGerald, 1995). The ancient
ones include the Shimosa Group delta in Japan
(Okazaki and Masuda, 1989) and the Scar House Beds
These deltas have a similarity to the Taishu delta, but
are different from the latter except the Scar House
Beds delta complex in the extent of their distributary
channels. The distributary channels of these deltas
end on the delta plain or delta platform, and do not
extend out into the subtidal zone of the delta front
like the Taishu delta.

The Scar House Beds delta complex show deposi-
tion in the river–dominated delta system, in which
the river–mouth regime was inertia–dominated
(Martinsen, 1990). The distributary channels of the
delta deeply incised into the delta front similarly to
the Taishu deltaic successions. The distributary
channels of these deltas had an active sedimentation
of coarse materials at their mouth concurrently with
channel extension out into the delta front, producing
the channelized mouth–bars. In the Taishu delta,
tidal processes further enhanced the extension of the
subtidal channels and accelerated reworking and re-
distribution of bar sand. As a result, the transitional
zone of the Taishu delta was characterized by narrow
and elongated protrusions of a channelized mouth–
bar origin. The Taishu deltaic successions, thus,
record an important role of the interaction of fluvial
inertia force and tidal processes controlling the
morpho–dynamic development and facies organiza-
tion of the delta.

Conclusions

The succession of the deltaic deposits in the lower
formation of the Tertiary Taishu Group shows verti-
cally stacked, coarsening–upward successions record-
ing repetitive progradation of the delta system
toward the north. Six sedimentary facies associa-
tions constitute these deltaic successions. They are
the basin floor (facies association I), prodelta (facies
association II), channel–mouth bar (facies association
III), lower distributary–channel (facies association IV),
upper distributary–channel (facies association V) and
interdistributary deposits (facies association VI). The
Taishu deltaic succession are characterized by abrupt
facies change in the mouth–bar deposits to coarse–grained
distributary–channel fills showing remarkable
erosion at the bases. This demonstrates that the active
distributary channels deeply incised into channel–mouth bars in the delta front due to
inertia–dominated river–mouth regime. Ebb–tidal
currents enhanced acceleration of outflows from the
channel, resulting in extension of subtidal channels out onto the channel–mouth bars and reworking and redistribution of bar sand. These channelized
mouth–bars grew as a narrow and elongate protrusions in the transitional zone of the delta. As a result,
course–grained bird's–foot shaped delta generated.

The interaction of fluvial inertia force and tidal pro-
cesses was the major controlling factor in morpho-
dynamic development and facies organization of the
Taishu delta.

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*: in Japanese with English abstract

**: in Japanese

(地 名・地層名)

Taishu Group ･･････････対州層群 Shimo-jima Island ････････下島 Kunehama ････････････久根浜

(要 旨)


長崎県対馬に分布する対州層群下部層は、北向きにプログラデーションする鳥趾状デルタにより形成された。このデルタ成堆積物はIからVIの6つの堆積相組み合わせからなり、それらはそれぞれ堆積盆地（堆積相組み合わせI）、アプロデルタ（堆積相組み合わせII）、河口州（堆積相組み合わせIII）、下流分岐チャネル（堆積相組み合わせIV）、上流分岐チャネル（堆積相組み合わせV）、チャネル間低湿地（堆積相組み合わせVI）の環境を示している。

対州層群下部層を形成したデルタは、慣性力が卓越した河川作用と潮汐作用の相互作用により、分岐チャネルが湖下帯深くまで侵入していた。その結果、河口州はチャネルを伴った細長く延びた形状となり、粗粒堆積物から構成される鳥趾状デルタが形成された。