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Tidal influences on distributary-channel sedimentation of the Tertiary delta in the Taishu Group, Tsushima Islands, southwestern Japan

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Abstract

The distributary-channel deposits in the deltaic system of the Tertiary Taishu Group, Tsushima Islands, southwestern Japan, are classified into two types of sequence; the lower and upper distributary-channel deposits. The lower distribuatry-channel deposits represent deposition in a lower reach of distributary channels, which extended out into the subtidal zone of a delta front. The lower part of the sequence comprises thick, cross-stratified sandstone, which illustrates fluvial-dominated sedimentation. The upper part of the sequence is represented by interbedded sandstone and mudstone, which demonstrates tide-influenced sedimenatry structures such as mud-draped cross-stratification and flaser to lenticular bedding. However, unidirectional paleocurrents and the erosional base of sandstone beds indicate fluvial-dominated processes, as in the lower part of the sequence. They are interpreted as indicating that sedimetation in the lower distributary-channel fills was controlled by the combined effects of tidal and fluvial processes. The upper distributary-channel deposits represent deposition in distributary channels on a delta plain, characterized by fining-upward sequences which lack mud interbeds. They represent fluvial-dominated, channel-fill sedimentation. These facies changes between the lower and upper distributary-channel deposits are caused by the rate of tidal influences on distributary-channel sedimentation.

Key words: distributary channel, fluvial process, tidal influence, delta, Taishu Group

Introduction

Distributary channels on a delta plain have many of the characteristics of fluvial channels, such as predominant unidirectional flows, periodic stage fluctuations, switching and avulsion of channels, and accumulation of fine materials in the adjacent low-lying areas. Resultant deposits are similar to fluvial-channel deposits, which show erosively based sand with basal lags that fine upwards, through cross-bedded sands, into ripple-laminated finer sands, topped by mud with rootlets indicative of emergence (Oomkens, 1970, 1974; Coleman, 1976). However, differing from fluvial channels, the lower reaches of the distributary channels, near the coastal area of deltas, are influenced by basinal processes. Tidal processes particularly have an effect on distributary-channel sedimentation, because tidal influences row up the distributary channels from the river mouth.

Unlike the fining-upward sequence of grain size, de Raaf and Boersma (1971) and Smith (1987, 1988) have reported that channel-fill sequences contained interbedded sandstone and mudstone from modern and ancient distributary-channel and estuarine deposits. They suggested that these sequences were formed by tide-influenced, channel-fill deposits. Similar sequences have been reported from ancient channel-fill deposits (e.g., Cotter, 1971; Elliott, 1976; Jackson, 1978; Flach and Mossop, 1985). However, depositional processes and depositional conditions of these channel-fill sequences have not been fully understood.

This study focuses on facies changes of distributary-channel deposits in the delta system of the Tertiary Taishu Group, Tsushima Islands, southwestern Japan. The successions of distributary-channel fills in the Taishu delta system have various sedimentary facies, including thick-bedded sandstone with interbedded sandstone and mudstone, and fining-upward sequences. The facies changes of the distributary-channel deposits depend on the rate of tidal influences on the channel-fill sedimentation. This paper reports depositional processes and facies organization of distributary channels under the interaction of fluvial and tidal processes.

Geologic setting

Paleogene clastic rocks are widely distributed in North Kyushu and the adjacent area in southwestern Japan (Fig. 1). These Paleogene basins are regarded as intra-arc basins which formed due to a change in plate motion of the Pacific Plate, from north-northwest to west-northwest (Sakai, 1993). Intra-arc basin fills are commonly 1000 to 3000 m thick in North Kyushu. These deposits comprise mainly coarse, clastic sediments deposited in continental to paralic environments. The successions generally contain coal-bearing deposits, and many coalfields have been developed in North Kyushu. In contrast to the deposits in North Kyushu, the equivalent deposits in Tsushima and Iki Islands, which are located to the north of Kyushu, are mainly of marine origin and are dominated by mudstone.

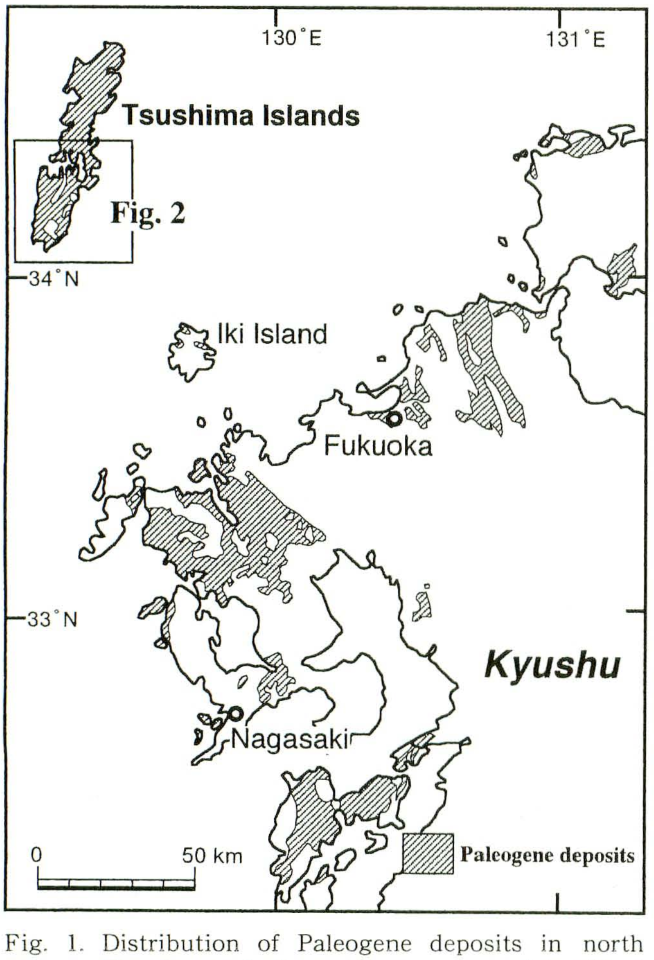

Fig. 1. Distribution of Paleogene deposits in north Kyushu and the adjacent areas (simplified from Sakai, 1993).

