Storm and Recovery Stage Sedimentation Records in the Shoreline Deposits of the Miocene Tōgane Formation, Southwestern Japan

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Abstract

Wave-work processes originated the shoreline facies on the margin of the prograding fan-delta plain in the Kanaso Conglomerate and Sandstone Member of the Middle Miocene Tōgane Formation, Shimane Prefecture, southwestern Japan. The shoreline deposits, up to 3 m thick, are subdivisible into the lower, cross-stratified sandstone unit and the upper, planar-stratified sandstone unit. The lower unit is attributed to upper shoreface sedimentation and is characterized by complex interfingering of gently inclined, thin conglomerate layers deposited on the erosional surface as a coarse lag in a peak stage of major storms; onshore-dipping, planar cross sets representing landward migration of longshore bars; and longshore trough fills revealing along-shore directed, trough cross stratification. The upper, planar stratified unit is dominated by seaward dipping, low-angle cross-sets, implying deposition chiefly in a foreshore.

Gravels on the fan-delta plain or on the marginal beach were removed by storm waves, swept into the shoreface by the backwash action of storm waves or by storm-enhanced rip currents, and deposited as a coarse lag on the erosion surface produced by waves or wave-induced strong currents in the peak stage of a storm. During the declining and following stage of storms, long-period swells resulted in the development of a longshore bar system. Bars migrated onshore and climbed over the lag conglomerate resting on the erosional surface. With the development and onshore migration of the longshore bars, the longshore trough became distinct and active sedimentation took place in the troughs as waves were still powerful enough to generate strong longshore currents in the declining and following stage of storms. The longshore bars did not finally weld to the beachface and the nearshore morphology of a barred system was not replaced by a non-barred reflective system during the period between storms.

Key words: Barred system, Sedimentary facies, Storm, Tōgane Formation, Upper shoreface.

Introduction

Storms are an important mechanism for the deposition of clastic sediments in shallow marine environments. Many works on storm sedimentation have been concerned with the shelf and lower shoreface sequences, which commonly show storm-generated sandstones interbedded with fair-weather mudstone and amalgamated storm sandstones respectively (e.g.,...
In the shelf and lower shoreface depths, limited or no influences modify the storm deposits during the fair-weather periods, and storm depositional records tend to be selectively preserved in the successions originating in these depths. The effects of storms in shallow marine environments also involve coastal erosion by wave attack and landward sediment transport during waning storms or post-storm recovery stages. These processes are most significant in an upper shoreface environment. Being different from the shelf and lower shoreface, fair-weather wave and current processes are much more intense in this zone, resulting in reworking and modification of storm-related deposits. Hence, in general, the upper shoreface successions in geologic records consist of materials deposited between the times of greatest storm erosion and greatest fair-weather buildup and, thus, include materials deposited during waning storms or post-storm recovery stages as well as during the following fair-weather periods (Hunter et al., 1979). Fair-weather sedimentation records probably dominate in the upper shoreface deposits of high wave-energy seas. On the other hand, records during waning storms or post-storm recovery stages should tend to have high preservation potential in the upper shoreface deposits of low to moderate wave-energy seas because of limited influences of fair-weather wave and current processes. Such deposits reveal successive sedimentation records from a peak stage of a storm through a waning or recovery stage to a fair-weather period and their responsibility for upper shoreface facies organization.

This paper describes and interprets facies of the shoreline deposits in the Miocene Tôgane Formation to the north of Hamada, Shimane Prefecture, southwestern Japan (Fig. 1). The rocks under study provide a good example of successive sedimentation records between the times of greatest storm erosion and greatest fair-weather buildup in an upper shoreface zone.

**Geologic Setting**

The Tôgane Formation is one of the early Middle Miocene formations in the western part of the Setouchi Geologic Province of southwestern Japan (Fig. 1).
These Miocene formations fill the basins that are thought to have developed due to regional downwarping in the Setouchi Province (Huzita, 1962; Shibata, 1985). Basin subsidence was slow, and the resultant basin-fills are represented by a relatively thin sequence, some 200 m thick, of clastic sediments. The successions are dominated by shallow marine deposits and consistently show gradual deepening of the water depth (Shibata and Itoigawa, 1980; Shibata, 1985).