The Tsushima Islands, which are composed of two major islands (Kami-shima and Shimo-jima Islands), are chiefly underlain by the Tertiary Taishu Group, intruded by Miocene igneous rocks (Fig. 2). Stratigraphic studies of the Taishu Group have been made by MITI (1972, 1973, 1974) and Takahashi (1992). The Taishu Group is more than 5400 m thick, and is mainly of marine origin. Its lower and upper limits are unknown. The predominant lithology is black to dark-grey mudstone with subordinate sandstone. The framework structure of the Taishu Group is controlled by folding. Major fold axes run en echelon in a NE−SW direction, plunging gently northeastward. The Taishu Group has been lithostratigraphically subdivided into three informal formations: the lower, middle and upper formations. 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 regarded as being entirely of marine origin. Planktonic microfossils suggest a geologic age of Early Eocene (Nakajo and Funakawa, 1996) and Early Miocene (Ibaraki, 1994) for the lower and upper formations, respectively.

In Shimo-jima Island, the Taishu Group is intruded by Miocene igneous rocks (Fig. 2), which include plagiophyre, quartz porphyry, rhyolite, dolerite, granophyre, and granite (Matsumoto and Takahashi, 1987; Takahashi, 1992). Takahashi and Hayashi (1985, 1987) reported fission-track ages of 16−18 Ma for the plagiophyre and 14−15 Ma for other rocks.

Taishu delta system

The distributary-channel deposits in the deltaic sequences under 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 in Shimo-jima Island (Fig. 2). Depositional processes and environments of deposition of these deltaic deposits have already been discussed in detail (Nakajo and Maejima, in submission).

The succession of the deltaic deposits in the

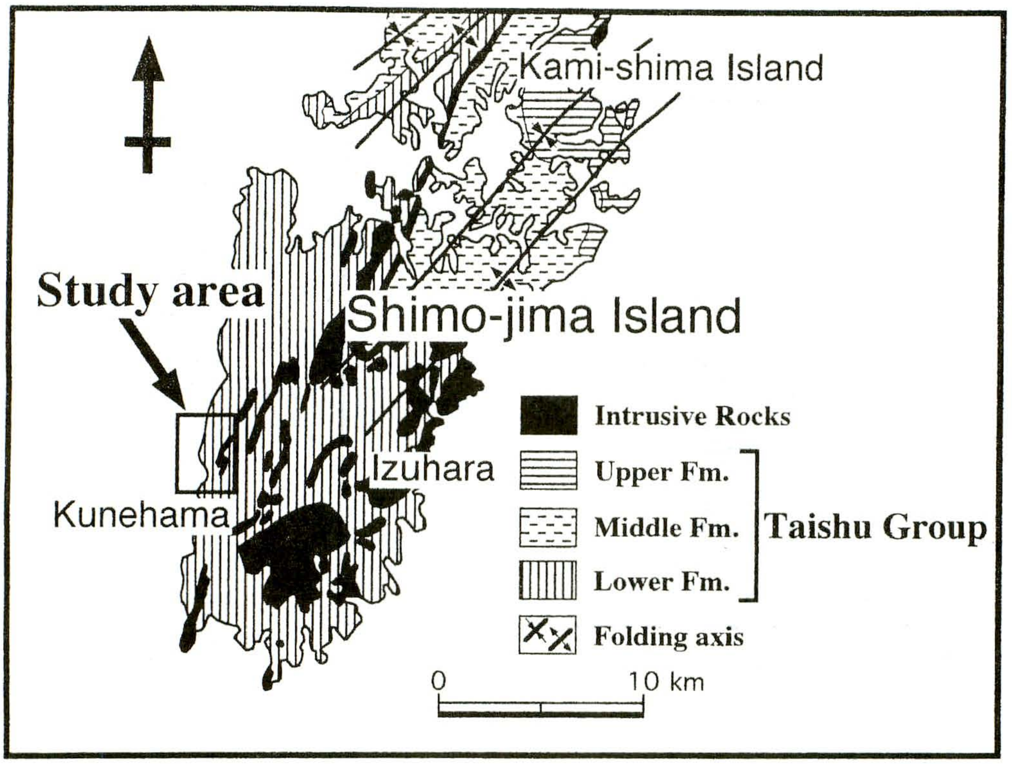

Fig. 2. Geologic map of southern Tsushima Islands (simplified from Takahashi, 1992).

lower formation of the Taishu Group shows vertically stacked, coarsening-upward sequences recording repetitive progradation of the bird's-foot-shaped to elongated deltaic system towards the north. Within the succession of the deltaic sequences, six sedimentary facies associations are recognized; the basin floor, prodelta, channel-mouth bar, lower distributary-channel, upper distributary-channel and interdistributary facies associations. The Taishu deltaic sequence demonstrates that the active distributary channels are deeply incised into channel-mouth bars in the delta front due to inertia-dominated, river-mouth regimes and tidal processes. These channelized mouth-bars grew as narrow and elongate protrusions in the transitional zone of the delta. As a result, a coarse-grained, bird's-foot-shaped delta was generated. The interaction of fluvial inertia force and tidal processes was the major controlling factor in the morphodynamic development and facies organization of the Taishu delta.

Distributary-channel deposits

The distributary-channel deposits in the Taishu delta system form 3 to 20 m-thick channel-fill sequences. Two types of channel-fill sequences have been recognized. They represent deposition in the lower and upper distributary channels, respectively.

Lower distributary-channel deposits

Description

The lower distributary-channel deposits are characterized by thick-bedded sandstone, up to 11 m thick, with interbedded sandstone and mudstone (Fig. 3). The channel-fill sequences are 5 to 20 m thick, and overlie the channel-mouth bar deposits (Nakajo and Maejima, in submission). In each sequence, the boundary between them is marked by a remarkable erosional surface at the base of a thick-bedded sandstone. Some of the successions show a fining- and thinning-upward sequence (Fig. 3).

Sandstones are medium- to very coarse-grained, and are 2 to 11 m thick. They have an irregular, erosional basal surface, with up to 50 cm-deep scours cutting into the underlying deposits. Shallow internal scours are also common within the sandstone (Fig. 4A). Mud clasts and pebbles tend to be concentrated on scour surfaces. Internally, sandstones are trough cross-stratified in sets that are 20 to 40 cm thick. Planar cross-stratification, asymmetrical-ripple

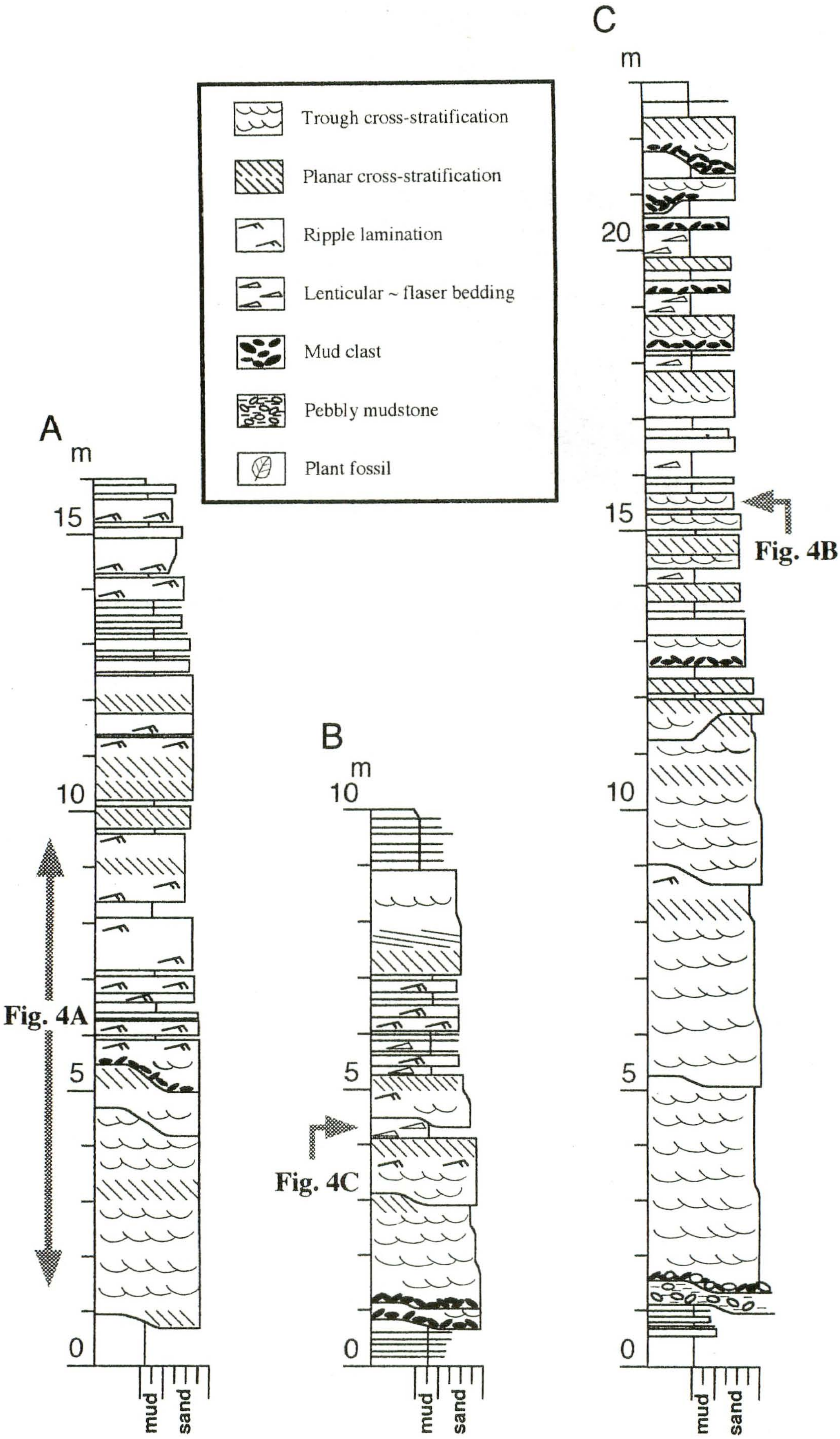

Fig. 3. Examples of logs of lower distributary-channel deposits.