The Tōgane Formation crops out in a small area to the north of Hamada (Figs. 1, 2). The formation rests unconformably on the Paleogene Kokufu Volcanic Rocks and is, in turn, unconformably covered by both the Pliocene-Pleistocene Tsunozu and the Holocene Kokubu Groups (Fig. 2). The Tōgane deposits appear to infill a N–S oriented depression in the basement rocks (Nakajo et al., 1993a, b). The lower part of the formation abuts against the basement. The structural dip is commonly less than 15°. The Tōgane Formation is 200 m thick, and shows, as a whole, a transgressive stratigraphy, like the equivalent formations in the western Setouchi Province. Continental deposits in the lower part of the formation grade upward into shallow marine sandstones (Okubo, 1982; Nakajo et al., 1993a, b). The for-

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Fig. 2 Geologic map of the northern Hamada area showing distribution of the Kanasō Conglomerate and Sandstone Member of the Tōgane Formation. Numerals indicate the localities of measured sections shown in Fig. 4.

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These data suggest that the Tōgane Formation is a transgressive sequence that records the progressive infilling of a N–S oriented basin in the Setouchi Province.
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Fig. 3 Generalized sequence and stratigraphic subdivision of the Tōgane Formation.

Depositional Background

The storm and recovery stage sedimentation records in an upper shoreface environment are well documented in the shoreline deposits in the Kanasō Conglomerate and Sandstone Member. The Kanasō Member has been attributed to deposition in an alluvial fan–fan delta system (Nakajo et al., 1993a; Maejima and Nakanishi, 1994). The alluvial fan prograded northward into a standing body of shallow water of a low to moderate wave-energy sea (Maejima and Nakanishi, 1994). Sediment delivered by the alluvial fan was deposited mostly subaqueously as the fan delta. The resultant sequence of the Kanasō alluvial fan–fan delta system shows a remarkable lateral facies change in a N–S direction (Fig. 4). Subaerial alluvial-fan conglomerates in the south pass northward, within a short distance, into subaqueous (delta front) deposits and associated subaerial (delta plain) and transitional (shoreline) deposits. The delta plain and shoreline deposits form two prominent tongues projecting northward into subaqueous deposits of fan-delta front origin. These tongues demonstrate that the relative sea-level rise episodically lost balance with the rate of sediment supply. The conglomeratic fan-delta plain deposits rest erosively on the accompanying shoreline deposits and have locally incised into the fan-delta front deposits. Such an erosional contact is highly suggestive of control by relative sea-level change rather than by an increase in the rate of sediment supply. The rate of relative rise in sea level significantly diminished and the sea level may have even fallen to some degree. Consequently, the alluvial fan rapidly prograded over the fan-delta front, resulting in development of an extensive fan-delta plain. The shoreline deposits represent significant reworking of the fan-derived sediments by waves and wave-generated currents. A beach and shoreface developed on the margin of the fan-delta plain and prograded northward, accompanied by episodic, basinward extension of the fan-delta plain (Fig. 4). Preservation of the shoreline deposits may reflect a diminished fluvial agency as a result of extension of the fan-delta plain. Fluvial processes, although powerful enough to produce conglomeratic fan-delta plain deposits, was probably overpowered by moderate-energy wave processes acting on the margin of the fan-delta plain (Maejima and Nakanishi, 1994).

Facies of Shoreline Deposits

Description

The shoreline deposits of the Kanasō Member consist dominantly of fine- to coarse-grained sandstone, with intercalations of thin conglomerate. The
The lower, cross-stratified sandstone unit, commonly 1 to 2 m thick, is characterized by complex interfingering of trough and planar cross-sets and thin conglomerate layers (Fig. 5A). The conglomerate layers, up to 20 cm thick, are usually poorly to moderately sorted, and have an erosional surface at the base. They are gently inclined northward with gradual decrease in inclination in the down-dip direction (Fig. 5A). Individual conglomerate layers tend to thin out and to be better sorted up-dip southwards into one-clast thick layers. Clasts frequently show well-developed imbrication, dipping either northward or southward. The planar cross-sets of sandstone are up to 60 cm thick. They commonly climb up the gently dipping conglomerate layers and wedge out southwards. Foresets consistently dip to the south (Fig. 6) at angles of 10° to 25°. Trough cross-sets with local pebbles are 10 to 40 cm thick, either isolated or grouped in up to 1 m thick cosets. Pebbles tend to be segregated on the basal surfaces of troughs. Foreset dip azimuths are bi-directional, oriented either to the west or to the east (Fig. 6). Biological influences are not common throughout this unit. Burrows, however, are locally observed at the top of the planar cross-sets and in the trough cross-sets.