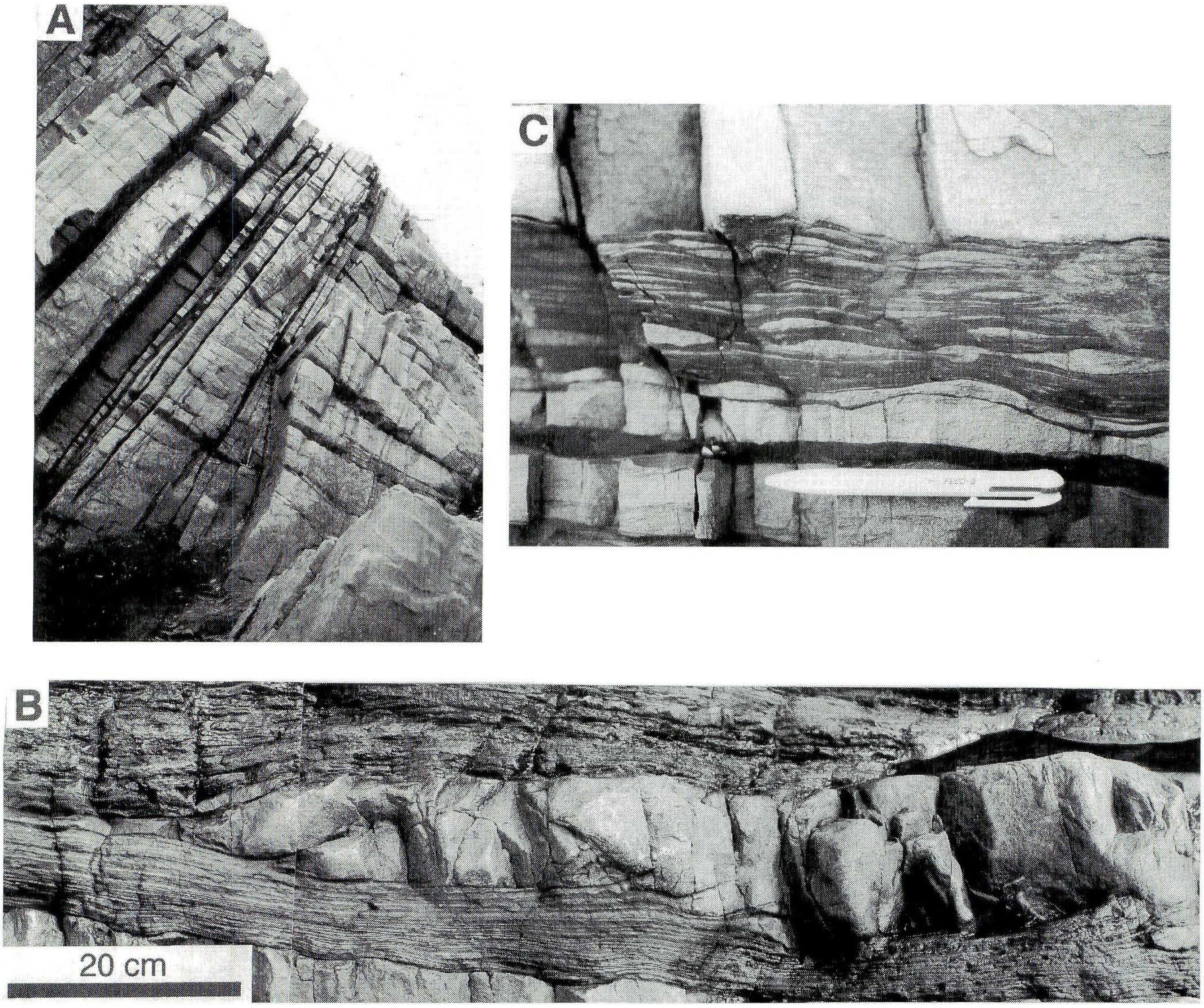

Fig. 4. Lower distributary-channel deposits. (A) Thick-bedded sandstone having internal scours, log A in Fig. 3. (B) Lateral transition of mud-draped foresets on the cross-bedded sandstone into very thinly interbedded sandstone and mudstone, interpreted as combined effects of fluvial flows and tidal currents, log C in Fig. 3. (C) Lenticular bedding in mudstones, log B in Fig. 3.

cross-lamination and climbing-ripple cross-lamination also occur, but are rare.

Interbedded sandstone and mudstone form 3 to 10 m-thick units, which either rest on or are intercalated within thick-bedded sandstones. Sandstone beds are most commonly 5 to 90 cm thick, and locally show flaser or wavy bedding. The beds generally have a sharp and flat basal surface. Some beds have an erosional base, 20 to 30 cm deep, and contain abundant mud clasts. The sandstones are internally planar and trough cross-stratified, asymmetrical-ripple cross-laminated or climbing-ripple cross-laminated. Thin mud drapes, which cover foresets of cross-stratification, are common. In some instances, mud-draped cross-stratification grades laterally into interbedding of very thin (1 to 3 mm) layers of sandstone and mudstone (Fig. 4B). Mudstone interbeds, up to 50 cm thick, are commonly silty to sandy. Mudstones show thin laminations or lenticular bedding (Fig. 4C).

Paleocurrent azimuths of these deposits, determined from cross-stratification and ripple cross-lamination, are generally unidirectional and indicate predominantly northward-flowing currents (Fig. 5).

Interpretation

These deposits represent deposition in a lower reach of distributary channels, which

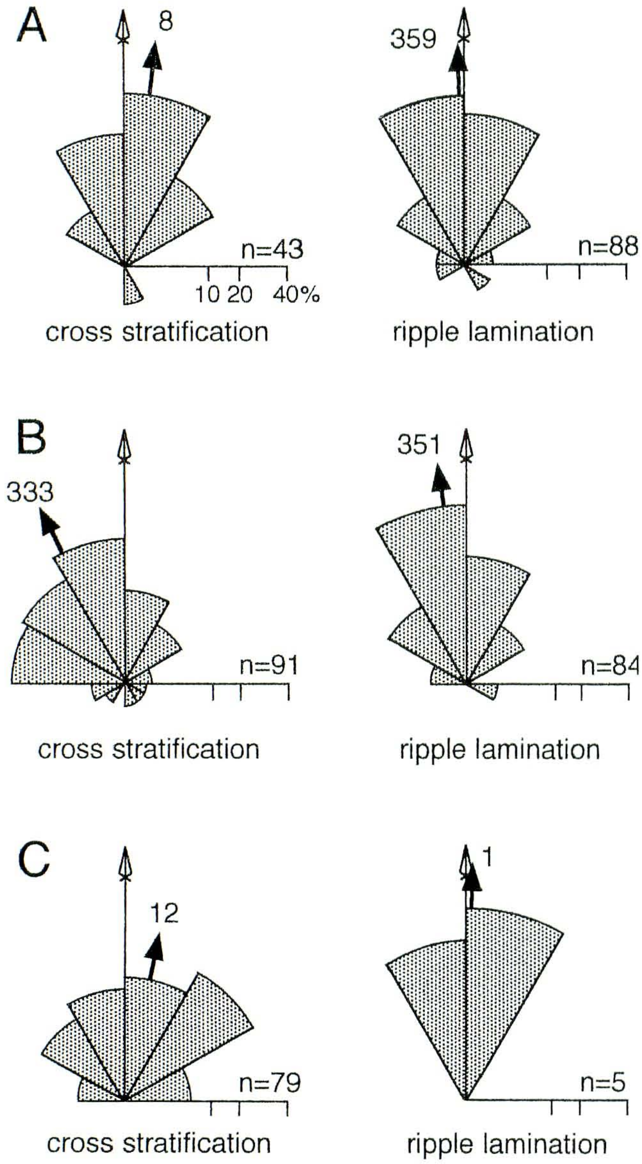

Fig. 5. Paleocurrent rose diagrams of the lower distributary-channel deposits. A, B and C correspond to the logs labelled A, B and C in Fig. 3. Arrows show vector mean. n: Number of readings.

extended out into the subtidal zone of a delta front. In this paper, the term lower distributary channel is used for these channels. The channel-fill 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 fining- and thinning-upward sequence.

Thick-bedded sandstone in the lower part of the fining- and thinning-upward sequences represents deposition in an active subtidal channel. The subtidal origin of a channel is documented by superimposition of the sandstone with a remarkable erosional base on the channel-mouth bar deposits. 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.

The interbedded sandstone and mudstone in the upper part of the fining- and thinning-upward sequences indicate decrease in activity of the channel. Mud drapes on foresets indicate pauses in the migration of dunes and sand waves, and suspension settling of mud on them in slack-water conditions. Flaser to lenticular bedding indicate intermittent currents, accompanied by slack-water periods. Very thin interbedded sandstone and mudstone is attributable to repetition of regular shifts in the transport of materials, and is similar to tidal bedding (cf. Dalrymple, 1992). These features are strongly suggestive of tidal influences on sedimentation. However, an overall paleocurrent pattern is not multi- or bidirectional but is consistantly unidirectional, and is quite similar to that of fluvial-dominated, channel-mouth bar deposits (Nakajo and Maejima, in submission). This suggests that fluvial flows in a channel overpowered the tidal activity and played a principal role in sediment transport and deposition in a channel, with modification by tidal processes. In this context, the erosional bases of some sandstone beds may be attributable to erosion of the substrate by high-energy flows in the fluvial flood stage rather than by periodic tidal currents (Fig. 6A). Except in the fluvial flood stage, however, tidal influences increased on the channel-fill sedimentation (Fig. 6B). Sand transport was enhanced by the combined effects of fluvial flows and ebb-tidal currents (Fig. 6Ba). 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 (Fig. 6Bb). Accumulation of mud during slack-water periods promoted infilling and up-building of the lower distributary channel.