The upper, planar-stratified sandstone unit is 1 m or so thick. The sandstones are fine-grained and well sorted. Planar stratification is characteristic throughout the sandstone of this unit (Fig. 5B). Laminae are subhorizontal or dip gently to form low angle cross-beds. The inclination direction of laminae is bi-directional, with a dominant mode to the north and a distinct secondary mode to the south (Fig. 6). The sandstones are free from biological influences, apart from sparse burrows in the uppermost part of this unit. The planar-stratified sandstones generally rest on the cross-stratified sandstones of the lower unit. Locally, however, the planar-stratified sandstone passes laterally to the north into the trough cross-stratified sandstone of the lower unit (Fig. 5B).
Fig. 5 Field sketches of the shoreline deposits which are erosively covered by fan-delta plain conglomerates, viewed normal to the paleo-shoreline (land to right). A) Upper shoreface deposits at the south of section 7. Onshore-dipping planar cross-sets climb up the gently seaward-dipping thin conglomerate layer and interfinger with trough cross sets. B) Lateral transition of planar stratified foreshore sandstones with longshore-directed trough cross-sets of longshore trough origin, section 8.

Interpretation

The variability in textural and stratification characteristics in the shoreline deposits of the Kanasō Member reflects complex hydraulic processes related to wave and wave-generated current activities on the coast. The shoreline was approximately oriented east-west with the seaward side to the north. This paleogeography is inferred from consistently northward-flowing paleocurrents in the alluvial and fan-deltaic deposits (Maejima and Nakanishi, 1994) and lateral facies relationships revealing transition from the alluvial fan conglomerates in the south to the subaqueous fan-delta front deposits in the north (Fig. 4).

The planar-stratified sandstones of the upper unit are interpreted as beach deposits. Subhorizontal or gently dipping planar laminations composed of well-sorted sand are documented from many present-day beach deposits (Clifton et al., 1971; Howard and Reineck, 1981, among others), and are explained by processes of swash action. Dominantly seaward dipping, low-angle cross-sets imply deposition chiefly in a foreshore. The oppositely dipping laminae are attributed to deposition in a backshore which is flatter or even slopes very gently landward.

The lower, cross-stratified sandstone unit is interpreted as an upper shoreface deposit, because of the predominance of cross-stratification, variability of
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Planar cross
stratification
20%

Trough cross
stratification
20%

Planar
stratification

Fig. 6 Rose diagrams summarizing dip directions of planar and trough cross sets in the upper shoreface deposits and planar stratification of foreshore deposits.

foret azimuths and occasional burrows (cf. Clifton, 1976; Hunter et al., 1979; Howard and Reineck, 1981). An upper shoreface interpretation is further suggested by the local, landward transition with the planar-stratified sandstone of beach origin (Fig. 5B). The conglomerate layers in the lower unit represent a record of intensive storm sedimentation on the upper shoreface. During major storms, waves or wave-induced strong currents tend to erode the shore-zone materials and sweep them into a deeper area (Elliot, 1986). The erosional surface at the base of gently seaward-dipping conglomerate layers represents the record of the peak of such events (Massari and Parea, 1988) and shows that the upper shoreface profile was planed off. Clasts were probably emplaced on the erosional surface as a coarse lag. Bi-directional clast-imbrication is suggestive of oscillatory storm-wave motion. The conglomerate layers become thinner and better segregated into one-clast thick layers landward, implying intense winnowing of finer fractions towards the toe of the beachface.