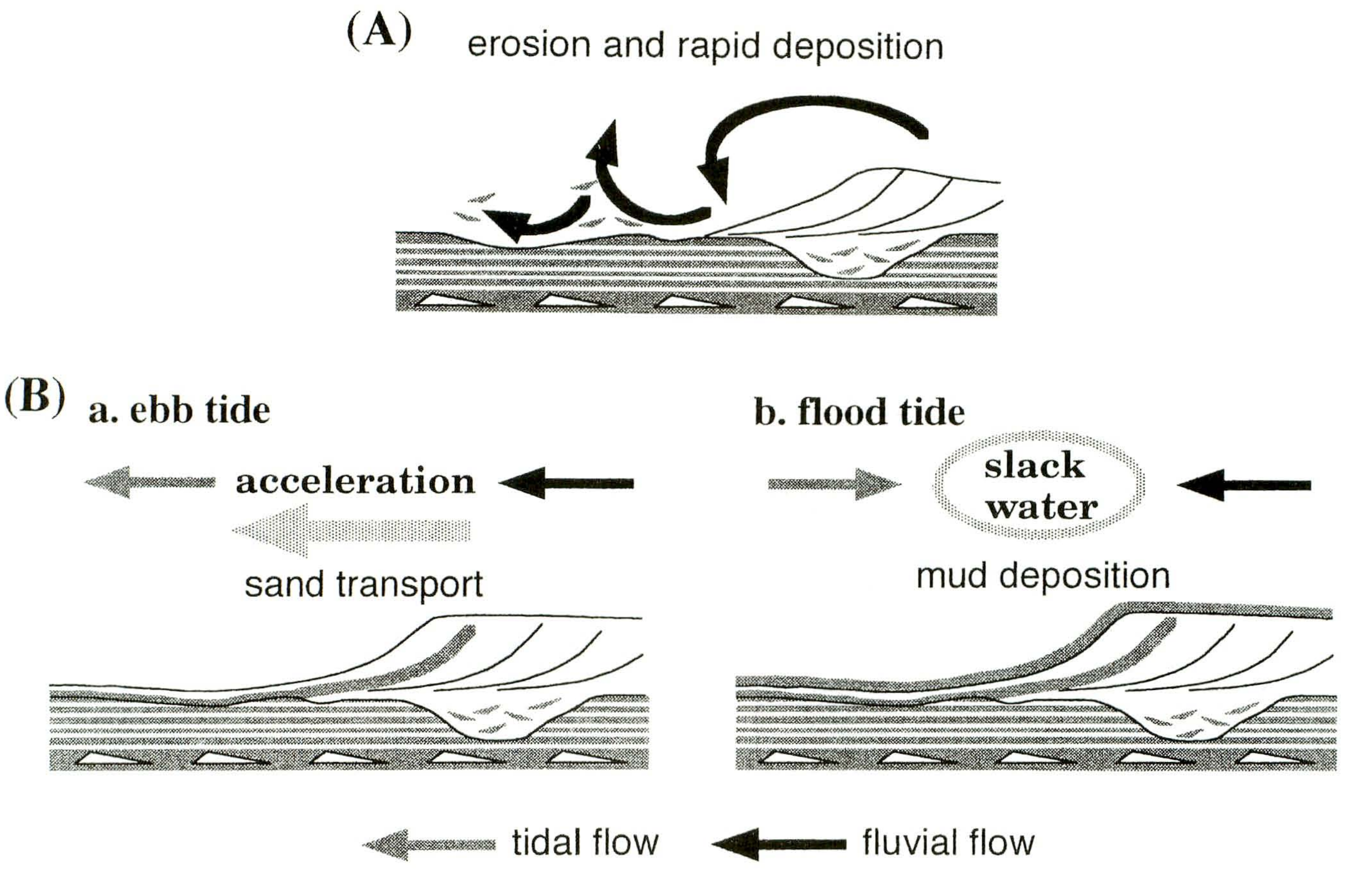

Fig. 6. Depositional processes of the interbedded sandstone and mudstone in the lower distributary-channel deposits. (A) Fluvial flows overpowering tidal activity in the fluvial flood stage. (B) a. Sand transport was enhanced by the combined effects of fluvial flows and ebb-tidal currents. b. Flood tides were responsible for producing slack-water conditions against fluvial flows and for suspension settling of mud.

Upper distributary-channel deposits

Description

The succession of the upper distributary-channel deposits are 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 upwards into very fine- to fine-grained sandstone with intercalations of mudstone (Fig. 7). These fining-upward sequences are enclosed within the mud-dominated interdistributary deposits (Nakajo and Maejima, in submission).

The sequences show marked erosion, 30 to 50 cm deep, at the base. Shallow internal scours are also common in the lower part of the sequence. Mud clasts are locally concentrated 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 and asymmetrical-ripple cross-lamination also occur, but are rare. In the upper part of the sequences, sandstones are asymmetrical-ripple cross-laminated, and locally show flaser to wavy bedding. Paleocurrent azimuths determined from cross-stratification and ripple cross-lamination are generally unidirectional, and indicate predominantly northward-flowing currents (Fig. 8). The mudstone intercalations are silty to sandy, and occur in up to 1 m-, commonly less than 10 cm-, thick units. Mudstones are generally massive, and locally contain abundant plant debris.

Interpretation

These deposits represent deposition in distributary channels on a delta plain. In this paper, such channels are called upper distributary channels. Presence of plant debris, channel scours, fining-upward sequences and unidirectional paleocurrent patterns are most compatible with a fluvial-dominated, channel-fill interpretation. Fining-upward sequences suggest decrease in activity of such channels. Mud clasts,

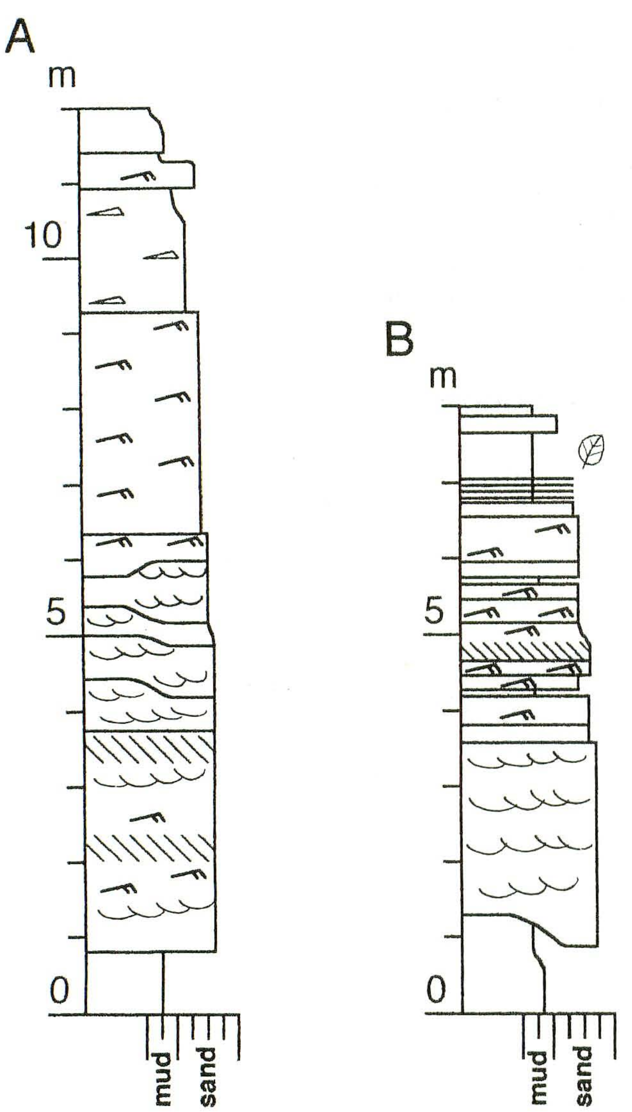

Fig. 7. Examples of logs of upper distributary-channel deposits. For legend see Fig. 4.

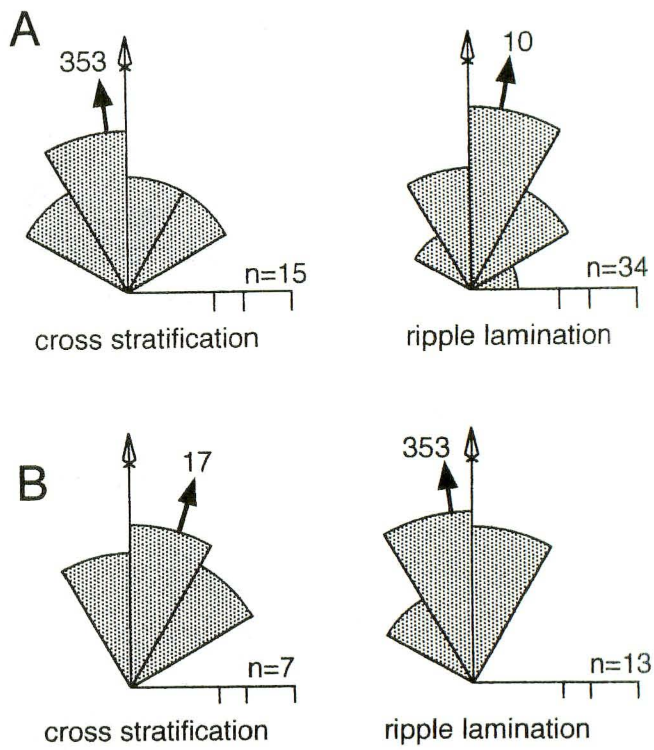

Fig. 8. Paleocurrent rose diagrams of the upper distributary-channel deposits. A and B correspond to the logs labelled A and B in Fig. 7. Arrows show vector mean. n: Number of readings.

concentrated on the scour surfaces are interpreted as lag deposits on a channel floor. The cross-stratified sandstones in the lower part of the sequence are interpreted as an infilling of an active channel by vertical accretion of bedload in the form of migrating dunes and sand waves. Asymmetrical-ripple cross-laminated sandstones found in the upper part of the sequence represent deposition under the lower flow regime conditions, implying decreased channel activity. Locally flaser to wavy bedding and intercalations of mudstone are suggestive of fluctuations in flow conditions, which have might been due to tidal processes. The limited occurrence of these facies, however, indicates that tidal influences, if any, were minimal even in inactive or abandoned channels. This is in contrast to the tide-influenced sedimentation of the upper part of the lower distributary-channel sequences, and is consistent with the interpretation that the channel sequences of this type originated in the upper reach of distributary channels on the delta plain.

Discussion and conclusions

The distributary-channel deposits in the Tertiary Taishu delta system are classified into two types of sequence: the lower and upper distributary-channel sequences. Facies changes between the lower and upper distributary-channel sequences were the consequence of the difference in the rate of tidal influences on sedimentation. Sedimentation in the lower distributary channels occurred under the interaction of fluvial and tidal processes. In the active stage of the channel, however, intensity of fluvial flows overpowered tidal processes, and thick-bedded sandstones were deposited. When the channel became inactive, decreased fluvial action allowed an increase in the effects of tidal processes on channel-fill sedimentation. The combined effects of fluvial flows and ebb-tidal currents enhanced acceleration of outflows, resulting in active sand transport and deposition in a channel. Flood tides were seldom able to generate reversal currents against fluvial flows, but were only responsible for producing slack-water conditions and suspension settling of mud. The upper distributary affected minimal or no tidal influences on sedimentation. Deposition took place almost totally due to fluvial processes.

The delta in the lower formation of the Taishu Group had an elongated channel-mouth bar on which a distributary channel extended and deeply incised into the subtidal zone in the delta front, and formed into a bird's-foot-shaped to elongated geometry (Nakajo and Maejima, in submission). This is probably due to a limited lateral effluent expansion because of high-velocity fluvial discharge from the river mouth and an inertia-dominated river-mouth regime. Tidal processes further accelerated the development of the elongated protrusions of the channelized mouth-bar. Ebb-tidal currents enhanced acceleration of outflows from the channel, resulting in extension of the distributary channel out onto the mouth bars. 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 subtidal channels.

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References

Coleman, J. M. (1976) *Deltas: Processes of Deposition and Models for Exploration.* Continuing Education Pub. Co., Champaign, 102pp.