As storms wane, shoaling waves rework the sediment previously swept offshore and return the materials landward in the form of a longshore bar (Davis et al., 1972; Hunter et al., 1979, Elliot, 1986). The onshore-dipping, planar cross-stratified sandstones represent deposition from such landward-migrating longshore bars (Massari and Parea, 1988). Individual planar cross-sets tend to climb and wedge out over the gently seaward-dipping, upper shoreface slope that had planed off during the storm (Fig. 5A). This suggests that bar growth and landward migration was most significant during waning storms or post-storm recovery periods as well as during the following periods when the shore profile was of fair-weather form. Long-period swells following storms were probably responsible for the development of a bar system. Deposition in longshore troughs in such a barred shore is represented by trough cross-stratified sandstones. The trough sets show dominantly eastward- or westward-flowing paleocurrents (Fig. 6), parallel to the inferred shoreline orientation. This indicates that these trough sets were deposited from dunes migrating in an along-shore direction in the longshore troughs.

Conclusions and Discussion

The shoreline deposits that originated on the margin of the fan-delta plain of the Kanasa Conglomerate and Sandstone Member record storm and recovery stage processes in an upper shoreface environment. During major storms, the shore zone is subjected to erosion that affects not only the beachface but also the upper shoreface (Elliot, 1986). Erosion of the shoreface substrate due to storms is well documented by gently seaward-dipping, thin conglomerate layers having the erosional surface at the base. Gravels on the fan-delta plain or on the marginal beach were removed by storm waves, swept into the shoreface by backwash action of storm waves or by storm-enhanced rip currents, and deposited as a coarse lag on the erosion surface produced by waves or wave-induced strong currents during the peak stage of a storm. Finer materials would have been transported further offshore. Following storm erosion, the bed materials could have been reworked to make the erosion surface obscure. A veneer of lag conglomerate, however, prevented later-stage modification of a storm erosion surface on the upper shoreface bed. Intensive oscillatory water-motion due to storm waves was responsible for to and fro rolling of clasts on the sea bed, producing both offshore- and onshore-dipping clast imbrication. Winnowing of finer fractions took place also under intense storm-wave agitation, especially towards the toe of the beachface, resulting in thinning and increased segregation of a conglomerate layer landward.

During the declining and following stage of storms, long-period swells rework much of the sediment previously eroded in the shore zone and transported offshore, tend to selectively remove finer materials, and transport them onshore, leaving behind coarse particles (Clifton, 1981). Through this process, a longshore bar system develops and bars migrate...
towards the shore. The profile of bars is modified as they migrate shoreward and becomes sharply asymmetrical with a steep slip face on the landward slope (Davis et al., 1972). The sedimentation record during such waning storms or post-storm recovery stages is represented by landward-dipping, planar cross-stratified sandstones, which are interpreted as bar lee deposits marking net onshore-migration of the longshore bar system. Climbing of planar cross-sets over the lag conglomerate resting on the gently seaward-dipping, erosional surface demonstrates landward migration of the bar onto the upper shoreface slope that had planed off during the peak stage of storms. The development of the longshore bar system and its onshore migration probably took place within a rather short time after the erosion of the upper shoreface substrate in a peak stage of storms. At the depth of the upper shoreface, high orbital velocities and high orbital asymmetry capable of onshore sediment transport are produced by long-period waves, and probably not by short-period waves (Clifton and Dingler, 1984). In the low to moderate wave-energy sea, in which the Kanaso fan-delta was built (Maejima and Nakanishi, 1994), long-period waves would have been most significant in the waning stage of storms and have been uncommon in the fair-weather periods that occupy the great intervals between storms. Such an interpretation is consistent with direct covering of planar cross-sets of a bar slip-face origin on the lag conglomerate without any intervening deposits and with indications of faunal activity suggesting a fair-weather, calm condition (Fig. 5A).

With the development and onshore migration of the longshore bar, the longshore trough becomes distinct. Under the waning stage of storms, waves would have been still powerful enough to generate strong longshore currents in the trough. Consequently active sedimentation took place in the longshore trough through this stage, depositing trough cross sets having along-shore paleocurrent directions. After the establishment of the distinct longshore trough, wave-driven longshore currents were probably capable of depositing cross sets even in the fair-weather period, as suggested by local lateral transition of the trough cross sets with the planar stratified, beach deposits that are most likely the fair-weather products (cf. Komar, 1976; Hunter et al., 1979; Maejima, 1983). The planar cross-sets commonly wedge out into the trough cross-stratified sandstones of a longshore trough origin (Fig. 5A) and are separated from the beach deposits. This implies that the longshore bars did not finally weld to the beachface. The nearshore morphology of the barred system was not replaced by a non-barred reflective system and was basically maintained during the period between storms.

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