Cotter, E. (1971) Paleoflow characteristics of a Late Cretaceous river in Utah from analysis of sedimentary structures in the Ferron Sandstone. *Jour. Sed. Petrol.*, **41**, 129-138.

Dalrymple, R. W. (1992) Tidal depositional systems. In: *Facies Models: response to sea level change* (Walker, R. G. and James, N. P., eds.), Geol. Assoc. Can., 195-218.

Elliott, T. (1976) The morphology, magnitude and regime of a Carboniferous fluvial-distributary channel. *Jour. Sed. Petrol.*, **46**, 70-76.

Flach, P. D. and Mossop, G. D. (1985) Depositional environments of Lower Cretaceous McMurray Formation, Athabasca Oil Sands, Alberta. *Am. Ass. Petrol. Geol. Bull.*, **69**, 1195-1207.

Ibaraki, M. (1994) Geologic ages and paleoenvironments of the Tertiary deposits in northwestern Kyushu on the basis of planktonic foraminiferal fauna. *The Earth Monthly (Gekkan Chikyu)*, **16**, 150-153.**

Jackson, R. G. (1978) Preliminary evaluation of lithofacies models for meandering alluvial streams. In: Fluvial Sedimentology (Miall, A. D., ed.), *Can. Soc. Petrol. Geol., Mem.* **5**, 543-576.

Kanno, S. (1955) Tertiary molluca from Taishu Mine, Tsushima, Nagasaki Prefecture, Japan. *Trans. Proc. Palaeont. Soc. Japan. N. S.* no.18, 31-36.

Matsumoto, Y. and Takahashi, K. (1987) Igneous activities in the Tsushima Islands, Nagasaki Prefecture, Japan. In: *Various topics of the late Cenozoic volcanism in Kyushu, Japan* (Matsumoto, Y., Hase, Y., Takeshita, H., Hayasaka, S. and Furukawa, H., eds.), Monogr. of Ass. Geol. Collabor. Japan. no. 33, 1-20.*

MITI (Ministry of International Trade and Industry) (1972) Report on the regional geological survey, Tsushima-Kamiagata district of the 1971' fiscal year. 29pp.**

MITI (Ministry of International Trade and Industry) (1973) Report on the regional geological survey, Tsushima-Kamiagata district of the 1972' fiscal year. 34pp.**

MITI (Ministry of International Trade and Industry) (1974) Report on the regional geological survey, Tsushima-Kamiagata district of the 1973' fiscal year. 52pp.**

Nakajo, T. and Funakawa, S. (1996) Eocene radiolarians from the Lower Formation of the Taishu Group, Tsushima Islands, Nagasaki Prefecture, Japan. Jour. Geol. Soc. Japan, **102**, 751-754.**

Nakajo, T. and Maejima, W. (in submission) Morpho-dynamic development and facies organization of the Tertiary delta system in the Taishu Group, Tsushima Islands, southwestern Japan. *Jour. Geol. Soc. Japan,*

Oomkens, E. (1970) Depositional sequences and sand distribution in the postglacial Rhône delta complex. In: *Deltaic Sedimentation: Modern and Ancient* (Morgan, J. P. and Shaver, R. H., eds.), Spec. Pub. Soc. Econ. Paleont. Miner., no. 15, 198-212.

Oomkens, E. (1974) Lithofacies relations in the Late Quaternary Niger Delta complex. *Sedimentology*, **21**, 195-222.

Raaf, J. F. M. de and Boersma, J. R. (1971) Tidal deposits and their sedimentary structures. *Geologie Mijnb.*, **50**, 479-504.

Sakai, H. (1993) Tectonics and sedimentation of the Tertiary sedimentary basins in the northern Kyushu. In: *Evolution of the arc crust in Southwest Japan* (Komatsu, M., Takeshita, T. and Sakakibara, M., eds.), Mem. Geol. Soc. Japan, no. 42, 183-201.*

Smith, D. G. (1987) Meandering river point bar lithfacies models: modern and ancient examples compared. In: *Recent Development in Fluvial Sedimentology* (Ethrighe, F. G., Flores, R. M. and Harvey, M. D., eds.), Spec. Pub. Soc. Econ. Paleont. Miner., no. 39, 83-91.

Smith, D. G. (1988) Modern point bar deposits analogous to the Athabasca Oil Sands, Alberta, Canada. In: *Tide-influenced Sedimentary Environments and Facies* (de Boer, P. L., van Gelder, A. and Nio, S. D., eds.), D. Reidel Publishing Co., 417-432.

Takahashi, K. (1992) Tsushima Islands area. In: *Regional Geology of Japan, Part 9 Kyushu* (Editorial Committee of Kyushu ed.), Kyoritsu Shuppan, 120-123.**

Takahashi, K. and Hayashi, M. (1985) Fission track ages of igneous rocks from Tsushima Islands (I). *Bull. Fac. Lib. Arts, Nagasaki Univ., Nat. Sci.*, **25**, 9-19.*

Takahashi, K. and Hayashi, M. (1987) Fission track ages of igneous rocks from Tsushima Islands (II). *Bull. Fac. Lib. Arts, Nagasaki Univ., Nat. Sci.*, **27**, 19-31.*

Takahashi, K. and Nishida, T. (1975) On the molluscan fossils from the Lower Formation of the Taishu Group in the Kamiagata district of Tsushima Islands. *Bull. Fac. Lib. Arts, Nagasaki Univ., Nat. Sci.*, **15**, 15-20.*

*: in Japanese with English abstract
**: in Japanese